INNOVATION IN THE JAPANESE CONSTRUCTION INDUSTRY

A 1995 APPRAISAL

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Ronald H. Brown, *Secretary*

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Mary L. Good, *Under Secretary for Technology*

National Institute of Standards and Technology
Arati Prabhakar, *Director*

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The U.S. Panel on Innovation in the Japanese Construction Industry:

Dr. Richard G. Gann, Panel Chair
Chief, Fire Science Division
Building and Fire Research Laboratory
National Institute of Standards and Technology

Dr. Thomas L. Anderson
East Coast Regional Manager
Fluor Daniel Technologies

Dr. Steven J. Bomba
Vice President, Technology
Johnson Controls, Inc.

Richard A. Cemenska
Manager, New Technology
Caterpillar Inc.

Edward E. DiTomas
Chief Engineer
The Turner Corporation

Lloyd A. Duscha, P.E.
Consulting Engineer

Professor Ezra Ehrenkrantz
Sponsored Chair
Architecture and Building Science
New Jersey Institute of Technology

Burton Goldberg
Senior Analyst
Economics and Policy Analysis
National Association of Home Builders
Research Center

Charles I. McGinnis
Associate Director
Construction Industry Institute

Professor Boyd C. Paulson, Jr.
Construction Engineering and
Management Program
Department of Civil Engineering
Stanford University

Noel J. Raufaste, Jr.
Manager, Cooperative Research Programs
Building and Fire Research Laboratory
National Institute of Standards
and Technology

Dr. Kenneth F. Reinschmidt
President, Stone & Webster
Advanced Systems Development Services

Dr. Arthur H. Rosenfeld
Senior Advisor
Energy Efficiency and Renewable Energy
Department of Energy

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ABSTRACT

As part of a national effort to benchmark the competitiveness of U.S. industries, this study evaluates the state of technology and innovation in the Japanese construction industry. That industry is large, solid and progressive, leading the world in the size of its construction industry relative to GDP, in the modernity and quality of its constructed facilities, in the size and quality of its physical research laboratories, and in its private and public investments in construction research and development. The Japanese have built an integrated approach toward incorporating new technologies into their design and construction projects and lead in such areas as large-scale bridges, tunnels, soft-ground construction, congested area construction, high performance construction materials, automated "jack-up" erection techniques for high-rise buildings, and computer visualization of residences for prospective buyers. The United States leads in computer integration of design and construction, the economy of constructed facilities, and global positioning systems. The Japanese are generally faster in providing nationwide acceptance of innovations. The Japanese industry has taken strong measures to increase the pace of its internationalization, but still lags both United States and European competitors in market penetration, in large part due to the currently strong yen. Recent economic pressures have reduced the Japanese allocation of resources to construction R&D. The United States and its construction industry can benefit from the practices and innovations developed by the Japanese. While a direct transfer of the Japanese R&D approach and the emerging technologies may not always be feasible, the opportunities for modified application and the potential value of increased U.S. investment in construction R&D should not be overlooked. The U.S. industry would derive considerable benefit from the establishment of a U.S. public/private sector program both to conduct multidisciplinary R&D and to efficiently disseminate evaluated technology focussed in the construction field.

KEY WORDS: Construction; construction industry; innovation; Japan

EXECUTIVE SUMMARY

Construction is a major U.S. industry, and the quality of the constructed facilities it produces is important to the competitiveness of all U.S. industry and the quality of peoples' lives. In 1994, new construction amounted to over $500 billion, 8% of the GDP, and employed 6 million people. The global industry is manyfold greater. There is thus both an opportunity for international trade in construction products and services and a concurrent risk of substantial foreign penetration into the U.S. market.

Technical leadership is essential to competitiveness in construction in the developed world. Therefore, as part of an effort to benchmark the international competitiveness of major U.S. industries, the Technology Administration of the U.S. Department of Commerce requested this appraisal of technology and innovation in the Japanese construction industry. The project was co-sponsored by the National Science Foundation, the National Institute of Standards and Technology, and the Department of Energy.

The study was conducted by an interdisciplinary panel of experts from the private and public sectors. Following collection and review of earlier studies of the Japanese construction industry, especially two organized in 1990 by the Japanese Technology Evaluation Center (JTEC) and the Civil Engineering Research Foundation (CERF), the panel visited Japan from June 9-18, 1995 to confer with Japanese leaders and visit major construction sites and laboratories. The panel's hosts provided clear, candid views of the technical aspects of the work and the context in which it was being conducted. Valuable assistance in the planning and conduct of this project was provided by the Public Works Research Institute of the Japanese Ministry of Construction and the Advanced Construction Technology Center of Japan.

The panel found the Japanese construction industry to be a large, solid, and progressive industry, driven by national expenditures on infrastructure and construction in general that are twice the percentage of their GDP as is spent in the United States. In a country susceptible to earthquakes, typhoons, and other natural disasters, the Japanese lead the world in the modernity and quality of their constructed facilities, in the size and quality of their physical research laboratories, and in their private and public construction R&D investments whose sum is an order of magnitude greater than that in the United States.

While the government research institutes contribute substantially to generic construction technology development, the majority of applied construction research is performed by industry using its own funding. The corporate R&D institutes are made possible by a close relationship between the construction companies and the government Ministry of Construction (MoC), which assures that those companies with R&D establishments that support the Ministry's 5-year plan for R&D will gain access to the vast public works program. Other forces driving investment in R&D are its use as a competitive marketing tool in the domestic market, improvement in public health and safety, the need to construct facilities underground and in constrained spaces, the need to make production more cost-effective, a conviction that the development of new, more refined products and services is the only way to expand the domestic market, and the maintenance of an active, highly-employed, and productive work force. Direct profit on intellectual property from research investment, surprisingly, is not a common motive.

Research and development by the Japanese engineering-construction firms has no counterpart in the United States. The large Japanese firms have laboratories of a scale larger than the government laboratories of Japan or the United States. However, the work in these laboratories is not equivalent to that in U.S. government or university laboratories. The major Japanese laboratories conduct duplicative work aimed at improving their designs and construction practices. The work appears to be aimed more at developing capabilities, improving quality, and testing of materials or specific applications of products or processes than at producing new or unique knowledge.

The panel was struck by the large toll that the domestic recession and the strongest yen in history are having on the construction industry in general and on the R&D institutes in particular. The resources committed to research in Japan have been reduced, reflecting economic reality. Although public works investments have been increased to offset private sector declines in contracts, the R&D institutes are currently especially understaffed and underutilized due to budget reductions. The panel saw no totally new construction technologies or innovations during this visit. Rather, the large Japanese contractors are refining those introduced earlier and applying lessons learned, including holding off on some high visibility innovations as costly and unproductive in today's circumstances. A prolonged recession could extend the hiatus in R&D advances and, in the worst case, might render the R&D institutes unaffordable in their current role.

Two additional factors may change conditions for research and innovation in the Japanese construction industry from those observed in the 1990 predecessors to this study. First, procurement scandals in 1993 have led to a revised, more competitive and transparent procurement system in the public sector and may subject engineering-construction firms to competition from contractors who do not invest in R&D. Second, the catastrophic Hyogo Ken Nanbu (Kobe) earthquake in 1995 has revealed needs for improving construction practices and for retrofitting existing constructed facilities.

The JTEC and CERF reports found the Japanese industry surpassed the U.S. industry in most construction technologies. This panel observed that the relative strengths of the two countries have not changed since those 1990 appraisals. The Japanese have built an integrated approach toward incorporating new technologies into their design and construction projects and lead in such areas as large-scale bridges, tunnels, soft-ground construction, congested area construction, high performance construction materials, automated "jack-up" erection techniques for high-rise buildings, and computer visualization of residences for prospective buyers. Operating under a different set of cultural and economic circumstances, the United States leads in computer integration of design and construction, the economy and flexibility for evolutionary use of constructed facilities, and global positioning systems. The Japanese MoC has responsibility for regulations for private and public construction and provides mechanisms, often multi-year in length, for assessment of innovations and for their acceptance by regulators. Since the United States lacks a formal process recognized by federal, state and local regulatory authorities, nationwide acceptance is generally slower in the United States.

The Japanese industry has taken strong measures to increase the pace of its internationalization. Should the yen return to the higher exchange rates of recent years, Japan is well-poised to increase it's currently few successes in the international competition.

The United States and its construction industry can benefit from the practices and innovations developed by the Japanese. While a direct transfer of the Japanese R&D approach and even the emerging technologies may not always be feasible, the opportunities for modified application and the potential value of increased U.S. investment in construction R&D should not be overlooked. The panel also suggests the establishment of a U.S. public/private sector program both to conduct multidisciplinary R&D and to efficiently disseminate evaluated technology focussed in the construction field. Funded jointly by government and private industry, this program could be organized under, *e.g.*, the Manufacturing Extension Partnership of the Department of Commerce's Technology Administration, working with the existing public and private construction-related organizations.

Finally, construction technology must be proven on construction sites, and the future leadership in construction technology will go to the nation that performs the most construction and builds the most ambitious projects.

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construction: *the act or process of putting parts together to form a complete, integrated object, esp. a building or structure.*

innovation: *the introduction of something new.*

appraisal: *estimation of the quality, amount, size and other features.*

I. INTRODUCTION

Construction is a major United States industry. In 1994, new construction amounted to $510 billion, 8% of the GDP, and employed 6 million people. Rehabilitation of existing facilities was an additional $340 billion. The global industry size is many times the sum of these. There is both a realm of high opportunity for expansion for U.S. firms and a concurrent risk of incursion into the U.S. market from foreign competition.

There is thus a premium on knowing the capability of the building and construction sector in other countries. Such information would characterize the current and potential competitive positions of U.S. firms; identify the bases for the differences; note areas where the differences may become economically threatening; and identify the potential for cooperation, collaboration or joint venturing between firms.

The Japanese building and construction industry is highly competitive with our own, both in size and capability. In 1991, the Japanese Technology Evaluation Center (JTEC), under sponsorship from the National Science Foundation (NSF), published a report entitled *Construction Technologies in Japan* (Tucker *et al.*, 1991). The report documented the structure and operations model of the Japanese industry, its recent technical innovations, and projections of the future relative to its U.S. counterpart. Later that year, the Civil Engineering Research Foundation (CERF), with partial sponsorship of the U.S. Department of Commerce (DoC), issued a report entitled *Transferring Research into Practice: Lessons from Japan's Construction Industry* (Hampton *et al.*, 1991). The two reports clearly portray the Japanese industry in 1990 as generally more progressive than that in the United States and likely to become more so in several ways. This presented a challenge to the U.S. industry regarding its presence in the global construction market. The reader is urged to examine these two documents as context for the current report.

Recently, the DoC Technology Administration requested that the Building and Fire Research Laboratory (BFRL) of the DoC National Institute of Standards and Technology (NIST) lead a similar appraisal during 1995. The Asia Pacific Technology Program of the (U.S.) Office of Technology Policy is responsible for reporting on important Japanese discoveries and technical innovations. The BFRL, as the Nation's laboratory for improving the life cycle quality of constructed facilities, has committed resources to this study. Two other Federal agencies with common interests also have co-sponsored this assessment: the NSF Structural Systems and Construction Processes Program, which sponsors research in this technical area, and the U.S. Department of Energy, which is concerned with issues affecting the large fraction of our energy consumption that occurs in buildings.

The objective of this project is to provide an evaluation of the state-of-the-art of the various aspects of the Japanese building and construction industry, featuring comparison with the U.S. counterparts. To accomplish this task, a team of experts was assembled in the technical areas to be included in the assessment:

- Innovative construction projects and construction-related research and development (R&D) activities at government and company research institutes,
- Construction materials and new capabilities facilitated by new materials,
- Construction field operation and automated equipment,
- Building mechanical, control, and safety systems,
- Types and design of structural systems,
- Computing and information sharing in design and construction operations; information networking and integration of CAD/CAM/CAE and field operation,
- Construction technologies related to environmental protection and energy conservation, and
- Construction industry business and contracting practices.

Within the above technical areas, the report examines the innovation process:

- How does innovation occur and who "does" it?
- What is the rate and extent of innovation?
- What are the components of the Japanese culture and infrastructure that promote the implementation of new technology into commercial application?
- What are the successful (*i.e.*, actually introduced into practice) innovations of the past few years?
- What attempts have been made that didn't work out and why?
- What are the innovations looming on the near and far horizons?

The experts were selected from industry, academia, and research laboratories. After obtaining significant background material, the team visited Japan from June 11-18, 1995 to meet with representatives of principal construction and research organizations and to observe recent and ongoing construction.

It is appropriate at this point to acknowledge the outstanding support we received during our time in Japan. Dr. Takashi Iijima, then Director-General of the Public Works Research Institute (PWRI) and Mr. Takashi Sakai, Executive Director of the Advanced Technology Construction Center (ACTEC) acted as our official hosts. Dr. Yashushi Sasaki of Hiroshima University (formerly of ACTEC) and Dr. Toshio Iwasaki, President, Construction Engineering Laboratory, served as

coordinators during the initial planning of our trip. The PWRI and ACTEC staffs extended themselves on our behalf, arranging access to the most appropriate executives, staff, and construction sites; many accompanied us on our trips throughout the Kanto regions, and we appreciate their efforts:

<u>Public Works Research Institute</u>

Dr. Koichi Yokoyama
Mr. Tomofumi Nozaki
Mr. Tutomu Yoshiki
Mr. Ryutaro Oishi
Mr. Tatsuo Arakawa
Mr. Itaru Nishizaki
Mr. Noriyuki Imamura
Mr. Hideto Hatakenaka
Mr. Tomoo Inoue
Mr. Takashi Nishi

<u>Advanced Construction Technology Center</u>

Mr. Satoru Osawa
Mr. Toshiro Kidokoro
Mr. Hiroyuki Utagawa
Mr. Makoto Kamei
Mr. Takeshi Kuwabara
Mr. Kouichi Yoshida
Mr. Shigeru Nakagawa
Mr. Hidetoshi Kaneko
Mr. Shigenori Ochiai
Mr. Akira Fujioka
Mr. Kouji Harada
Mr. Makoto Kishiya
Mr. Tatsuma Noda

Our hosts at those corporations, institutes, and construction sites provided us with clear, candid views of the technical aspects of the work and the context in which it was being conducted. Their names are listed in the individual site visit reports in Appendix A. Without the help of all those involved, this report would be far less informative.

In the United States, there also were contributions that were essential to our success. Drs. Richard N. Wright and Andrew J. Fowell, both of BFRL, provided valuable guidance and awareness of related concurrent activities. Ms. Kellie Beall made most of the travel arrangements, became the communications link with the panel members, and was instrumental in the preparation of this report.

We believe that we perceived correctly the forces affecting the Japanese construction industry and their responses. However, despite the efforts of the team members and the above supporters, we caution the reader that the portrayal here was reached based on limited information. This was a fixed-time project, with the constraints that accompany one. There was strong emphasis on the civil engineering aspects of construction. Even so, we did not have the time to visit, *e.g.*, as many types of construction sites or as many construction suppliers as would be needed to complete a comprehensive picture. Our focus was mainly on the large construction firms, *i.e.*, those in the top 20 out of about 500,000 in the country. We did not visit practitioners of building design or manufacturers of building systems. Our travels were concentrated in the greater Tokyo area to enable as many visits as possible during the roughly one-week trip. In partial compensation for these limitations, we have availed ourselves of an extensive array of supplemental readings which are listed in Section VII.

Since the 1991 reports, important changes have occurred that have impacted the Japanese construction industry. The world-wide recession and the strengthening of the yen have depreciated Japanese corporate investments abroad. Construction company profits have declined. The industry has lost domestic credibility due to scandals in the competition for public works contracts. The serious Hyogo Ken Nanbu earthquake has changed the public perception of the resilience of their homes, work places, and infrastructure. Many of the technological innovations identified in 1990 have not yet proved economical in practice, and there appear to be fewer identified on this trip.

Yet the fundamentals of the industry today are similar to those in 1990. The primary companies are the same, their revenues are comparable, their safety and on-time completion records are laudable, and the fraction of revenues invested in their R&D institutes remains consistently high relative to the U.S. firms. The Japanese companies were formidable competitors in 1990 and remain so in 1995.

The study and report have been organized to provide a wide audience with useful input. The report begins with an overview of the Japanese construction industry, noting how it differs significantly from that in the United States. Next is a discussion of the how innovation occurs in Japan. There follow two crosscuts of the industry: by components in the construction process and the finished product, and by sector in which the construction occurs. The appendixes contain summary reports of our site visits while in Japan, answers by the Japan Society of Civil Engineers to a list of our questions about the industry, and brief information about each of the team members. A number of organizational acronyms appear throughout the report. The most frequent of these are included here for quick reference:

ACTEC	Advanced Construction Technology Center (Japan)
BRI	Building Research Institute (Japan)
CERF	Civil Engineering Research Foundation (U.S.)
JFCC	Japanese Federation of Construction Contractors
JSCE	Japan Society of Civil Engineers
JTEC	Japanese Technology Evaluation Center (U.S.)
MITI	Ministry of International Trade and Industry (Japan)
MoC	Ministry of Construction (Japan)
NSF	National Science Foundation (U.S.)
PWRI	Public Works Research Institute (Japan)

Finally, unless otherwise noted, values in yen have been converted to current U.S. dollars using ¥83=$1, the value at the time of our trip to Japan.

II. CHARACTER OF THE JAPANESE CONSTRUCTION INDUSTRY

A. Character of the Japanese People

To understand the character of the Japanese construction industry, it is helpful to characterize the nation, *i.e.*, the people who make up the industry and for whom the work is performed. The following is abridged from Kobayashi *et al.* (1994).

Japan is possessed of a long and memorable history. Like England it is a small island nation located not far from a continental land mass on which advanced culture has thrived for millennia. However, there the similarity ends. While England built herself into a sea power and became one of the most extroverted of nations, Japan for the most part looked inward. With the exception of occasional forays to the Asian mainland and limited interaction with traders and missionaries from Europe, Japan was a self-contained entity.

Over the centuries, geographic isolation and the high concentration of people on the 30% of Japan's land mass which is habitable, combined with its limited natural resource base, developed a culture which required maintenance of order and harmony. Quite naturally, the social system evolved to placing a higher value on service to society than to the individual. A feudal social structure divided the population into essentially four classes. Though no longer formally identified and recognized, the influence of this structure continued through to the present time (Kobayashi *et al.*, 1994).

An essential characteristic of the Japanese population was and is its daily concern with potential natural disasters. In a land where earthquakes are numerous and occasionally violent, active volcanoes exist, typhoons recur, and ocean waves of seismic origin wreak havoc with the concentrated population on and near the coast, the Japanese people have confronted a constant series of natural threats. The constant threat of a natural "enemy" brought the people closer together, made them more amenable to government leadership focused on society as a whole rather than on individuals, and led to the study of hazards which are of lesser importance to most of the world.

The first of two major externally driven changes occurred in 1853 when Japan was reopened to foreign visitors. By 1868, with the beginning of the Meiji era, a process had been undertaken of blending information, knowledge, and the systems employed by Western civilization with the traditional Japanese spirit. Nonetheless, to this day, cultural vestiges of the earlier system continue to guide many interpersonal relationships. Individuals tend to follow precedent, avoid personal responsibility, and circumvent new challenges, although collectively the leadership can be forward-looking. Personal failure is to be avoided at all cost. Commercially, pride of craftsmanship and client satisfaction and admiration are valued highly. The customer is king. Managers are more concerned with and responsive to employees than to shareholders of a corporation. Enduring relationships are extremely important in current decision making, leading to a very traditional industrial structure.

To a great extent, the Japanese spirit is a modern embodiment of Confucianism:

> "The important elements of Confucius' teaching are as follows:
>
> priority of the public before the individual;
> the spirit of self-sacrifice;
> maintenance of a rigid hierarchy based upon seniority;
> modesty and humility;
> desire to learn;
> working diligently;
> devotion to culture (the Samurai was proud of his own intelligence and knowledge);
> asceticism;
> thriftiness;
> integrity and purity;
> honest poverty (as proof of a man's integrity and purity; an intellectual of honest poverty was not disdained); and
> honor (a Samurai's face was regarded more important than his life).
>
> "The Samurai's spirit at that moment, as described above, is still the noble ideal of Japanese people in the modernized society in this moment." (Kobayashi *et al.*, 1994)

B. Historical Perspective of the Japanese Construction Industry

Construction is considered "the most traditional element within the Japanese industrial structure," and several large construction companies of today date, in some form, from early times: Mitsui, 1586; Takenaka, 1610; Shimizu, 1804; Kajima, 1840; and Taisei, 1873 (Kobayashi *et al.*, 1994). In the latter part of the 19th century, the development of infrastructure and a more sophisticated constructed environment became a high governmental priority. Risk aversion by most managers and leaders resulted in a government-controlled industry, highly centralized, and embracing the total spectrum of planning, design, and construction functions. As the need for an increased capability developed and as trust was built between the government and the commercial contracting industry, the present delivery system evolved. First, some construction activity was contracted, later design was entrusted to the private sector, and finally, the private sector became involved in planning as well. Trust, the crucial element in Japanese business relationships, develops slowly, remains somewhat fragile, and inhibits experimentation with new entrants.

The second of two major externally driven changes occurred following the end of World War II in 1945. Extensive measures to rebuild Japan and its economy were taken by both the U.S. occupation forces under General Douglas MacArthur and the reconstituted Japanese government. A principal component of this effort was the reconstruction of the national infrastructure, much of which was damaged in the war and much of which remained from post-feudal times. A fusing of American technology and regulations with Japanese cultural attitudes dominated the surge of construction in the ensuing years.

Over the following four decades, the Japanese construction industry grew, both in size and in character, to a powerful and profitable position in the world economy. The essence of this industry in 1990 was well described in the reports published by the Japan Technology Evaluation Center (JTEC) (Tucker *et al.*, 1991) and the Civil Engineering Research Foundation (CERF) (Hampton *et al.*, 1991).

C. The Japanese Construction Industry Today

1. Similarities to 1990

The fundamental nature of the industry now is similar to that five years ago. There is also a similarity in comparison with the United States construction industry, although the latter has undergone a large transfer of resources from industrial to heavy construction.

The data in Table 2.1 merit several observations:

- At the current exchange rate, the Japanese total expenditures are about twice the U.S. industry volume. Normalized to the populations of the two countries, the Japanese spend about four times as much on construction as does the United States.

- In 1994, the Japanese construction industry dropped from a steady 18% of the nation's gross domestic product over the prior 6 years. The U.S. construction fraction was under one half of that. While 6% to 12% of the gross domestic product is a normal range for worldwide construction, the United States has not achieved 12% in recent years, the 11.9% in 1966 being the closest (Construction Forecast Draft, 1995).

- There was a sharp drop in 1991 in new housing starts in Japan. They averaged 1.4 million for 1991-1993 after averaging 1.7 million from 1987-1990. There was a 6% recovery in the first 10 months of 1994. In the United States, new housing starts decreased from 1.4 million in 1989 to 1.0 million in 1991 and returned to 1.3 million in 1993. New starts were up an additional 14% in the first 10 months of 1994, more than erasing the decline in the early 1990s. (Construction Review, 1994). Note that a housing unit in the United States may be typically about double the living area of one in Japan.

- The public sector investment in Japanese construction is the highest of modern industrialized nations; the United States has the lowest level. Recently, the Japanese public investment has been increasing at a more rapid rate than initially planned, partially as a tactic for fighting the current recession. The Japanese estimate that the return (in terms of triggering an increase in the number of people employed) on investment in construction significantly exceeds that of other major manufacturing industries, and in their view is more effective than a tax cut in effecting economic recovery (RICE, 1994).

- The number of people involved in construction in the United States and in Japan is close to the same, although rates of change are different. In 1994, U.S. construction employment increased 6 percent to a record 6.8 million employees. In Japan, employment for 1993, the most recent year recorded, increased 2.99% to a record 6.45 million people.

Table 2.1 Comparison of Japanese and U.S. Construction Industries

	Japan		U.S.A.	
	1989	**1994**	**1989**	**1994**
Total Expenditures (billions)	$520[a]	770[b]	444[c]	$507[d]
Market Distribution (percent)				
Housing	30[a]	30[e]	40[a]	45[f]
Building	30	33	25	29
Industrial & Heavy	40	37	35	26
Public Sector Investment (percent)	5.0[e]		1.7[e]	
People Employed (millions)		6.45	5.2[c]	6.8
Percent of GDP	18.2[e]	16.9[e]	8.5[c]	7.5[c]

[a] converted to dollars at the rate of ¥135 = $1.00, from Tucker *et al.*, 1991
[b] 1993 data (converted to dollars at the rate of ¥110 = $1.00), from JFCC (1994)
[c] *Construction Review* (1994) and U.S. Bureau of the Census (1994)
[d] *Construction Review* (1995)
[e] RICE (1994)

- The JFCC reports an increase in construction employment in every year from 1987 through 1993; however, it shows a flat level of construction investment from 1990 through 1993 and a dramatic decline in private sector domestic orders beginning in 1991. Since fiscal 1991, the shortfall in private sector construction demand has been covered by increased public investment (JFCC, 1994 and RICE, 1994).

There are many other factors that remain essentially unchanged since the JTEC report.

Government Role. The functions of the Ministry of Construction (MoC), established in 1948, are to assure the safety of the Japanese people against natural disasters and to maintain order in the construction industry. The Japanese government, through the MoC, continues to exert considerable central control over the policies and practices of the Japanese construction industry. The MoC, in conjunction with the Ministry of International Trade and Industry (MITI) is also highly concerned with the image of the Japanese construction industry to the outside world, as evidenced by its numerous publications in English comparing the Japanese construction industry with others.

Planning. The Japanese philosophy is that where projects go according to plan, the time and money invested in pre-project planning is more than compensated by a more efficient construction process. Government-identified driving values serve in the well-disciplined Japanese system to insure adequacy of scope definition. Japanese planners have been noted for their early, detailed, and expansive planning effort which tends to exceed that of other industrialized nations. A closer working relationship between planners, designers, builders, and owners promotes more effective planning.

The benefit of this approach is offset somewhat by a cultural bias toward collective decision making and a determined commitment to avoid loss of face. There is a greater rigidity to plans once developed in Japan as compared with the U.S. system. This lack of flexibility impedes prompt response to emergency or rapidly changing situations. There is, however, no significant movement away from the Japanese commitment to this approach.

Companies. During the past 5 years, there has been no significant change in the overall profile of the industries in either the United States or Japan. In both countries, the industry consists of a small number of large companies and a large number of small companies. In Japan, 99% of the 530,000 construction companies registered in 1993 have a capitalization of less than ¥100 million ($1.2 million) (RICE, 1994). The "Big Five" Japanese companies are unchanged, although there has been some shifting among them and within the next tier of companies.

Table 2.2 **Comparative Data on the 20 Largest Japanese Construction Firms in 1994 and the 10 Largest Firms in 1987 (¥ billion)**
[1993 and 1994 data from the Public Works Research Institute (Japan); 1987 data from Tucker *et al.*, 1991]

Company	1994 Total Sales	1993 R&D Investment	1987 Total Sales	1987 R&D Investment
Shimizu	1,861	16.1	970	12.2
Kajima	1,796	25.4	860	8.6
Taisei	1,558	17.1	950	7.0
Obayashi	1,445	18.4	750	6.5
Takenaka	1,235	15.1	810	8.0
Sekisui	1,178	<1.7		
Daiwa	969	<1.7		
Kumagai	829	3.3	700	2.5
Fujita	664	5.1	450	1.7
Toda	641	4.0	370	1.0
Nishimatsu	623	4.4		
Tokyu	564	3.9		
Sato	564	2.5		
Goyo	530	3.9		
Maeda	530	4.1	320	1.3
Hazama	522	4.2	370	2.4
Mitsui	515	3.2		
Konoike	450	<1.7		
Tobishima	418	<1.7		
Haseko	392	2.3		

The average currency exchange rates (¥/$) were: 145 (1987), 111 (1993), 90 (1994).

Competition. Order in the Japanese construction industry is not manifested by equal opportunity to compete for jobs in a winner-take-all environment; rather, order means obtaining a share of the available work. "The members who compose the order arrange to fairly share available business in order to create long-term satisfaction for all concerned" (Kobayashi *et al.*, 1994). Thus, the Japanese system cannot be directly compared to the U.S. construction experience because this behavior is illegal in the United States, and U.S. construction firms are very sensitive to antitrust considerations.

Private sector competition between major companies is focused more upon qualification for bidding than upon the final bid price (although this may be changing due to the decline in the national economy). Final prices are affected by a "share the work" attitude, which is defended as a way of assuring a viable industry in the long term. Quality and schedule are important factors in insuring development of trust and the resulting repeat business.

Joint ventures are formed to spread the risk, but not as often as is common in the U.S. market. It is not unusual for owners to require joint venture undertakings by both general contractor and subcontractors simply to spread the *work*. Owners recognize that this process adds complexity and cost to the project and often makes coordination between partners awkward. However, the value placed on maintenance of a relatively stable industry and protection of trusted colleagues is considered worth the expense. Joint venturing is usually accomplished through dividing the project into parts and assigning each of the parts to a different contractor rather than according to U.S. custom, wherein the project remains a single entity and one of the joint venture partners assumes overall management responsibility. Additional purposes include mobilizing essential expertise or manpower not otherwise available to the preferred contractor (Gann *et al.*, 1993).

Alliances. Enduring alliances are a fact of life in Japan, in both domestic and international businesses. Cultural expectations are such that Japanese owners find it much easier to work with Japanese contractors. The development of essential trust between parties to a construction undertaking is strongly supportive of long-term commitments. The industry is based upon the maintenance of these commitments, which provide a degree of stability not found in other countries. Alliances between owners and contractors, and contractors with their subcontractors and suppliers are common. These alliances assist in stabilizing the workload and in minimizing the impact of economic cycles. The electrical industry reports that up to 50% of a typical electrical contractor's normal workload derives from a continuing alliance (Gann *et al.*, 1993).

Disputes. Harmony is important, as are schedule, price, safety, and quality. Relationships are based upon a long-term view, with trust and confidence in the other parties' willingness to ensure that justice is done. Contract administration avoids strict, legalistic answers. In keeping with this cultural predisposition, claims and disputes are rare. Work is undertaken often before formal contract documents are executed, and changes are effected on verbal direction from the owner. Litigation which would harm the long-term relationship is rarely considered.

Schedule. The Japanese contractors claim that the Japanese construction industry is second to none in completing projects on schedule; the scheduling is designed conservatively to ensure this. This timeliness fulfills a near-moral commitment made during the planning process.

Safety. The Japanese people are highly safety conscious. Tables 2.3 and 2.4 show the results of a recent analysis (JSCE, 1995). While the reporting of fatalities and compiling of the data may vary in the different countries, on a *per capita* basis, the Japanese safety record is not exemplary. The data in Table 2.4 indicating that the Japanese record is superior relative to the size of its industry must be regarded carefully. The "construction investment" figures are susceptible to currency exchange rates, may not reflect equivalent fractions of investment being in staff time, and do not include possible differences in hours worked per year in the various countries.

Table 2.3 Fatal Injuries per 100,000 Construction Workers, 1990-1992 data

Fatal Injuries	Country
Below 10	Ireland (4.2), Denmark (9.0), Norway (9.0), U.K. (9.2)
10-15	Czechoslovakia (11.0), Finland (11.1), Switzerland (14.7), W. Germany (15.0)
15-20	U.S. (16.2), Japan (17.4), France (18.7)
20-30	Tunisia (26.0), Austria (28.4), South Korea (30.0)
Above 30	Egypt (32.0), Peru (36.0), Singapore (43.7), Hong Kong (116.7)

Table 2.4 Fatal Injuries per ¥1 Trillion Construction Investment

Country	Year	Construction Investment (¥1 Trillion)	Number of Fatal Injuries	Injuries/ Investment
Japan	1992	85.0	993	11.7
U.S.	1992	52.1	1300	25.0
U.K.	1985	4.8	105	28.1
France	1992	15.1	295	19.5
W. Germany	1990	19.1	332	17.4
S. Korea	1990	5.7	673	118.0

Public interest and government pressure is forcing even more attention to this important aspect of the business. In every visit to a construction site by the 1995 team, we observed strong sensitivity and commitment to safety in the workplace, generally with a goal of no injuries.

Productivity. It might appear from the aggregated economic data in Table 2.1 that the Japanese construction industry is far more productive than the U.S. construction industry. In 1994, 6,450,000 construction workers in Japan put in place $770 billion in construction value, whereas in the U.S. 6,800,000 construction workers put in place $507 billion in construction. This gives a productivity of $120,000 per construction worker in Japan and $75,000 per construction worker in the United States. Yet almost no one in either the Japanese or the U.S. construction industry believes that Japanese workers are nearly twice as productive as U.S. construction workers. The exchange rate is responsible for this anomaly; it is impossible to accept that, as the value of the dollar falls with respect to the yen in international money markets, U.S. construction workers somehow get less productive or Japanese construction workers somehow become more productive.

Although specific productivity comparisons are difficult due to variations in the exchange rates, it is clear that construction in Japan is very expensive relative to other countries. The Japanese MoC has stated that "housing construction costs in Japan are higher than those in the United States" (RICE, 1994). According to an official of the Housing Institute of Complete Project Management, ABC Development Corporation: "A $100,000 house in the United States could cost twice as much in Japan." (See Appendix A of this report.) This estimate is consistent with a statement by the U.S. Department of Commerce, that "Japanese construction and distribution costs are so high that the erected cost of U.S. factory-built housing exported to Japan is more than double the cost in the United States" (Construction Review, 1994).

Other comparisons of housing costs show even greater differences. Table 2.5, compiled from World Bank data published in *The Economist*, shows comparative data on housing construction costs in various world capitals. Tokyo is far and away the most expensive city, with housing construction costs over 2½ times the costs in the next most expensive city, Paris, and over five times the cost in Washington, DC. Lest this difference be thought an artifact of exchange rates, the second column of the table shows house construction costs relative to household income in each locality. In Tokyo, this ratio is third in this survey only to Beijing and Algiers. In Washington the average house costs one-fourth that in Tokyo and slightly less than in Paris.

It is not immediately obvious why housing construction costs in Tokyo should be so much higher than those in Hong Kong or Singapore, which are also rapidly growing Asian cities with little land available. However, Tokyo housing construction costs are 4 times those in Hong Kong and 3.5 times those in Singapore on an areal basis, and nearly double and over 4 times as expensive, respectively, relative to household incomes.

This substantial difference in housing costs between Tokyo and comparable Pacific Rim cities must be attributable to Japanese government policies and to the characteristics of the Japanese construction industry. This comparison indicates clearly how the Japanese public is bearing the costs of construction in Japan.

The situation is only slightly better in terms of delivery time. In Tokyo the average (detached) house takes 12 months to construct, three times as long as in Washington, and much less than in equally congested cities such as Hong Kong. In administrative time the Japanese are better: permit delays average only 8 months whereas Washington, with permit delays averaging 36 months, for governmental efficiency is in a class with cities such as Bogota, Dar es Salaam, Manila, and New Delhi.

It is not clear at present in which direction the productivity of the Japanese construction will move. On the one hand, the industry is moving to embrace concepts of "lean construction," modeled after lean manufacturing in the Japanese automobile industry. Lean construction is defined as involving full team cooperation to reduce time and cost through extensive prefabrication, waste reduction, and strict quality control (Gann *et al.*, 1993). On the other hand, according to data from the Japanese Federation of Construction Contractors (JFCC), the productivity gap between the United States and Japan is widening due to the current Japanese approach of moderating the recession by employing more construction workers.

Unions. Labor unions in Japan continue to perform in a different role from that experienced in the United States. Major companies deal more often with company-based unions rather than with national trade unions. Unions in Japan, where they exist, do not have the influence common in the United States. Wages are set on a company-by-company basis. The Japanese government publishes statistics twice a year which provide baseline data to assist in wage negotiations.

Attitude toward change. The Japanese construction industry is quick to experiment with selected new technology, both because it is mandated in some competitive situations and because its leaders value the competitive advantage provided. The Japanese government in its long-range planning looks to a more "mature" industry, one better adjusted to a holistic, socially integrated, technologically advanced view of requirements and design (RICE, 1994). Government sponsorship of innovation insulates the innovator from the type of legal responsibility so common in the United States. As a result, insurance coverage is limited in Japan. However, the recently-instituted product liability law, which went into effect in July, 1995, will likely increase the practitioners' exposure.

Openness of domestic market. The U.S. government has asked Japan to open its markets to broader-based international competition. U.S. companies have found it difficult to compete in Japan according to Japanese rules and customs. Obstacles of language, long-term relationships, major R&D commitment, and experience with enduring alliances based in Japan have contributed to the apparent domestic monopoly enjoyed by domestic companies. The problems involved in a joint venture within the Japanese market are well described in Kobayashi's study (Kobayashi *et al.*, 1994). Independent operation would be even more difficult.

Table 2.5 Comparative Data on Housing in World Capitals
[1990 Data from the World Bank, published in *The Economist*, 29 July 1995, page 8.]

City	Construction Cost ($ U.S./m^2)	House Price to Income Ratio*	Construction Time (months)	Permit Delay (months)
Algiers	500	11.7	6	2
Bangkok	156	4.1	5	11
Beijing	90	14.8	17	24
Bogota	171	6.5	6	36
Dar es Salaam	67	1.9	28	36
Hong Kong	641	7.4	30	2
Istanbul	110	5.0	16	2
Jakarta	65	3.5	2	28
Johannesburg	192	1.7	2	24
Karachi	87	1.9	12	n.a.
Kingston	157	4.9	12	6
London	560	7.2	20	5
Madrid	510	3.7	18	8
Manila	148	2.6	3	36
Melbourne	383	3.9	3	36
New Delhi	94	7.7	24	36
Paris	990	4.2	8	2
Rio de Janiero	214	2.3	18	6
Seoul	617	9.3	18	20
Singapore	749	2.8	9	2
Tokyo	2604	11.6	12	8
Toronto	608	4.2	6	30
Washington, DC	500	3.9	4	36

* Ratio of median price of house to median family income

"Sustainable" construction and "green" construction. These have become fashionable terms around the world, in some cases used by people sincerely hoping to change to better practices and in others cynically exploited as marketing buzz words. In some ways Japan's geographic and demographic constraints have made them sensitive to social and environmental impacts of their work for some time. Their urban construction methods have long been less disruptive than those in the United States, and it appears that Japan is intensifying work in related topics. However, they seldom used these words.

2. Differences from 1990

Since 1990 there have been major setbacks to the Japanese construction industry. Government fiscal policy contributed to the nation being saddled with immense bad debts (The Economist, 1994). The world-wide recession of the early 1990s took its toll on Japanese investments at home and abroad. Aggravated by the decline of the dollar against the yen, the value of some prestige real-estate acquisitions in the United States and Europe declined by over 50%. At about the same time, major corruption scandals in the leading companies and some government agencies saw several senior executives and politicians going to jail in 1994. Public confidence in the industry began to erode. Most recently, the unexpected devastation wrought by the Hyogo Ken Nanbu earthquake in January, 1995 caused even the engineering and construction community to question its own capabilities and assumptions.

Decline in revenues. The Japanese construction market has been under substantial pressure during the period 1991 to 1995. The JFCC reports a virtually flat rate of construction investment from 1991 to 1993, measured in constant value yen (JFCC, 1995). The Japanese gross domestic product in 1993 grew by less than 0.5% in real terms. In 1993, the Japanese construction industry expanded by 0.6% on a current monetary basis, but if the value of the yen in 1985 is used as a base, volume actually fell by 0.7%. One author reports that Japanese construction volume during this period was actually down 40%, and that it will take from two to four years beyond 1994 for full recovery (Li, 1995). Another report notes that six or seven bidders were involved in relatively recent electrical contracting work which would have been offered to no more than two bidders during busier times (Gann *et al.*, 1993). Most recently, Shimizu reported that sales for the year (ending March 31, 1995) fell 9.7%, Obayashi reported sales fell 14%, and Taisei reported that sales fell 12%. Also, "Taisei joined other major Japanese contractors in forecasting a sharply weaker performance for the current year ending March 31, 1996" (Asian Wall Street Journal, 1995). Conversely, in the United States, though slow in earlier years, new construction volume increased by 5% in 1994 to near the record level established in 1986.

Decline in profits. The construction industry has suffered worldwide during the past three years. Profitability in both Japan and the United States has reflected economic pressures in the respective national economies. Though Japan reported a 3.4% contractor profit in 1990, essentially the same as was enjoyed by manufacturing industries in Japan, more recent figures show that construction company bankruptcies in Japan have increased dramatically, with a 68% increase in 1993 (RICE, 1994). Concern has been expressed by government officials that this trend may continue or even increase under current circumstances.

The large contractors, although in no danger of bankruptcy, have seen declines in profitability. "Shimizu Corporation, Japan's largest general contractor,...reported a net loss for the year [ending March 31, 1995] of ¥3.93 billion, compared with net profit of ¥43.70 billion in the previous year" (Asian Wall Street Journal, 1995). U.S. construction companies' net profit in recent years has averaged less than 3% (Tulacz, 1995). Increased pressure on Japanese company profits has forced higher priority attention to the international market, some review of the "employment for life" policy generally accepted in Japanese companies, and substantial reduction in R&D program funding.

The period of construction expansion was not so good for the smaller contractors either. Their average profitability increased but their market share declined, and the total number of licensed construction contractors actually declined, from 518,964 in 1985 to 508,874 in 1990, a period in which the volume of construction increased 43% in real terms (JFCC, 1994). Although data are not available to determine whether this decline was due to business failures or to mergers and acquisitions, the MoC notes that "There are many bankruptcies. One out of five companies in Japan which goes bust with over ¥10 million in debts is a construction company" (RICE, 1994). This contraction in the number of contractors in a boom period for construction is remarkable.

Taken together, these statistics indicate that the years of rapid growth in construction were particularly advantageous to the largest contractors. As the largest general contractors spend the most on R&D, as a percentage of sales, and have the largest profit margins, it is clear from the JFCC data that profitability and investment in R&D are positively correlated (but may not be causative). Although the specific contribution of the corporate research institutes to this result cannot be determined, it is clear that Japanese construction R&D contributed to the consolidation of the construction industry and benefited the large contractors both in market share and in profitability, at the expense of the smaller contractors.

In the period of stagnation, this picture turned around: the volume of Japanese construction declined by 2% in real terms from 1990 to 1993, the market share of the 59 JFCC contractors declined from 32.6% to 21.5%, and their profitability declined from 4.3% of sales to 3.5%. Conversely, in the same period, the number of licensed construction contractors increased over 4%, from 508,874 to 530,665 (JFCC, 1994). Although the number of new construction firms started may have been influenced by conditions in other sectors of the Japanese economy, and data on the number of new firms started versus the number of failures are not available, one has the general picture that the period of stagnation may have opened up some of the Japanese construction market and diminished the influence of the large contractors' research institutes on the consolidation of the industry.

Procurement reform. A dramatic change has occurred in the Japanese government's role in construction. In 1993 there were a number of arrests incident to charges of bribery involving public works. The public was severely critical of both government officials and construction company executives for their administration of the public sector procurement system. After careful study, the Cabinet in January, 1994 approved and announced to the public a new procedure for public works procurement. The prescribed open competitive bidding process maintains control of bidder qualification through a prequalification procedure, but *all* companies become eligible for prequalification consideration upon petition, and the total number of companies permitted to compete for the work is not limited. Companies failing to meet the prequalification test are formally notified of the reasons for their failure to qualify. Ministry of Construction projects costing approximately $10 million (¥83 = $1.00) or more are subject to this new open bidding procedure, as are quasi-governmental agency projects estimated to cost approximately $25 million or more. It was recommended that prefectures and municipalities follow the same approach. Reforms include creating organizations to monitor and enforce the rules, strengthening qualifications for contractor licenses, studying the introduction of performance bonds as a public sector bidding requirement, and strengthening penalties for bid rigging (RICE, 1994).

These reforms in public sector procurement are too new to be evaluated completely. The extent to which plans are actually implemented is yet to be demonstrated, and it is possible that the reformed system may well operate much like the prior one. The effect of implementation remains highly conjectural; however, the possibilities are quite significant. The substitution of a more U.S.-oriented procurement system could damage commitment to benefits associated traditionally with the Japanese approach. Development of trust and long-term relationships would become less important because the marketing opportunity payoff would be diminished. More focus on low bid awarding will inevitably spawn adversarial relationships, hitherto rare in the Japanese industry. In short, the benefits of reform carry corresponding disadvantages, and the overall impact on the industry remains to be determined and is a subject of intense interest.

Employment Stability. Historically, and continuing in the present, the typical Japanese construction company employee has worked for a single company during his entire career. Under this compact, in exchange for lifelong employment, personnel have given up control over their roles in the company, the opportunity to change jobs or companies at their own choosing, control of their own careers, and the opportunity for professional self-expression.

Should the recession continue, and should the large contractors begin to lay off some of their employees, there is the potential for momentous change. There are Japanese professionals who would like the freedom to change jobs to fulfill their individual goals. Should they become free to seek better, higher-paying, or more interesting jobs, the biggest threat to the stability of the large contractors and the construction system as a whole may lie in the "Westernization" of the Japanese work force.

A compunding factor is the characterization of construction industry jobs by what is locally known as the "3 Ks:" *kitanai* (dirty), *kiken* (dangerous), and *kitsui* (physically demanding). Most of the younger work force seeks more comfortable and less strenuous jobs in other fields.

Hyogo Ken Nanbu Earthquake. On January 17, 1995, a tremor registering magnitude 7.2 on the Richter scale and centered at the northern tip of the Osaka Bay island of Awaji devastated the city of Kobe and the surrounding area. Over 5,000 people were killed and the damage exceeded $150 billion. All over Japan there was surprise at the extent of death and damage. Most were critical of the slow and ineffective response of the MoC, which has the lead responsibility in disaster recovery.

There had been rumors that the earthquake had severely shaken the confidence of Japanese engineers as well as the general public in their structural design capabilities. This delegation saw few if any signs of this shaken confidence on our trip, some 5 months later. Instead, it seems that they had refocused some priorities and buckled down to extensive additional work on finding improved methods for the repair and retrofit of existing structures.

An interesting footnote is that the Akashi Kaikyo, a suspension bridge, soon to be the world's longest with a 1990-meter center span, which was described in the JTEC report and is still under construction, came through with only minmal damage to its pier foundation. However, due to the surface earth movement, it will now be 1990.8 meters long and its center span will be 1.3 meters higher than originally planned. The computational analysis for the new configuration has been checked out, and the construction is proceeding on schedule.

Aging Population. Japan's population is aging quickly, more rapidly than the populations of other industrialized nations, including the United States. In 1990, both the United States and Japan had approximately 12 percent of its population at age 65 and older. Twenty years later, by the year 2010, the U.S. fraction will have remained nearly steady, equaling approximately 13 percent, while Japan's portion will increase to 22 percent of the total (RICE, 1994). This rapid increase has profound impacts on the Japanese construction market because:

- The favorable rate of Japanese savings will decline with an aging population.
- Standards and other design criteria must be adjusted to accommodate an aging population.

Role in the International Market. The major Japanese general contractors are very large but have traditionally worked predominantly within the domestic construction market, where they have substantial advantages, as noted elsewhere in this report. They have in the past been somewhat less active in obtaining international business than other large international engineering-construction companies.

Table 2.6 compares the largest Japanese firms with the top international construction contractors, taken from the top 25 contractors listed by 1994 revenues from all sources, each with total 1994 revenues of at least $5 million U.S. (ENR, 1995b). Revenues shown are in millions of U.S. dollars, and the percentage is the percentage of work obtained outside the firm's home country.

Japanese firms clearly dominate in this list. They represent the top six construction contractors and eighteen of the 25 firms worldwide with 1994 revenues of more than $5 billion (U.S.) (along with two U.S. firms, two German, two French, and one British). These 18 Japanese construction firms accounted for over 74% of the $231 billion in total 1994 revenues by these top 25 companies.

Table 2.6 **Magnitude of the Top 25 Global Construction Contractors**
[Data from ENR, 1995b]

Rank	Name	Country of Origin	1993 Revenues ($ millions)	Percent of Revenues Overseas
1	Shimizu Corp.	Japan	17,914	5
2	Kajima Corp.	Japan	17,765	4
3	Taisei Corp.	Japan	16,742	4
4	Obayashi Corp.	Japan	16,083	6
5	Mitsubishi Heavy Ind.	Japan	15,309	28
6	Takenaka Corp.	Japan	12,792	5
7	Philipp Holzmann AG (Germany)	Germany	11,716	20
8	Bouygues SA	France	11,224	28
9	Trafalgar House	U.K.	9,044	75
10	Kumagai Gumi Ltd.	Japan	8,615	10
11	GTM-Entrepose	France	7,948	41
12	Toda Corp.	Japan	7,096	1
13	Nishimatsu Ltd.	Japan	6,923	11
14	Hochtief AG	Germany	6,751	34
15	Fluor Daniel Inc.	U.S.A.	6,638	36
16	Bechtel Group Inc.	U.S.A.	6,553	24
17	Kinden Corp.	Japan	6,274	2
18	Kandenko Co. Ltd.	Japan	6,258	0
19	Sato Kogyo Co. Ltd.	Japan	6.144	4
20	Maeda Corp.	Japan	5,954	4
21	Tokyu Co. Ltd.	Japan	5,836	5
22	Hazama Corp.	Japan	5,647	6
23	Fujita Corp.	Japan	5,622	0
24	Penta-Ocean Co. Ltd.	Japan	5,312	11
25	Mitsui Co. Ltd.	Japan	5,162	5

However, most of these revenues were obtained from the internal Japanese construction market. The Japanese firm with the highest overseas sales, 28% of 1994 revenues, is Mitsubishi Heavy Industries, a manufacturing company that exports equipment as well as engineering and construction services. The 17 other Japanese construction contractors (excluding MHI) averaged 4.9% of their 1994 revenues in the international market, compared to an average of 30.4% for the two U.S. firms and 36.6% for all seven non-Japanese firms in the top 25. Thus, the volume attained by the major Japanese general contractors is obtained predominantly from domestic work, unlike the non-Japanese firms in the top 25 who are truly dependent upon international construction business.

Major Japanese construction companies moved aggressively into the international market in 1993, particularly into the very active Asian market, to help offset the impact of sluggish domestic work. The total Asian market is reported to have increased 20% during 1993 (Reina *et al.*, 1994). This accelerated international thrust resulted in Japanese companies capturing 63% more international work in 1993 than they had done previously. Their total international volume rose to $20.2 billion. Though small by comparison with the domestic volume, the rate of expansion in the international market is noteworthy. The Japanese impact on the international market place is shown in Table 2.7. The empty boxes indicate insignificant market share.

Table 2.7 1993 International Market Share ($ billion)
[Data from Reina *et al.*, 1994]

Constructor	Construction Sites							
	Europe	Africa	Mid. East	Latin Am.	Asia	U.S.A	Canada	Total
U.S.A.	13.4	4.3	13.6	5.7	22.1		2.0	61.1
Japan			2.5		14.3	1.6		18.4
All Others	20.3	9.8	10.7	6.8	15.0	10.9	2.1	75.6
Total	33.7	14.1	26.8	12.5	51.4	12.5	4.1	155.1

Apparently Japan's successful international efforts are focussed on capturing the Asian market (78% of their total), where logistic lines are short and cultural differences are minimized. At present, the Japanese share of the foreign-controlled part of the Asian market is 28%, compared with the U.S. share of 43%. In the total international market, the United States holds a 43% share as compared with Japan's 12%.

The U.S. market is becoming more attractive to offshore contractors, their volume having climbed 40% in 1993 alone. At present, this is only about 2½% of the total, but the 1993 increase is significant.

During the panel's visit, numerous sources expressed the hope that the recent and substantial change in monetary exchange rate will moderate. The highly valued yen is certain to curtail Japan's growing international market share.

III. UNDERSTANDING INNOVATION AND R&D IN THE JAPANESE CONSTRUCTION INDUSTRY

A. Background

At the time of the 1990 visits by the JTEC and CERF delegations, Japanese R&D was ascending and there was little indication that it may have been approaching its zenith. Delegations from around the world came to marvel at their research, development and implementation of new ideas and technologies in fields as diverse as construction automation and robotics, composite materials, long-span bridges, very tall buildings, integrated computer-aided design systems, intelligent building control systems, long-distance tunneling, earthquake resistant structures, factory-built luxury housing, and many others. The delegations visited some of the world's largest superprojects, including the four km long Akashi-Kaikyo suspension bridge (Furuya *et al.*, 1994), the 4 km long offshore man-made island of the new Kansai International Airport, the 15 km Trans-Tokyo Bay Highway Project, and the Mukuhari New City. They saw in industry laboratories technologies that enabled several companies to use substantially automated methods to build high-rise buildings starting in 1993 (Cousineau, 1995). The JTEC (Tucker *et al.*, 1991) and CERF (Hampton *et al.*, 1991) reports paid appropriate respect to these exceptional achievements, noting the important role that the strong government and industry R&D capability played in supporting them.

As noted in the previous section, significant forces have been exerted on the Japanese construction industry. Indeed, before going to Japan, some members of the 1995 panel had heard rumors that the much-acclaimed company research institutes had become mere shells of what their predecessors saw in 1990, with many highly skilled researchers being transferred to mainline corporate duties such as estimating and marketing. This section addresses the following questions: Have the aforementioned problems only caused short-term interruptions to the world's leading construction R&D capability? Have they caused a long-term restructuring and reorientation of Japanese business enterprises to make them less likely to sustain such long-term investments in the future? If there are fundamental shifts toward a much less significant role for R&D, what are the implications for both Japan and for the international marketplace?

B. Definition of Research and Development

In any comparison of U.S. and Japanese R&D, it is essential to understand the meaning of the term "research and development" used in each country. It is well-known, for example, that the definitions of industrial robots are quite different in the United States and Japan, leading to substantially higher numbers of industrial robots reported in the Japanese manufacturing industry than in the United States. Similarly, the Japanese definition of R&D as used in the research institutes of the major general contractors is far different from the U.S. understanding of that term as used by the National Science Foundation and research universities.

Specifically, the Japanese usage of "research and development" includes activities that would not be included in the U.S. definition. Much of what is termed "research and development" in Japan would be called "testing" in the United States. This follows from the sense that the purposes of R&D in the two countries are entirely different. In the United States, the objective of research conducted under government sponsorship at research universities and government laboratories is primarily to obtain new knowledge and to develop new principles. In Japan, the objective of the contractor R&D institutes is primarily to verify and improve engineering designs and construction procedures through experiment and to assure the safety of Japanese constructed facilities.

C. Support for Advanced Technology and R&D

1. Driving Forces and Objectives

There are a variety of diverse factors that determine the existence and direction of Japanese construction R&D.

Improve infrastructure. Japan, with its population concentrated along its long, narrow coastline, is continuously pressured to make better use of the limited land space where people want or need to be. Thus, in urban areas, there is the need for more residential units; higher high-rise buildings in the central city; new or better bridges and tunnels, etc. to get people to work faster, to open up new residential areas, and to give them improved access to where the jobs are. New technology is needed to build bigger, better, faster, and safer.

Reduced cost of construction. As the industry looks increasingly to the international marketplace, the need for a real contribution to cost effectiveness will increase. In all of our visits to industrial research institutes and construction sites, we heard an emphasis on economy. The staff is well aware that Japanese domestic construction costs are higher than elsewhere and that real opportunities exist for improvement.

Mitigate natural disasters. The Japanese people have a deep concern for the loss of control over the physical environment due to a breakdown in the order of nature, particularly characterized by typhoons and earthquakes. This concern is motivated by the extensive experience of the Japanese with these extremely damaging events, and a common perception that Japan is uniquely afflicted by these events. An earthquake may be considered the ultimate breakdown of the natural order, and if earthquakes cannot be prevented, then at least all possible measures to mitigate their consequences are justified.

Improve the size of the work force. A stated goal of the construction research program of the Ministry of Construction is to respond to the shortages of construction workers. As recently as 1989, it was reported that Japan's construction labor was 26% short of the requirement, the largest shortfall faced by any domestic industry, and a result of a steady growth in construction volume and the 3 Ks. However, in the period from 1990 to 1993, (*i.e.*, after the boom years of the 1980s), construction volume actually decreased 2% (in constant yen) while the number of construction employees increased almost 9%, construction wages increased 11% (in constant yen), and productivity decreased 10% (in constant yen) (JFCC, 1994). Thus the construction industry was willing to raise real wages to add employees to meet long-standing labor shortages even in the period of no growth. Should these trends continue for even two more years, there should be a sufficient pool of construction workers.

Improve the quality of the work force. However, the problem has become a shortage of *skilled* construction workers (although it was not stated specifically which skills were in short supply). The industry is being used as a damper for unemployment in other industries and market sectors while the percentage of school dropouts in the construction labor force appears to be increasing. The current image that construction is dangerous, dirty, and physically demanding (Sterling, 1992) has hurt the industry's ability to recruit and retain highly qualified workers. Thus, there is an impetus to develop technologies which move on-site labor needs to a more controlled work environment, allow for use of a less-trained labor force, and permit continued utilization of an aging labor force. Implementation of new technology that makes the work seem more "high tech" would improve the industry's image with younger potential workers. As a way of minimizing on-site labor, the industry developed prototype construction robots, which were highly regarded in the JTEC Report (Tucker *et al.*, 1991) as the wave of the future in construction. More recently, a strong trend has been identified toward support of modularization, prefabrication, and preassembly (Gann *et al.*, 1993).

Aging population. New facilities and different designs are needed to provide a comfortable life for older citizens.

Improved safety. This is a concern both on the job (*cf.* Tables 2.3 and 2.4 and the related discussion) and for the occupants.

The *White Paper on Construction in Japan 1994* also identified two additional construction technology objectives:

Address environmental issues. The Japanese consider it a national responsibility to minimize man's negative effects on the natural environment. This includes effects of both facility design and construction methods, as well as on-site restoration of nature.

Improve aesthetics. As the Japanese economy has matured and as the people have become more affluent, there has been an increase in sensitivity to aesthetics, which might have been compromised for economic efficiency. "Buildings and structures should be regarded as an integral part of the cityscape." "Beauty can be created through well-designed public facilities in harmony with the surrounding environment."

In terms of strategic planning, the investment in individual research institutes by the major general contractors serves purposes beyond the general incentives described above:

Increased Market Share. From a U.S. perspective, it is most surprising that R&D efforts in construction technology are *not* justified on an economic basis. The Japan Society of Civil Engineers explicitly stated that a payback period for new developments is not even calculated and is not an issue in the development of research programs. (See Appendix A of this report.) They also asserted that there is no direct correlation between the level of R&D activity and construction company profitability. Moreover, the companies stated that certain of the products of R&D are more valuable to demonstrate R&D prowess and thus to provide competitive advantage than they are to reduce cost or improve quality.

However, the research institutes have clearly been advantageous to the large general contractors. The direct payoffs may not be measurable, but the indirect benefits to the contractors with R&D institutes have been substantiated. According to the Japanese Federation of Construction Contractors (JFCC), in the period of expansion in construction, from 1983 to 1992, the top ten construction contractors (with R&D institutes) increased their share of the total construction market from 12.6% to 14.8%, and the top 100 contractors increased their market share from 27.5% to 31.6% (JFCC, 1994). The market share of the 59 firms in the JFCC improved even more in the period of expansion, increasing from 22.2% in 1985 to 32.6% in 1990. The profits of this group also increased, from 2.5% of sales in 1985 to 4.3% of sales in 1990. These large construction companies also maintained an advantage in profitability of about 1% on sales compared to the average of all construction companies (JFCC, 1994). It is interesting that this margin is approximately equal to the expenditure by the large companies on R&D.

Limit on Competition. The existence of a research institute constitutes a barrier to entry of other contractors who cannot afford such facilities. As the possession of a research institute is a prerequisite to obtaining joint research program funding from the Ministry of Construction and to obtaining large public works projects controlled directly or indirectly by the Ministry, some medium-size companies have established research institutes, while smaller contractors are effectively excluded. As is well known in strategic planning, the existence or creation of barriers to entry to a market is one method for achieving and maintaining higher profit margins (Hasegawa *et al.*, 1988), so that there has been ample incentive for Japanese general contractors to invest in research institutes. At the lower levels of the construction industry, no comparable barriers to entry exist, and the Japanese construction industry appears to be as easy to enter at the bottom as are the construction industries in other countries.

2. Funding of R&D

Source of R&D funding. The United States and Japan have evolved different ways of paying for construction R&D. These put the direct burden on different segments of the populations.

In the Japanese construction industry, the large general contractors, with substantial capital assets, have their own research institutes and, along with the research institutes of the MoC, perform the majority of the construction R&D. The government institutes are publicly funded and represent about 2% of the national R&D investment.

As was noted earlier, the Japanese maintain that R&D is not performed solely for economic reasons, and therefore cannot be funded out of strictly financial returns on the investment in R&D. In fact, the Japan Society of Civil Engineers members emphasized that there is *no direct connection* between R&D and profit. If not funded from profits, then another, indirect mechanism is needed to pay for it. [While the research institutes perform consulting services for other companies, this is typically a secondary fraction, perhaps 30%, of the total establishment budget and does not cover the overhead costs of the institute.]

The Japanese have elected to fund research through an effective assessment on construction costs rather than by general taxes. Historically, the MoC indirectly provided the funding by permitting the costs of the R&D programs to be absorbed by projects. The Ministry controlled the short listing of firms eligible for major public works projects, giving access to those companies that support the goals of corporate R&D and effectively excluding any construction firms that might be able to underbid them because they did not invest in research institutes. Within the short list, either price competition might govern the contract award or, more often, joint ventures would be established among the prequalified firms to spread the work. However, any price competition would include the costs of R&D programs in the price, because only firms with these programs qualified. As a result, the cost of construction increases by the amount of the R&D costs, about 1% for the Big Five construction companies, about 0.7% for the next tier, and "the construction industry as a whole laid out R&D investments amounting to an average of 0.5% of total sales in 1986" (Hasegawa, 1988). This will likely be affected by the procurement reforms described earlier.

The same process is also used by major private clients, even though one might suppose that they would be interested in more intense price competition. Major private clients have accepted this situation because they share the same value system as the MoC, which is essentially the value system of the Japanese public, that an increase in safety against natural disasters is preferable to a minor decrease in costs. Major private clients who wished to bid costs down would find nowhere to go, because all the major construction contractors were participants in the public works programs of the MoC, and hence all would include approximately the same markup for R&D. And private clients who wished the lowest possible prices could turn to the smaller contractors, who perform little R&D.

In the U.S., the situation is quite different. There is limited direct sponsorship of university research by industry. However, the Federal government, through the National Science Foundation (NSF) and other agencies (*e.g.*, the Departments of Commerce, Defense, Energy, and Transportation, and the General Services Administration), directly funds most of the U.S. engineering and construction research at universities and agency or private laboratories. Therefore, in the United States it is the general taxpayer who pays the bill through the broad-based, progressive income tax.

Another view of the two systems is from the perspective of employment stability. U.S. engineering and construction firms will invest in construction R&D proportionate to the degree to which they can appropriate the benefits of the development to themselves through patent rights and trade secrets. Firms in which there is a high turnover of engineering, design, or construction personnel will not be able to maintain trade secrets, will not be able to afford the high retraining costs to use proprietary technology, and will be unable to appropriate the benefits of any investments in intellectual property. In Japan, a worker has traditionally worked for only one firm, while in the United States, high personnel turnover is common. Thus, a Japanese construction firm can appropriate to itself the benefits of its construction R&D, as the increased knowledge is retained by the individuals who are retained by the company. In the United States, that expertise can become part of the industry-wide pool, to be shared by all competitors. Therefore, U.S. construction companies have significant disincentives to perform R&D at their own expense, particularly when they can gain access to taxpayer-funded university R&D for free.

Which system is more equitable may be debated. The Japanese approach has strengthened the Japanese construction industry with respect to the universities, whereas the U.S. method has strengthened the universities with respect to the construction industry. Had the United States established a MoC instead of a NSF, and Japan had established a NSF instead of a MoC, the results might have been reversed. However, such a reversal would have been inconsistent with the differing goals, objectives, and historical background of each country. At any rate, it is clear that it is inequitable to compare R&D expenditures by Japanese construction firms to those by U.S. construction firms. One must assess the total of industry and government funding in both countries to arrive at a valid comparison.

Level of investment. Both the United States and Japan have a recent history of investing in construction R&D and using new construction technology proportionate to the national investment in engineering infrastructure, as measured by infrastructure investment per capita. The data in Table 2.1 show that the Japanese currently invest 50% more resources in construction than does the United States. As a fraction of GDP, the U.S. investment is half the Japanese level. It has fallen by about 50% over the past 30 years, while the Japanese fraction has risen about 50%.

If these data are accurate and if the national investment figures remain at their present levels, Japanese firms will continue to perform substantially more construction R&D than U.S. firms, simply because there is more construction to be done, and that which is done is expanding in size (length of tunnels, length of bridges, height of buildings, etc.) and difficulty (due to high congestion). Conversely, if construction volume falls, as it has since the Japanese recession in 1993, one would expect that construction R&D would also fall.

There are a variety of additional factors that explain Japanese firms investing more in R&D than do U.S. firms.

- Construction firms' investment in construction R&D is limited by their available discretionary funds, *i.e.*, profits. The profit factor of construction firms have been much higher in Japan than in the United States, but have been declining since 1993.

- Firms that regard technology as the basis for competitive advantage will tend to invest more in proprietary technology, whereas firms that regard technology as a commodity will not invest in new technology development.

- Engineering and construction firms with high turnover rates in personnel will be less willing to spend the effort to train personnel on proprietary methods or systems, and will be less likely to develop or enhance such methods and systems, than firms with low turnover rates.

- Firms will invest in construction R&D to the extent that these costs can be recovered from client fees. In the U.S. public works sector, many governmental agencies refuse to allow the use of proprietary technology on public projects. Also, the Federal Acquisition Regulation prohibits the recovery of R&D costs in overhead for engineering firms working for the U.S. Government. These policies of the U.S. Government actively discourage the development and use of innovative technology on public projects.

- Economic models show that intense interfirm competition leads to underinvestment in research and development (Reinschmidt and Tatum, 1993). More intense, price-based competitive bidding discourages the development and use of innovative technology, whereas the award of work based on performance or technology can encourage the development and use of new construction technology. This suggests that a country with intense price competition (such as the United States) is expected to invest less in new construction technology than a country in which jobs are not awarded solely on price-competitive bases (such as in Japan).

In Japan, there is substantial competition, but it is not predominantly based on price alone. In the past, "the central and local governments ranked construction firms according to past order-taking performance, sales, financial status, and technological capabilities." (Hasegawa, 1988) Presumably, "technological capabilities" were identified by the possession of research and development institutes. As a consequence, "during the high-growth economic period,... large general contractors got 80% of orders without having to compete with rival bids.... Today (1988) the general contractors acquire less than 60% of new orders without bidding." (Hasegawa, 1988) As was stated in the JTEC Report (Tucker *et al.*, 1991), in Japan the "...emphasis [is] upon competitive issues other than first cost.... Most private contracts are negotiated, and even government projects are awarded based upon bid lists of selected contractors...." Conversely, in the United States, "under the state's low-bid law, it's hard to deny an opportunity to a contractor unless he has a flagrant history of defaulting" (ENR, 1995a). In these circumstances, it is expected that Japanese general contractors will invest more in R&D than U.S. construction firms, and this is confirmed by the evidence.

However, as noted above, the Japanese MoC has recently responded to a series of scandals involving public works by moving to open competitive procedures. Based on the theoretical models, it is predicted that this shift, if successful, will put pressure on the research institutes of the general contractors. Under open competition, either construction firms that do no R&D may take contracts away from those that do by underbidding them, or the first rank general contractors will have to absorb the costs of their research institutes in their profit margins, which are already narrowed by the rise in value of the yen. For all these reasons, it is likely that the general contractor research institutes, valuable as they may be, will be adversely affected in the next few years.

3. Where Does Innovation Occur?

The 1995 panel sought to determine whether, in Japan, new construction technology is more likely to be developed by companies with large asset bases than by small companies with fewer assets.

Development and implementation of construction innovations is a risky process. Small companies, which are generally undercapitalized, run a higher risk of business failure and bankruptcy should the new technology prove unsatisfactory than do large companies, who have more assets to absorb losses. Many times, even the most valuable innovations take longer to become economically viable than expected, and large companies may have the financial resources to stay the course, whereas small companies may not. [An example is the development and commercialization of carbon fiber retrofit technology by Tonen Corporation; see Section IV.C.] This situation is characterized by the classical ruin problem in statistics: it can be shown mathematically that, in a risky environment, the player with greater assets will survive longer than a player with lesser assets. In the environment of survival of the fittest, small companies that take large risks on new technology (or on anything else) may not long survive. In the construction industry, as in the well-known cliche from the early days of aeronautics, there are old pilots and there are bold pilots, but there are no old, bold pilots.

Conversely, there is a general perception that small companies tend to be more innovative than large companies, perhaps because small companies are populated by entrepreneurs whereas large companies are more bureaucratic. Small companies may indeed be started by innovators who cannot function effectively inside large organizations. Therefore, it is possible that small companies may have a higher innovation rate but also have a higher failure rate, and one tends to preferentially remember only the survivors.

A question about the source of construction innovation was directly answered by the Japan Society of Civil Engineers (Appendix B):

> *Are very large construction firms more likely to innovate new construction technology than smaller firms?*
>
> Yes, that is the general tendency, but specialty contractors also innovate new construction technology.

From this response, it may be inferred that the large Japanese general contractors are innovative because of their size and assets and their ownership of a research institute. Smaller, specialty contractors are innovative because of their intimate and proprietary knowledge of their particular specialty and can see new opportunities for improvement. This innovation path is similar to that in the U.S. construction industry. There is evidence that the MoC is trying to encourage innovation among smaller contractors through the Advanced Construction Technology Center.

The team also saw evidence of innovation by the vendors and suppliers of construction materials, equipment, and services. Komatsu, for example, has been innovative in downsizing construction equipment to fit in close quarters, such as for renovation, and may capture a world market in this area. The directions taken by these vendors are likely driven by the expressed needs of the large general contractors and the requirements for MoC approval of any innovations.

We did not visit any university laboratories. However, we were frequently told by construction R&D institute personnel and construction site staff that there was relatively little development underway in universities, little direct involvement by university researchers with construction practice, and little regard by construction professionals for the universities' understanding of construction. The function of the universities was to produce a flow of graduates well-trained in the applicable engineering and scientific fundamentals. Nonetheless, Li (1995) describes the relationship between Japanese universities and the construction industry as rapidly changing toward stronger cooperation and points out examples of some significant practical university research, particularly in the construction materials area (Section IV.B).

Another source of innovative ideas is from other countries. The Japanese have proved themselves to be adept at advancing innovations made elsewhere, and many general contractors have endowed listening posts at major U.S. research universities to keep informed of new developments. The industrial and government R&D institutes are well-staffed and well-furnished to pursue such ideas.

Probably the most productive source of truly new innovations, not incremental improvements but process re-engineering breakthroughs that change paradigms, will come from the specialty contractors and firms in fields collateral to the construction industry. The changes in construction procurement laws, if effectively implemented, may open up opportunities for more innovative smaller contractors and result in a general increase in the innovation rate of the Japanese construction industry. Unfortunately, the team did not visit any such firms, and so their past contributions were not ascertained.

4. Nature of Construction Industry R&D

By 1990, over 25 of the largest construction companies had well-equipped research laboratories staffed by anywhere from a dozen to several hundred research professionals. The ten largest had 1987 R&D budgets ranging from about ¥1 billion (*ca.* \$7 million) to ¥12 billion (*ca.* \$80 million), which typically accounted for one percent of their gross revenues. While one percent may seem small compared to other industries, no construction industry anywhere else in the world even comes close. The industry laboratory facilities and equipment would be the envy of any university or government laboratory anywhere in the world. The professional staff includes many scientists and engineers with advanced degrees from the world's most prestigious universities (Tucker *et al.*, 1991).

Facilities. The large-scale testing facilities in the corporate and government research institutes are among the best in the world and often unique. The former typically contain a sizable subset of the following facilities:

- large reaction wall for static testing of full size (or large scale) structural elements,
- shaking table for seismic evaluation of structures and equipment,
- full-scale building on seismic shock base isolators,
- wind tunnel for determination of wind loads on buildings and air flow around buildings,
- wave tank for study of water forces and flows in harbors,
- geotechnical laboratory, including a centrifuge,
- environmental chamber for testing the effects of extreme heat and cold on building elements,
- anechoic chamber for acoustic testing,
- chemistry laboratory,
- Class 1 clean room, and
- experimental facility for jacking up buildings.

The largest contractors and the next-tier contractors have essentially the same kinds of research facilities, but those in the larger contractors are bigger, more powerful, more sophisticated, and more attractive than those in the smaller contractors.

It seems unnecessary that such extensive and expensive facilities should be replicated many times over, presumably being used in each location to pursue studies similar to those at each other location. Understandably, if only one construction company started on this program, it could gain a competitive advantage over the other companies by increasing its share of public works allocated by the Ministry of Construction or by other public agencies. Thus, once begun, the practice of establishing internal construction research institutes had to be followed by all the major Japanese construction companies.

Nonetheless, so much duplication and similarity from one lab to another cries out for better coordination and cooperation toward common national or industry goals. All of them left the U.S. team with the impression that they were vastly underutilized relative to what they could do. It would be beneficial to find a mechanism for collaboration with each other and leading researchers around the world, such as exists with the MoC research institutes.

What is also remarkable, considering the capital investment in large testing facilities at these research institutes, is the small size or even absence of corporate research libraries, computer facilities, and computer network connections. No corporate research institute had a computer graphics laboratory, an artificial intelligence laboratory, or a project management simulation laboratory, although the Japanese in general have placed considerable emphasis on these technologies. In part, this is because some companies do this kind of R&D in their information technology departments rather than their laboratories, but we did not visit the former.

Organization. The activities conducted in the industry and government laboratories draw upon a full spectrum of technical disciplines related to the engineering and construction process: civil and structural engineering, architecture, mechanical and electrical systems, chemical and biological processes for natural and artificial environments, acoustics, optics, and many others. In most of these they support long-term basic research as well as short-term, problem-focused R&D. Most avenues of investigation have been proposed, approved and funded within each company's own organization. The specialized facilities and equipment complement each avenue of research. Figure 3.1 indicates the integration of R&D into a typical Japanese company.

Focus on risk aversion. The Japan Society of Civil Engineers stated that construction research is conservative, to assure safety and to eliminate risk to the Japanese public and to the contractors. In response to another question, they said that "in order to avoid such risks (*i.e.*, of new construction technologies), construction firms in Japan concentrate their R&D efforts primarily in basic experiments, trial works, pilot works, etc." (Appendix B) The function of the general contractors' research institutes is seen to be largely confirmatory, in the nature of performance tests, to assure that designs, in particular novel designs, are adequate and will perform successfully. As has been noted elsewhere, much of this research is related to structural resistance to horizontal loads (earthquake and wind). This thesis is supported by the nature of the experimental facilities (wind tunnels, shaking tables, large reaction walls, etc.), which are oriented toward experimental testing and verification of designs, and the innovations in structural systems, building materials, seismic isolators, etc.

This observation is further supported by the participation of the Ministry of Construction in the selection and funding of research projects, which has the effect of reducing the risk for and spreading it around to a number of companies. With a number of research institutes working simultaneously on similar developments, such as jack-up building systems, confirmatory results are assured and the probability that safety problems will remain undiscovered is reduced. This conforms to the principle of scientific research, that a discovery by one laboratory should be confirmed independently by others before the results are accepted.

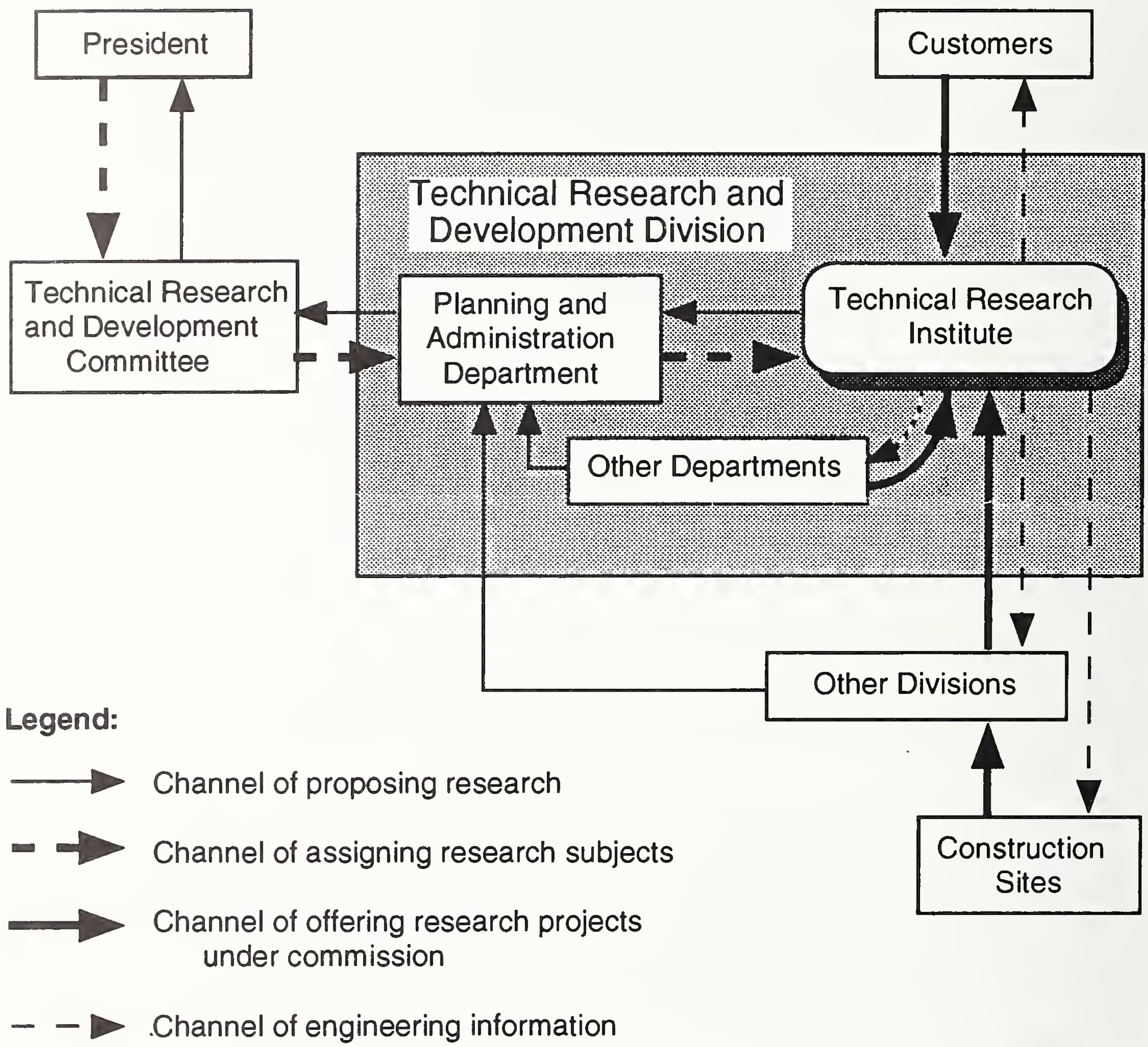

Figure 3.1. Organization of R&D in a Typical Japanese Construction Company (Adapted from Paulson, 1991).

This directed approach also assures that multiple contractors will be qualified to construct facilities using the methods developed, so that the MoC and other public works owners will not be dependent on a single supplier of proprietary technology. When the MoC certifies a new technology for use in construction, it has been thoroughly tested by several research institutes, although details of implementation may differ. This eliminates any basis for subsequent litigation (even if the Japanese were highly litigious), and the primary barrier to introduction of new technology in the United States, the threat of ruinous litigation, is effectively removed.

Thus, the Japanese system is designed to remove the risk of construction R&D, both to the contractors and to the MoC. This approach has contributed greatly to the alleviation of the Japanese public's concern about the safety of constructed facilities and achieved wide public support for the system and the participating organizations. Of course, the system also minimizes the probability that a unique, original, idiosyncratic, breakthrough technology will emerge.

Process vs. Product. The apparent purpose of the research institutes is to improve the *product* of the engineering and construction service, namely buildings and structures, by improving performance against disasters. Recently, research institutes have added environmental, biochemistry, and related laboratories to reflect increasing interest in environmental quality and sustainable development.

However, there is less apparent work on the construction *process* than on *product*. One notable exception is the automated jack-up high-rise building systems developed simultaneously by a number of general contractors, which apply the principles of factory assembly and automation to a strictly linear facility. That is, manufacturing principles have been addressed to a single type of construction, highrise office buildings, which are treated as vertical assembly lines. The research efforts spent on these developments are impressive; several buildings have been built using these methods, representing a high degree of integration, planning, and management. However, a number of questions regarding these automated building assembly systems arose that could not be answered:

> Is the expensive equipment, etc., necessary to assemble these buildings reusable for additional buildings?
>
> To what extent did these developments achieve the intent to reduce construction time and construction labor requirements?
>
> To what extent is this process applicable to diverse building designs?

We were told that at present there are no clients for these buildings outside the general contractors who developed them. Thus, it must be assumed that these full size (as much as 33 stories) buildings were constructed to demonstrate the feasibility of the technology rather than the economics. That general contractors can afford to perform these expensive experiments is one of the great strengths of the Japanese construction industry; but until economic data are made openly available, it is doubtful that these systems will travel.

A second, less revolutionary process improvement was observed in the Tokyo Rinkai Hukutoshin Project. During construction of this 29-story hotel, the technology used was known as the "Perfect Layered Construction Method for Steel Structures," a method devised to improve the safety of the working environment. The principal innovation was the erection of 4-story columns, building up entire floors one at a time. The safety record during the still-ongoing construction was described as excellent.

Construction software. It seems that the Japanese contractors are particularly adept at developing and implementing things primarily consisting of materials and hardware. The advanced soft-ground tunneling systems, even the prototype automated high-rise buildings, are examples of this prowess. But as best the team could tell, they are less advanced with software. For example, the Japanese contractors seem to be just starting to realize the advantages of 3-D CAD systems, where the primary benefits arise not in saving money on drafting but in better coordinated design, procurement and construction. Direct inquiries on this subject showed that most firms are still using 2-D and only use 3-D if the client requests them to. Meanwhile, some U.S. firms are already beginning to realize the benefits of 4-D CAD, where integration with schedule and incorporation of object properties even more strongly benefits not only construction but also facility management.

In construction, it seems that most of what the Japanese have been calling robotics are teleoperated devices or at best incorporate only a limited amount of programmed control. For example, the present showcase effort to automate earthmoving equipment to deal with recent volcanic debris seems to use fairly old technology. An effort by a manufacturer to automate mining equipment essentially amounted to programmed dead-reckoning, which severely limits its operating area. The answer from our host was that "most Japanese mines are small enough to make it work." There are some efforts to use lasers and global positioning systems, but these are imported and their utilization seems to lag in Japan.

Basic Research. Compared to the 1990 teams, the 1995 team had the impression that the industrial labs were doing much less basic or fundamental research and a much higher proportion of development, problem-solving, verification and testing. Indeed, in several of the site visits, research staff stated that they had recently been asked to work toward more short-term, high payoff objectives.

But even looking back over the recent past, one sees for the most part well-educated and experienced professionals doing capable work on topics whose basic research was done elsewhere. While there are some high points such as advanced soft-ground tunneling machines, it seems that much more ground has been gained by licensing and adapting technologies from others and then evolving them into better methods, machines and materials.

A stronger sense of fundamental research was observed in the materials research institutes of the Science and Technology Agency (Appendix A). They, however, stated they were isolated from their more applied counterparts in government and industrial institutes.

Integration within the company. The Japanese company's R&D process and activities have approval and wide visibility within the senior management and other parts of the company. The 1991 JTEC report illustrated this relationship with a diagram like that in Figure 3.1. As seen in this figure, there are established channels of communication for proposing research, funding and assigning projects, and getting the results back to clients, the operating divisions and to project sites. Similar charts were obtained from some of the large construction company R&D institutes.

However, there was no evidence that these research institutes were taking advantage of company integration. The large contractors' research institutes have essentially the same organization as the smaller contractors', *i.e.*, by discipline. Little or no interdisciplinary work was observed. There was little interaction between the product and the process of construction that creates the product, except in the case of the automated building construction systems, which mechanize a linear construction process and require changes in the design of the product in order to function. Mitsubishi Heavy Industries, a major engineer-supplier-constructor, made the point that each of its plants competes for business with the others, and MHI is the fifth largest of the Japanese contractors and the largest exporter of the group (Table 2.6). That is, there is little or no exploitation of the supposed advantages of integration, interior lines of communication, and economies of scale in these general contractors.

Links with external organizations. Perhaps the principal weakness of the corporate research institutes is their relative isolation from peer institutions. Given the motivations for having a research institute, the large general contractor has little reason to share information with other contractor research institutes, with other contractors, or with the public, although they do exchange data with the Public Works Research Institute and the Building Research Institute of the Ministry of Construction. Since there is little turnover in personnel at these contractors, at least in comparison with the United States, there is little information exchanged by movement of personnel. The fact that innovations developed in connection with public sector projects become public domain also reduces the need for peer contact.

In part to remedy this, in April, 1989 the MoC established the Advanced Construction Technology Center (ACTEC) (prior to the JTEC visit but not mentioned in the JTEC report). The ACTEC (see also Appendix A) is funded by private construction companies to promote, among other things, the following:

- Joint participation in research by private industry, government agencies, and academia, in all fields related to construction. ACTEC improves the lack of balance among academia, government, and private industry R&D. Also, ACTEC promotes more interdisciplinary R&D beyond the existing research programs which seem heavily weighted toward structural research.

- Dissemination of comprehensive information on construction technologies. ACTEC aids in communicating the results of the Building Research Institute, the Public Works Research Institute, the general contractors' research institutes, and others to the general construction industry.

- Improvement of communications and evaluation of technologies for practical applicability in construction, so that technologies are developed with sufficient input from construction practitioners.

Whether ACTEC will prove to be successful given the changed circumstances in the Japanese construction industry since 1989, which have led to cutbacks in research funding, cannot yet be determined. However, its existence implies the need even in Japan for improved cooperation between government, industry, and academia.

The Advanced Construction Technology Center is probably the only Japanese institution that would be applicable to the U.S. environment, and the panel suggests that the United States consider such a focus. There would be significant economic gain from both joint private/public/academic, multidisciplinary R&D in the construction field and the efficient dissemination of evaluated technology. Funded jointly by government and private industry, this could be organized under, *e.g.*, the Manufacturing Extension Partnership of the Department of Commerce's Technology Administration, working with the existing public and private construction-related organizations.

In fairness, it must be said that there are occasional well-coordinated cooperative projects among the various labs in Japan. Some have been stimulated by crises. For example, the oil shock of the early 1970s prompted a coordinated effort that led to the construction of the large underground LNG and LPG tanks over the past 2 decades (Appendix A). There were signs that the Hyogo Ken Nanbu earthquake may have stimulated coordinated efforts this year. Nevertheless, the impression prevails that most of the labs' researchers are working in relative isolation from their peers elsewhere. Where the coordination does happen, it seems to come from an outside agency such as the Japanese gas companies in the first case or the MoC and the railways in the second.

Staffing levels. In all discussions with corporate research institute staff, there appeared to be substantial weakening of activity on the part of most companies because of economic pressure. In one case, a 25% reduction in research institute personnel has been experienced. The function of R&D in winning new private sector contracts and in improving upon the productivity of labor remains essentially unchanged.

In the short run it seems that the labs may have to cut back even further as their companies adjust to what will probably be further market setbacks in the next year or two. But the commitment to maintain this in-house R&D capability remains strong, so it seems likely that these labs will still be there, probably working in much the same manner but in somewhat different areas, when foreign delegations come to call again in the future.

Quality. Japan rates itself periodically as to its relative level of preeminence in technology development. Technology continues to be embraced by the Japanese construction industry as a means of qualifying for certain projects; marketing services to the private sector; balancing the problems associated with recruiting, training, and retaining labor; and improving both safety and product quality. These purposes were summarized by contractor spokesmen as contributors to competing profitably and effectively. Competitive success is the ultimate purpose of their construction R&D program. Japan's areas of technological excellence align with industry sectors and project types of greatest interest or concern to the Japanese people. This has led to excellence in underground work, bridge construction, high-rise building construction, railway system construction, marine construction, and the design and construction of facilities resistant to natural disaster damage. Roads, utility systems, and environmentally related construction has been less intensively studied, although the latter is receiving increased attention.

5. Implementation of Construction R&D

Of principal interest to the pragmatist is how well research findings make their way into construction practice. Consistent with the discussion in Section II, the Japanese construction industry is quick to experiment, but cautious in adoption.

In particular, the MoC is not a promoter of uninhibited innovation. Through Public Law 38, the MoC must approve any technology prior to use. One can say that the MoC encourages innovation through strictly controlled means. These controls mean that:

- Innovations should follow the long range plans set and agreed to by the MoC and the major general contractors; independent, unplanned, or idiosyncratic innovations are discouraged;

- Innovations must be developed through joint ventures, consortia, or groups of contractors, not by a single contractor. The MoC often shares the costs of joint research programs with the contractors' research institutes. As a result, the major contractor research institutes perform very similar developments, often duplicative of each other. This redundancy minimizes the risk of innovation, not only for the companies, but for the MoC. Although Japanese firms take pride in their risk-taking on projects, they in fact have substantial mechanisms in place for risk sharing and risk reduction through participation by the government. The actions of the MoC do not actually insure the general contractors against risk, but they come very close.

- Proprietary innovations by one company may be actively or passively discouraged or delayed. Individualists and entrepreneurs, if they existed, would be frustrated by the system.

- Innovations take from five to ten years to reach deployment on projects; there is no available evidence that the Japanese system brings construction innovations to market faster than the more entrepreneurial U.S. construction industry.

The 1990 JTEC delegation identified the following as important R&D activities to watch in the years ahead:

- Civil works: Japan showed special strengths in tunneling and deep excavations, particularly in difficult soft-ground conditions.

- Seismically resistant structures: There was been considerable activity in active and passive control of structures, including base-isolation, passive dampers and active control systems.

- High-tech buildings: The construction industry had worked extensively on advanced building systems for clean rooms and other high-tech facilities to support Japan's extensive manufacturing capabilities.

- Energy conservation: High energy costs have made both passive (via materials and structural systems) and active (via intelligent building control systems) energy conservation a high priority for research since the early 1970s oil shock.

- Large-scale fuel storage: Given almost total dependence on imported fuels, Japan had undertaken major initiatives for deep excavations and floating structures to provide high-volume buffers against unfavorable world events.

- Automation and robotics: An aging and declining high-wage workforce combined with strict limits on immigration led Japan in the 1980s to make substantial investments in automation and robotics research to keep its industry competitive.

- "Intelligent" buildings: Japan was working on applied automated building control systems not only for energy conservation, but also for security and even for amenities such as scented air to stimulate various human behavioral responses (work productively, shop happily, etc.).

The 1995 panel followed up on most of these, and our findings are reported in Sections IV and V, as well as in Appendix A. In almost all cases, however, the rate of innovation activity has slowed, and most of the more ambitious long-term research programs have moved to lower priority.

6. Impressions

In general, the 1995 panel came away equally impressed with the capability of the construction industry research institutes, but less impressed with their importance, compared to the 1990 teams. Some members felt that the construction laboratories mostly served a marketing function, partly to qualify the firms for government projects and partly to impress potential clients. It also seemed that there was a considerable element of "keeping up with the Joneses." If one lab started into a new area, such as automated high-rise construction, others were soon to follow. We probed these impressions at several sites and generally found agreement that public relations, marketing, prequalification for bidding, and just keeping up were important functions. But most of the lab managers and company executives also strongly defended their labs' roles in finding and developing new technologies and innovations that helped make their companies more competitive and solved real problems. As one put it, their board of directors would not spend 1% of corporate revenues (or 30% of profits) year after year on high-tech gadgetry if there were not some significant returns. There are cheaper ways to market and buy publicity, and these companies already have extensive parallel activities of this type.

We also expected to see new extensions or counterparts to the advanced R&D capabilities described in the 1991 JTEC and CERF reports. We came away somewhat disappointed but perhaps with a more realistic view. On the other hand, given the triple blows from the Hyogo Ken Nanbu earthquake, the recession and the corruption scandals, we also wondered whether the company sponsored research institutes could continue in the form observed in 1990. They appear to be surviving quite well. The recession has indeed taken a toll, but the corruption scandals were seldom mentioned and seem to have had little direct impact on this part of the companies. The earthquake, if anything, has stimulated renewed interest and even more work in seismic engineering R&D, with applications to expanded markets in repair and retrofit of existing facilities.

We have probably said enough about the R&D limitations of these laboratories. But whether for marketing, public relations, testing and certification, or genuine research and development, it seems clear that they are very important to the way the large Japanese construction companies conduct their business. They are indeed magnificent facilities and are staffed by intelligent, well educated, experienced and practical scientists and engineers who are committed to doing their work in a professional and highly skilled manner. They have some commendable technological achievements to their credit.

IV. INNOVATION IN COMPONENTS OF THE CONSTRUCTION PROCESS

A. Process Integration

1. Benefit of Vertical Integration

Process integration should be one of the principal strengths of the Japanese construction industry, in view of its much higher degree of vertical integration compared to the United States. According to information theory, encoding and decoding of information must be performed at each communications interface: at the interfaces between people, between disciplines, and between organizations. The encoding takes the form of expression of ideas and concepts in words, drawings, specifications, and other forms of oral and written communications. Thus, more integrated and homogeneous organizations should have fewer interfaces and fewer encoding/decoding requirements than fragmented organizations. Moreover, efficiency losses at these interfaces (which might be compared to frictional losses) should be also reduced, and large, vertically-integrated companies in a homogeneous construction industry should be more efficient than companies in a fragmented industry. A corollary of this is that highly integrated firms are more efficient in project coordination and execution due to interior lines of communications, standard procedures and systems, common economic interests, etc., than organizations that are established *ad hoc* from separate firms for the purpose of a single project.

Moreover, the Japanese manufacturing industry is noted for its attention to process innovations. Japanese manufacturing firms have dominated in many areas of consumer products such as automobiles, television sets, VCRs, audio equipment, microwave ovens, watches, cameras, etc., by development of the manufacturing process even more than development of the products themselves. In many cases, product development has been driven by process development. Therefore, it might be expected that the Japanese construction industry would be driven by process innovation.

2. General Findings

It was stated a number of times by individual general contractors, by the Japan Society of Civil Engineers, by the Advanced Construction Technology Center, and others, that the focus of Japanese R&D is shifting from safety and physical design issues to issues of cost, labor saving (to meet the decline in construction labor force), and competition. However, observations made of the Japanese general contractors indicated very little ongoing R&D in process or software, as opposed to hardware. The general contractors' research institutes did not display any major current activity in the areas of:

- three-dimensional modeling for construction projects,
- virtual reality in construction,

- construction simulation,
- knowledge-based systems in design and/or construction, or
- electronic monitoring and tracking of construction progress, except for the use of global positioning systems (GPS) in surveying.

The reader should recall, however, that this team did not visit the information technology departments of the companies, where such advances might be underway. The team also did not visit small specialty firms, design offices, or software companies, possibly missing some innovations. However, the staff at the large contractors' research institutes did not profess knowledge of innovations in those organizations. Nor were there significant indications from component manufacturers or construction site managers that these technologies were in progress. The use of computer-aided design (CAD) was confined to the design departments of the general contractors, where nominally standard commercial CAD systems are used.

3. Specific Organizations: Corporate Software

a. Misawa Homes has developed a proprietary 3-D computer-aided design system that is used to conduct virtual walkthroughs of homes for potential customers. Using this system, the customer can view in perspective the interior and exterior of the house as it will finally appear. This approach is highly useful in marketing, as potential homeowners (worldwide) are typically unable to read architectural drawings effectively, and generation of drawings by hand for large numbers of possible customer options would be prohibitively time-consuming and expensive. This marketing system is not, however, fully integrated with the manufacturing process: it can compute bills of materials but apparently cannot compute precise estimates of construction costs, material cut lists, or other manufacturing and erection information.

b. Steel fabricators have developed a number of proprietary information systems. In particular, NKK has developed, over a period of more than twenty years, a Bridge Structure Lofting Language. Their system integrates steel bridge design, I-girder design, material takeoff, cutting plan, fabrication, and construction, and is based on a three-dimensional database.

- The design system provides structural axis single-line definitions, three-dimensional coordinate definitions, and three-dimensional member definitions using wire frames, surfaces, and solids. It supports parent-child inheritance of attributes and a hierarchy of bridge blocks.

- The integrated fabrication system produces data for numerically controlled tools for cutting, welding, and assembly. It provides definitions of fabrication methods and member development in blocks, pieces, and groups. Parts are nested on plates for efficient cutting. The system determines the optimal nesting plan and optimal path for laser cutting, under the constraint that the laser tool cannot retrace its path. These problems are mathematically very difficult and require sophisticated computer algorithms to work successfully.

- The monitoring system and output system provide inspection drawings, structural coordinate drawings, and member piece drawings, NC data, manufacturing drawings, member lists, and assembly drawings. Pieces are marked automatically and welded by robots.

The design system took 3 years to develop and the fabrication system took three years more. All coding was in the C language. The system is proprietary to NKK and is not based on any commercial CAD system. There is no provision for electronic output, although D.F. format output may be considered in the future. It apparently does not include functions such as material control or erection sequencing. It is not integrated with other functions, such as bridge structural analysis or bridge maintenance, because these functions are performed by others (consultants and customers, respectively). Neither does it provide direct electronic input or output to interface with these external functions.

The client receives the computer-generated inspection drawings, but no transfer of the electronic information for subsequent use by the owner for maintenance or other purposes has been contemplated. Structural analysis of the bridge could be, but is not yet, integrated with the system, with the structural analysis and design performed separately by the client's consultant and the bridge design data re-entered manually. In one major bridge application, NKK Corporation is fabricating one half of the bridge and Mitsubishi is fabricating the other; there is no interface between the systems used by the two fabricators.

According to NKK, the use of this type of system since 1971 has reduced costs and improved quality, but the primary justification seems to have been in client presentations, in order to secure more business for NKK Corporation. Presumably the desired effect is to display a high degree of competence, quality, and efficiency rather than to provide specific value to the customer. The system has not affected the process of bridge engineering, fabrication, and erection nor was it intended to; it automates the parts of this process that belong to NKK as steel supplier, fabricator, and erector.

c. In a related vein, Kawasaki Heavy Industries, with the support of the MoC and the Japan Highway Public Corporation, is developing a computer-aided assembly system that will automatically take three-dimensional coordinate measurements of fabricated steel bridge components at the end of the production step. Lasers will be used for the coordinate measuring process. These piece models will be automatically fitted together in the computer as a virtual assembly of the bridge, to determine that the pieces fit together. This computer fit up is to replace the trial fit up or preassembly of the actual bridge parts in the fabrication yard, prior to shipment and erection of the bridge in place. This computer system, then, is intended to automate a single, very expensive (10% of the total cost) step in the bridge construction process (a step that is seldom taken in the United States) rather than integrating the process of bridge design, analysis, fabrication, and erection. As a result of improvements in fabrication accuracy, the MoC has decided to stop preassembling the simple (*e.g.*, straight, I-beam girder) bridges.

d. A number of dual-screen (non-UNIX) Intergraph workstations were observed at Mitsubishi Heavy Industries (MHI). MHI stated that when a client requested delivery of documents in CAD format, MHI's policy was to use in production whatever CAD system the client preferred. Also, three-dimensional design was not used unless the client specifically required it, as it was considered too expensive; conventional two-dimensional drafting was the standard practice. This response is not unusual; it could be obtained from any average contractor in the United States, but MHI is not an average contractor. It is one of the top contractors in Japan and the largest exporter in the Japanese construction industry (Table 2.6). MHI manufactures plant equipment and performs construction under fixed price contracts, so that any realizable benefits of three-dimensional design, merger of equipment models with plant design models, interference detection, quantity takeoffs, construction sequencing, and other applications would be captured by Mitsubishi.

From these data it must be concluded that Japanese general contractors see little competitive advantage in CAD; in the use of 3-D computer models throughout design, procurement, and construction; or in the use of CAD models after construction for facility management, operations, maintenance, and renovation. In this they are not unlike the majority of U.S. contractors, but they are unlike the leading U.S. engineer-constructors. The hypothesis that the horizontally- and vertically-integrated Japanese general contractors would be better positioned to recognize and to exploit the benefits of three-dimensional databases through the entire construction project cannot be substantiated based on the information available to the panel.

4. Field Software

a. A number of contractors are experimenting with Global Positioning Systems (GPS), largely for plane table surveying in open country.

Mitsui Construction stated that GPS could not be used on their building sites in Tokyo because the satellites could not be sighted due to surrounding buildings. The equipment being used was standard, of U.S. manufacture. Komatsu described the development of an autonomous truck for mine hauling, with navigation by dead reckoning and motion control by operator training and play back, but a similar autonomous truck project under development by Caterpillar is said to use dynamic GPS feedback for navigation, as does a manually controlled bulldozer. Komatsu did not provide a demonstration of the autonomous truck, so the state of progress cannot be ascertained. The economics of such an autonomous haul truck, particularly in third-world countries where such mining is likely to occur, were not discussed.

Kajima, Komatsu, and others were developing a system, sponsored by the MoC, for cleanup of land covered by lava during a volcanic eruption. This system will incorporate bulldozers, excavators, trucks, and other construction equipment with spatial positioning using GPS. The equipment will be remotely teleoperated (because the lava is hot), rather than autonomous robots. This type of remotely controlled system could have applicability in other situations in which personnel access is limited by environmental conditions, but presumably could not function underwater or inside buildings (such as nuclear reactors) due to the requirement that the GPS satellites be visible.

b. It has been suggested that a fertile area for the introduction of new technology in construction is the reduction in total project delivery time, which is of great financial advantage to the facility owner. For projects with a high rate of return on the owner's investment, the owner should be willing to pay considerably more to get the services of the completed project sooner.

Japanese general contractors appear to see little need for new technology for project coordination and management, as they unanimously agree that they deliver projects on time and on budget. Their customers appear to be satisfied with the conservative, but sure (with minimal interactive parallel activities) scheduling. Several general contractors asserted that they complete projects earlier than the schedules, but receive no incentive fees from the clients for so doing. With the exception of the automated building erection systems, which were developed in part to reduce construction times for high-rise office buildings, Japanese general contractors are pleased with their budget and schedule performance and see no obvious ways to improve. Improvements, if any, are expected to come from robotics and other hard automation, exemplified by the high-rise building systems, not from management methods, information systems, or other soft approaches.

c. It might be expected that firms that are active in the international construction marketplace (*i.e.*, outside the home country) are more likely to engage in R&D of new construction technology, due to intense international competition, than firms that confine themselves to their domestic markets. This hypothesis cannot be supported by the evidence available: Japanese general contractors spend up to 1% of sales on R&D but do less than 10% of their business outside Japan, whereas U.S. firms that do relatively little R&D gain almost 50% of their business outside the United States. The Japanese research institutes are motivated toward domestic business and the policies of the MoC and have not been directed toward international competitiveness.

The increase in the value of the yen with respect to other currencies, especially the U.S. dollar, makes Japanese engineering, equipment, and other products and services relatively more expensive. As the cost per worker-hour increases, engineering-construction firms may become noncompetitive for international work, and may respond by outsourcing engineering and design services to lower cost countries. In the Pacific area in particular, there is a high volume of engineering and construction work, coupled with the availability of low cost engineering and design services (*e.g.*, in the Philippines). Japanese engineering and construction firms are acquiring or teaming with firms in these low cost countries, or otherwise outsourcing design work.

d. It has been stated that the greatest cause of low productivity on construction sites is the site logistics and materials handling system, so that workers lose productive time:

- by multiple handling of equipment and materials, from delivery vehicle to warehouse or other storage location, and from storage location to permanent location;
- waiting for instructions or information - supervisors, drawings, procedures, etc.;
- waiting for equipment or materials;

- waiting for tools or construction equipment;
- waiting for previous activities to finish; or
- waiting for inspections.

Japanese construction firms have recognized this issue, and have started to focus on robotics and other automation to address site materials handling and logistics. The automated high-rise building assembly systems are intended to be an answer to this issue, as they organize materials handling and logistics on the construction site just as a factory organizes materials handling in the manufacturing process.

e. Statistical Quality Control (SQC) is widely credited with being a major technological factor in the success of the Japanese manufacturing industries in international competition. As a result of this success, many U.S. manufacturers have had to take lessons from Japanese manufacturers in quality control, and SQC has been implemented in many U.S. factories. Its use is believed to be a major factor in both the success of the Japanese automobile industry and in the resurgence of the U.S. automobile industry.

Quality control is clearly an issue in construction. No major U.S. construction firm is known to have made a major commitment to SQC. The Japanese construction industry states that it has adopted the SQC methods that have been used successfully by Japanese manufacturers.

B. Construction Materials and Products

1. Introduction

The panel toured a number of laboratories performing materials R&D. As might be expected, given the relative funding levels, the private sector laboratories were better equipped and staffed than those of the public sector. One factor that was quite consistent in all laboratories was a direct reflection of the Japanese penchant for garnering the most from a given resource. For instance, while most of the laboratory computer equipment used Intel 286, Intel 386 or Motorola 68020 CPUs, the Japanese laboratory staff have found ingenious ways to continue using the older technology for tasks we would consider beyond the processor's capability.

While some investigations on new products and material uses were being conducted, much of the R&D effort in the private sector was directed towards solving problems, building systems and construction processes. Government R&D facilities tend to focus more on broader-scale issues such as the environment, river control, mitigation of earthquake effects, and large civil projects. The government laboratories also conduct feasibility studies in the potential for R&D in the areas of super-conducting alloys, fine ceramics, plastics and composites for fiber reinforced plastics.

It was also noted that most of the R&D facilities visited were sparsely staffed and the level of activity quite low - an apparent reflection of the current Japanese economy.

2. Concrete Research

High-strength concrete continues to play a significant role on the agenda of many Japanese R&D organizations. These efforts are driven, at least in part, by the need to resist seismic loading. Structures designed to resist seismic loads have a substantially higher density of reinforcing than other structures, translating into a need for a concrete that is highly fluid and high in strength - a need satisfied with silica fume high-strength concrete.

The use of super-plasticizers is also being studied to further increase high-strength concrete's fluidity. Other research includes investigations into the use of various admixtures and fly ash. Another facet of high-strength concrete being studied is the use of undensified silica fume. Both the United States and Europe use densified silica fume because it is easier to handle, albeit more expensive to produce.

Research is underway on the use of high-strength-concrete-filled structural tubes and placement by pumping. Pumping heights of 60 m have been reached, and at least one new project is now planning to pump 100 m. Strengths of 60 MPa (8,700 psi) are becoming more common, while 80 MPa (11,600 psi) is now being achieved in special situations at the job-site. At a more experimental level, super high-strength concrete with a strength of 100 MPa (14,500 psi) have been made. One beam at the Takenaka R&D facility was built using 140 MPa (20,000 psi) super high-strength concrete.

While most high strength concrete is used in beams and columns, it is sometimes used throughout a structure. Takenaka is now planning a 600 m high structure (TAK 600) using high-strength concrete.

There is also considerable research underway on self-placeable concrete, both in industrial laboratories and under a joint university/industry program (Li, 1995). The improved flow properties of this type of material will reduce the time and labor required for site-poured applications. Taisei Corp. has developed Biocrete 21, a highly workable concrete requiring little or no vibration to cover dense rebar configurations, and used it successfully on very large underground LPG and LNG storage tanks. While Biocrete 21 is highly fluid it retains the structural strength and durability of more conventional concrete.

Other investigations in the broad field of concrete include:

- "Green concrete," an extremely porous concrete that facilitates the growth of plant life on its surface. One anticipated application would be to place green concrete on the surface of a steeply sloped structural concrete wall to provide a more natural aesthetic appeal to a structure and decrease the thermal load on the enclosed space.

- The study of different materials to reduce the permeability of concrete, thereby reducing corrosion of reinforcing steel. Materials such as silica fume, fly ash and porcelain ceramics are among those under study. A side benefit to this study is that most of the products being studied are now considered waste materials. Parallel research is underway in the United States.

- A joint university/industry consortium to solve the brittleness problem (Li, 1995).

One laboratory devoted to the chemical analysis of concrete focuses on the micro-structural analysis of concrete to improve its quality and to develop the use of new materials in the making of concrete. The laboratory is no longer studying the use of polymers in concrete because they cost too much.

While not specifically directed to the development of a specific material or new product, composite construction (combinations of steel and concrete) as well as steel reinforced concrete are receiving investigative attention. As a result of the Hyogo Ken Nanbu earthquake a substantial amount of the research effort has been redirected towards the repairing and reinforcing of existing concrete. The Building Research Institute has been conducting R&D in the use of high-strength fibers, both Aramid and glass, to combine with epoxy resins for retrofitting concrete columns and other structural members that have been damaged by seismic loading or are in high risk of receiving such damage. The process is to wind the structural element with the fiber and use the epoxy to hold the fibers in place.

3. Building Envelope Materials

Building envelopes are currently the subject of a number of R&D efforts in Japan. Takenaka is doing substantial research in the design and use of 2-D fiber arrays in Direct Sprayed Carbon Fiber Cement (DSCFC) cladding panels. With the current cost of carbon fiber now at ¥3,000 per kilogram, a cost comparison shows DSCFC panels to be about 30% to 40% more expensive than standard reinforced concrete panels. However, there are other substantial savings to be considered, such as the reduced weight of the panels, allowing a reduction in the size of the building frame and foundations, lower transportation costs, and greater ease of erection. Some research has been done on the use of high strength silica fume concrete in DSCFC panels, but no specific results were available for discussion.

Another wall system under investigation was a rain shield system with a thin stone veneer. Most of the tests conducted were for determining durability and methods of applying sealants, and were done on full and half scale mock-ups. While similar systems have had great popularity in Canada, they are not typically used in Japan and the United States.

Also within the venue of building envelopes were investigations on the durability of a variety of associated materials, with a focus on metals, especially aluminum and stainless steel, and coatings for these metals. A variety of stone types were also being studied for a variety of characteristics, especially strength and durability. Stone species included domestic and foreign granite, sandstone and limestone.

While no actual testing was observed, the panel was advised that some investigations into sealants were being conducted, with a particular emphasis on thermosetting structural sealants for glazing systems. This is an active research area in the United States, where long-range investigations are developing ways to control the properties of glass to meet user's needs, and new silicone sealants are being introduced with broader ranges of elasticity, easier installation, superior elongation, substantially less volatile organic chemicals, and a longer service life. The team did not visit Japanese chemical companies that might also be developing such products.

4. Metals Research

Fire resistant (FR) steels, structural steels capable of maintaining structural integrity at temperatures up to 600 °C through the addition of molybdenum and niobium, continue to be an important item on Nippon Steel's R&D agenda. FR steel has been incorporated in several Japanese buildings, although the estimated cost of using it increases structural costs by 25%. There are other factors, such as reduced need for fireproofing, that at least partially off-set this added cost.

Concerned with the potential for corrosion on the huge Trans-Tokyo Bay Highway bridge project, Nippon Steel used a titanium alloy applied to the steel piers via a special process for corrosion protection. The alloy, used over a 5 m section of the bridge piers' splash zones, is bonded to the piers using a process never previously used in a construction application. A thin sheet of copper is sandwiched between a 1 mm titanium sheet and the steel pier. The sandwich of metals is then hot-rolled to squeeze out a molten titanium-copper metallic compound that forms a 180 MPa or greater bond with the steel substrate.

One area of R&D being conducted by Nippon Steel and several other companies was integrated circuits. While not considered a construction material or product, the fact that Nippon Steel is diversifying its R&D into such an area may well be the result of the impact that Korean steel manufacturers have had on the world-wide production of steel. Nippon Steel is also conducting research into aluminum steel alloys for use in the automotive industry as well as carbon fibers.

The use of ribbed steel tubing for many applications is coming into use although it costs approximately 15% more than standard steel pipe. Uses include:

- cast-in-place reinforced concrete piles using interior ribs,
- composite columns with ribs on the inside of the tubes, and
- composite soil-cement tubular piles with interior and exterior ribs.

Compared with conventional cast-in-place reinforced concrete piles, ribbed tube composite soil-cement tubular piles offer the following advantages:

- the quantity of steel remains the same,
- pile and concrete volume, and the volume of displaced soil are reduced by 30%,
- installation cycle is reduced by 10% to 20%, and
- can absorb twice the energy when placed under seismic loading.

5. Other Materials

Although the panel did not witness any significant R&D work on new composite materials such as fiber-reinforced concrete (FRC) and fiber-reinforced plastics (FRP), Li (1995) notes that Japan has been leading the world in their use in the construction industry and cites several examples. The panel also heard a number of direct and indirect references to such work in Japan. Takenaka is doing substantial research in the design and use of 2-D fiber arrays in Direct Sprayed Carbon Fiber Cement (DSCFC) cladding panels (Appendix A). Komatsu is participating with Mitsubishi Chemical to develop applications for Carbon Fiber Reinforced Plastic (CFRP) Rod as a replacement for conventional reinforcing bar (Appendix A). This material has been used at several demonstration sites in the United States and Canada starting in 1993.

At present, numerous plastic materials are used in the construction industry, although in the United States they comprise only about 2% of building materials (Reisch, 1994). Virtually none of the materials are FRP or used in structural applications. Both Li (1995) and CERF (1994) cite a number of factors constraining the broader use of FRP materials in construction: high initial cost, undocumented life-cycle cost advantages, structural brittleness, difficulty in connecting components, long-term creep, potentially poor fire resistance, and low rigidity after concrete cracking. The CERF report states that "the conservative nature of the (U.S. construction) industry .... may prevent even the most visionary and creative of practitioners from taking the first steps with structural composites." Li states that "FRP demands new structural design concepts in order to boost its performance/cost ratio ..... Conventional structural design concepts may need to be abandoned." However, he adds, "Japan appears poised to take this next step."

Substantial R&D on composites is being conducted throughout the United States, with many successes in the introduction of such materials in a wide range of products. However, the use of composites in the construction industry continues to be quite minimal, mostly for repair and retrofitting of concrete structural elements. Some research efforts are now being directed toward products that go beyond the use of resins for the matrix, *e.g.*, cementitious and wood products.

Research in "smart" materials is being pursued both in Japan and the United States. These are materials that are engineered to "recognize" problems and react positively. This can be achieved both by material structure design and by built-in sensors and processors. For example, at Science and Technology Agency laboratories, the panel saw basic research on materials that exhibit self-control of fatigue crack growth (National Research Institute for Metals) and on intelligent glass that changes its light transmission according to changes in air temperature (National Institute for Research in Inorganic Materials) (Appendix A).

As is the case in the United States, there is extensive R&D directed towards creating chlorine-free refrigerants in Japan. Additional concern is also being directed towards the interaction of these new refrigerants with existing compressors, lubricants, heat exchangers, etc.

C. Structural Systems

1. Introduction

Structural systems are addressed from three perspectives: new construction, retrofit and seismic design. Also included are special elements or mechanisms added to or integrated with the structure in such a manner as to influence the response of the structure to loads. Examples include passive and active damping, and seismic isolation. Glass fiber reinforcing systems also fall into this category.

The panel focused on building and bridge structures. Building structures included housing; office, apartments, industrial/process plant; and high-rise and special-purpose building construction.

The panel did not observe any new structural systems not in evidence during the 1990 assessment. At best incremental improvements have been made over the last five years as the industry gains experience with the implementation of previous construction technology innovations. The Japanese continue their research and implementation of active structure displacement control technologies and clearly lead the United States in implementation in this area.

In accord with the report by the 1990 panel, the traditional beam-column type of support structure using the various construction materials predominates. In terms of overall floor area, steel continues to be the most widely used material, followed closely by timber.

In 1987, Japan had about 43,000 bridges with span lengths greater than 15 m on the national highways, expressways, and prefectural roads (Tucker *et al.*, 1991). About 43% were steel, 54% are reinforced and prestressed concrete, and 3% are "other materials." In 1993, the number of such bridges had increased to 124,600, with the steel percentage dropping by 2% and "other materials" increasing by the same percentage.

The Hyogo Ken Nanbu earthquake of January 17, 1995, the most devastating to hit Japan since the 1923 Kanto (Tokyo) earthquake (Comartin, 1995), was a grim reminder that Japan is located in one of the world's most active seismic areas with most people living and working in a densely populated urban built environment. The type of structural system used in Japan is largely determined by required earthquake or typhoon resistance. Although seismic resistant structures are used throughout the country for buildings and bridges, the Hyogo Ken Nanbu event underscored several vulnerabilities of these structural systems. Until the research, now underway to understand these vulnerabilities and avoid them in the future, is completed, the lessons learned and implications to earthquake prone areas of Japan (and the United States) will not be completely known. Accordingly, panel observations of the Japanese response to the earthquake threat in the form of improved earthquake resistant structural systems for both new and retrofit construction should be regarded as only preliminary (Comartin, 1995).

The major challenge to widespread commercialization of new and innovative structural systems in Japan is generally not influenced by the legal environment, but rather cost, human resources and intellectual property rights. Financing of technology transfer has caused delays in the past and when personnel are transferred between projects there can be a failure to follow through with implementation.

2. New Construction

The availability of materials and seismic design requirements have led to extensive use of the rigid frame structural system in Japan (Tucker *et al*., 1991). Steel moment frames and moment frames combined with braced frames are very popular in Japan. Connections of steel components are typically shop welded beam-column connections and field bolted, with field connections located well away from high-stress joint regions. It is common practice to weld beam stubs to columns prior to erection and bolt beams to beam stubs during erection (Comartin, 1995).

The panel was impressed with extensive prefabrication of column-beam stub steel assemblages. Single unit mixed production, as seen at Kawasaki Heavy Industries, makes possible efficient production of a large variety of small quantity runs of large and small, simple and complex steel assemblies in the shop. These prefabricated sections are sometimes elaborate by U.S. standards and in the United States would likely be replaced with heavier sections employing simpler details. Extensive use of built-up, concrete-filled box columns and beams was also seen, especially for elevated road and railway structures. The modular nature of these prefabrication assemblies (whether in steel, reinforced concrete or in combination) is suited for shop production with its inherent accuracy, productivity and quality; less field labor; safer work conditions; and increased site productivity.

Other mixed structural systems commonly used in the United States are also used in Japan. The composite steel beam with formed steel deck and concrete floor slab is increasingly used. Precast floor panels are also used to form the concrete slab then finished with a cast-in-place topping layer to level the surface and provide added seismic resistance.

Obayashi has recently reported promising experimental test results of steel plate reinforced concrete walls as a replacement for reinforced concrete. In effect the steel plates are the forms for the concrete. This system uses factory-fabricated steel plate and claims to result in shortened construction periods and improvement in quality (Obayashi, 1995).

Fire-resistant steel that does not require the addition of fireproofing, thereby cutting weight and reducing labor, is beginning to be used in Japan in several buildings, including the Glass Hall of the Tokyo International Forum. In this application, the fire-resistant steel gave the architect considerable artistic freedom in the design of the striking, 7-story tapered columns. This steel has a 25% cost premium.

Taisei Corporation has developed an innovative use of the new super-high strength steels for super high-rise buildings by welding low yield strength, high ductility steel (100 MPa, 14,500 psi) for webs of secondary columns to conventional framing of the 800 MPa (116,000 psi) super-high strength members. The combination allows fewer columns to be used in the lower stories, creating more open indoor spaces, while the secondary columns dampen vibration caused by strong winds and earthquakes.

Cast-in-place monolithic reinforced concrete construction was often seen for low-rise commercial and industrial buildings, generally handled by smaller building contractors. Prefabricated concrete elements were much in evidence for larger projects. A common type of precast reinforced concrete construction was seen at the Harumi District Redevelopment Project site. The precast elements are delivered just-in-time from an offsite casting yard. Column steel and beam top steel are added and the upper portions of the beams are cast with the columns and floor slab.

Another approach to reinforced concrete prefabrication has been developed and used by Kajima Corporation, using precast U-section members. They are extending this approach to a new "building production" system as a means to further reduce labor, decrease waste and improve the work environment. The system is under development and uses the U-shaped precast concrete or steel WF sections as beams, with precast hollow rectangular sections as columns. Special cross-shaped steel stub plate assemblies are cast into the column sections and permit beams to be readily bolted in place for erection. The concept has led to an automatic "push up" construction system that will be showcased with the construction of an 8-story building for Kajima next year. The system has been demonstrated for 2-story construction only.

Steel reinforced concrete (SRC) was much in evidence for floors in building construction. SRC incorporates shop-fabricated steel column and beam stub sections which are erected and field-bolted. Concrete rebar is next placed, followed by exterior form work, then concrete placement. Concrete formwork is supported by the steel frame and may or may not become a permanent part of the finished construction. Encased concrete composite sections have not been in use in the United States for several decades (Tucker *et al.*, 1991). The popularity of SRC in Japan has led to the development of a new type of rolled wide flange which was introduced in 1989 and reported by the JTEC panel (Tucker *et al.*, 1991). The uniform depth of this new section greatly simplifies design work, fabrication and the form work necessary for encasing the steel beams. Since the introduction of this new constant depth shape, use of this type of system has grown over the last 5 years, principally finding its way into high-rise construction with longer spans.

A mixed structural system combining a concrete core with steel girders and outside columns, common in the United States, is seldom seen in Japan (Tucker *et al.*, 1991). This system, along with three other composite and hybrid structural systems, is the subject of a U.S.-Japan cooperative research program begun in 1993 under the auspices of the UJNR Panel on Wind and Seismic Effects. It is co-sponsored by the government and industry on the Japanese side and by NSF on the U.S. side. The project is an outgrowth of U.S.-Japan cooperative research started over 15 years ago, involving full-scale tests of structures of mutual interest. This is the fifth phase of that work and is intended to clarify behavior (particularly of connections) at limit states and improve seismic performance of these systems. The four focus areas are the following:

- Concrete filled steel tube,
- Reinforced concrete (RC) column with steel girders,
- RC core with exterior steel frame, and
- New materials and systems, *e.g.*, fiber reinforced plastic, high performance concrete, recycle of structural members, hinge device systems, high performance steel and intelligent materials.

Research progress is essentially on schedule and amounts to stub-column tests, literature searches, design studies and comparisons of test results to computer simulations of very high strength concretes and steels. It is recognized, however, that many people concerned with sustainable development feel that the use of concrete-filled steel and related steel-concrete composite elements is contrary to the recycling and re-use of structural materials.

It was reported by the 1990 JTEC panel (Tucker *et al.*, 1991) that studies on the use of carbon fiber reinforced plastics (CFRP) for the tendons of prestressed concrete members had proven to be very successful in the battle against structure deterioration attributed to chloride ion penetration of the concrete. A demonstration prestressed concrete bridge using CFRP tendons and epoxy-coated reinforcement bars for stirrups was completed in 1988 (Tucker *et al.*, 1991). Unlike the United States where there are no all-advanced composite materials (ACM) highway structures in existence, there are a number of composite bridges in Japan. It was reported in late 1994 that the Japanese had installed and were evaluating an estimated 150 composite (fiber reinforced plastic) demonstration projects, including bridges, buildings and a variety of seismic retrofits (CERF, 1994). The panel learned that there has been no organized effort made to collect data on performance of these projects and that no additional projects have been undertaken. A notable exception is the use of high performance composites in seismic retrofit of non-ductile reinforced concrete structures.

The challenge to use of high performance composites on a project in Japan is not first cost. It is safety (in installation and use) and durability (building maintenance and operation). Prices remain very high relative to conventional materials, but are used based upon life cycle thinking and delivery of project quality.

Other mixed systems that have seen trial use include carbon fiber reinforced concrete (CFRC), jointly developed by Taisei and Toho Rayon Co., Ltd. This is applied to tall columns in the form of a layered tube (Li, 1995). The high carbon fiber strength of 3600 MPa (520,000 psi), stacked in both circumferential and longitudinal directions in the tube layers, serves as an external confining reinforcing layer, as part of a permanent formwork and as finishing materials for the columns. Test results show no surface spalling under extreme compression load and reveal improved ductile failure mode and improved reversed cyclic load response. Performance and cost comparisons with the CFRP recently applied by Caltrans in retrofitting bridge columns in California is not available. Its fire resistance is a clear advantage; however, costs remain high.

Since 1992 the Regional Construction Bureaus of the MoC has had two innovative construction technologies under observation. One system is a multi-span continuous bridge with Menshin Shoe (isolation) bearings. The other is a T-shaped girder bridge assembled with precast concrete block elements. These projects are under observation for an extended period of time to assess performance. Plans are to report results in 1996.

New materials development continues to parallel and be driven by new construction/structural systems development. The significant impetus to modularize and automate the construction process will likely bring the construction industry even more in line with the manufacturing industry. Self-placeable concrete and permanent formwork technologies appear to be particularly promising in Japan and are well-suited to automation and modular construction (Li, 1995).

Public works construction projects of bridges spanning the straits at the mouth of Tokyo Bay and numerous other straits between the islands of Japan are planned to be launched in the next ten years. The projects involve super long-span bridges, in excess of 2 km. The PWRI is studying design and construction methods for such pioneering structures, including severe wind, nearby earthquake sources, deep undersea foundations and structural response control. Experimental investigations include wind tunnel testing and the conduct of field vibration tests of existing long-span bridges.

The BRI of the MoC also has current projects on:

- Ultra high-rise reinforced concrete buildings using high performance concrete and reinforcement;
- Application of continuous fiber reinforcement for concrete, short cut fiber reinforcement for cement-based composites and reinforced inorganic board;
- Cast-in-place concrete construction methods using permanent forms;
- Development of new reinforced-masonry systems using high quality concrete and clay block units; and
- New construction systems for public housing including large-panel reinforced concrete elements and high-rise precast reinforced concrete elements assembled by post tensioning.

On a final note, some progress has been made in the move from prescriptive to performance specifications for design of structural systems. The BRI has started a 3-year program to develop a rational performance-based seismic design system, with implementation to follow in 3-5 years. The framework for their thinking about this issue is based on joint U.S.-Japan meetings held in 1991. They hope to form a U.S.-Japan cooperative research structure in the near future to continue this work and avoid duplication of effort. The new method is envisioned to encourage more creativity and enable greater flexibility in meeting project objectives, including aesthetics, economy and selected levels of functional behavior.

3. Retrofit

Work on retrofitting existing bridge and building structures for repair and increased strength somewhat lags efforts in the United States. Deterioration of concrete and steel bridges and other structures in coastal regions in Japan is a serious problem as is the need to repair earthquake-damaged structures and strengthen structures to accommodate increased loads or to improve seismic performance. On the other hand, fatigue damage of steel bridges caused by repeated loads is less of a problem in Japan than the United States, likely because Japan has only comparatively recently experienced increases in truck traffic volume and truck weights of the order seen in the United States over the past several decades as a result of our interstate highway system (Tucker *et al.*, 1991).

Advanced composites hold great appeal for revitalization of civil structural systems, both in rehabilitation and seismic retrofit. A number of companies including Mitsubishi Chemical (formerly Mitsubishi Kasei), Obayashi Toray and Tonen Corporation have been spearheading the use of carbon fiber based products for civil infrastructure (Karbhari, 1995), and useful cost information, in terms of cost relative to conventional techniques, is available.

Mitsubishi Chemical, Kasei, and Obayashi have jointly developed a retrofit strategy for columns and chimneys using a unidirectional carbon fiber strand applied with a robotic machine. Prior to the application of the strand, the concrete surface is ground smooth (corners of rectangular sections are rounded to a 50 mm radius). The method consists of the application of a carbon fiber sheet to a column or chimney in the longitudinal direction followed by the automated wrapping/winding of carbon fiber strand in the hoop direction. The fiber is impregnated before winding. Coating for UV protection, fire resistance and aesthetics is the last step (Karbhari, 1995). Full cure requires 2 to 3 days. This is an efficient system which enables safer, 30% faster, quieter and 40% less costly construction than the use of steel jacketing (circumferential steel shells with the annular space between the column surface and shell pressure grouted to induce confining prestress). This latter system has seen limited application in Japan, but was employed to repair and retrofit slightly damaged bridge columns in Kobe immediately following the Hyogo Ken Nanbu earthquake. Both systems (with variations in materials and application techniques) are also in use in the United States for column retrofit, and employ ideas similar to those developed and patented by U.S. developers.

Mitsubishi Chemical is developing a "Replark" prepreg sheet, and its use is touted for rehabilitation and seismic retrofitting of columns, walls, slabs, girders and beams. Properties of the "Replark" sheet, which like the carbon fiber strand is elastic up to failure, are shown in Table 4-1. An epoxy-based resin is used as the matrix and the prepreg is cured at room temperature after exposure at 20 °C for one week or 10 °C for two weeks. Prior to the use of the Replark sheet, the concrete surface is ground smooth to present a good bonding surface and a coat of primer is applied. The sheet is then placed on top of the resin applied on the primer. The assembly is compacted with a roller and allowed to cure (Karbhari, 1995). Two hundred structures have been rehabilitated or retrofitted using this method to date.

Table 4.1. Properties of the Replark Prepreg

Properties	Prepreg Type	
	Type 17	Type 30
Fiber Tensile Strength (MPa)	3450	3430
Fiber Areal Weight (g/m^2)	175	300
Fiber Cross-Sectional Area (cm^2/m)	0.97	1.67
Areal Tensile Strength (kN/m)	237.8	409.4
Thickness (mm)	0.16	0.28

The Tonen Corporation has developed a retrofit/rehab technology that attaches a "FORCA" carbon fiber tow sheet (with properties similar to the Replark sheet mentioned above) on a structural surface to increase the strength and overall performance through the use of external reinforcement on the tensile surface. The scheme is similar to that used conventionally by adhesively bonding steel plates to tensile surfaces of girders and beams. The FORCA tow sheet is attached with a proprietary epoxy-based resin system and cured under ambient conditions.

The initial development of FORCA started eight years ago, and it has been in use for 5 years. The technology has been used to repair or retrofit over 200 projects, including structural elements ranging from girders, beams, columns, culverts, walls, parking garage structures, floors and chimneys. One observer has reported that a majority of the application used a minimal amount of FORCA, which would seem to indicate (in the observer's view) that the use of the FORCA was more to provide a protective layer while filling in cracks with epoxy and for the prevention of further crack growth, than for the purpose of strengthening (Karbhari, 1995). In addition to Tonen, Mitsubishi Chemical and Toray manufacture this material with a total market estimated to be on the order of 50,000 kg/year and growing (Weaver, 1995). It is estimated that Tonen material is used for 90% of applications of carbon fiber strand/sheet reinforcement. Japanese government interest in this technology helped promote its technical acceptance. A change in Japanese regulations in 1994 allowing heavier trucks to use the roads, combined with a proactive government initiative to find uses for carbon fiber have served to drive increased application.

This technology is now undergoing trials in the United States, with claims from a bridge recently repaired in Delaware that carbon fiber stand/sheet can be cheaper than steel when installation costs are considered (Weaver, 1995). The only cost reference available suggests \$26/kg (\$12/lb) of primer and resin (each) and \$46/m^2 (\$4.6/sq. ft.) of strand/sheet for raw material. (The exchange rate for the unnamed year was given as ¥120 = \$1.00.) Erection and application costs were not included.

The Building Research Institute has recently completed their evaluation of the high-strength fiber repair and strengthening method described above. Carbon, glass and aramid fibers were evaluated and application guidelines developed. Ten private sector companies are now approved to use this system. A cooperative study, supported by the disaster Prevention Council, is underway to establish a standard method to measure performance of a treated structure. The findings are expected to be published in 1996. Most recent applications include the following (all are square, rectangular or flat sections):

- Restoration of earthquake-damaged bridge piers (Shinkansen Line) in Kobe (addition of shear capacity to slightly damaged sections),

- Restoration of earthquake-damaged building columns near Kobe (several projects),

- Strengthening of (undamaged) bridge piers to support highway widening near Tokyo (increase axial capacity),

- Strengthening of earthquake-damaged Hanshin Expressway with application to underside of roadway slab, and

- Strengthening of floor slabs of a school building to stop progress of excessive cracking and deflection (application to top and bottom of slab).

Although a large number of demonstration projects have been undertaken with high performance composite materials, there still appears to be, outside the *keiretsu kaisha* (the grouping of companies, subsidiaries, subcontractors, concerned banks and trading companies) structure, a lack of overall acceptance in areas beyond that of rehabilitation and retrofit or for the use of short fibers in concrete., although the economics and durability of the products are already known. It is clear that strong ties have been formed between some contractors and the composites industry (Karbhari, 1995).

The Hyogo Ken Nanbu earthquake caused the failure of many bridge support structures -- those designed before modern ductile details were developed. However, older bridge columns and piers with steel shell retrofits performed well during this earthquake. Although retrofit activity was reported as "in much use" in the Kobe area, elsewhere in Japan the start of new retrofit projects is awaiting the results of the code re-evaluation, triggered by the Hyogo Ken Nanbu earthquake, and its impact on retrofit standards and incentives. It should be noted that Japan started seismic retrofitting of bridges in 1971 and has completed about one quarter of the estimated 110,00 bridges (EQE, 1995).

Some evidence of seismic retrofit of older buildings and underground structures in and around Tokyo was seen by the panel during their travel to scheduled site visits. Addition of X-bracing (in all or nearly all bays and in every story), thickening/strengthening of exterior walls, addition of an independent exterior braced frame (X, chevron or knee), and additional shear walls were most commonly seen. Retrofit of bridges generally consists of the addition of jackets (both steel and high performance composites) to non-ductile piers and installation of restrainers linking adjacent spans across common supports. Earthquake-damaged reinforced concrete bridge structures in the Kobe area are being rebuilt to original designs, but with the addition of partial-height shear walls to strengthen piers in their weak direction. A water jet device developed by Kajima that removes concrete, but leaves reinforcing bars intact, has been employed to remove damaged concrete from piers and columns in Kobe prior to their rebuilding. It should be noted that a significant change in the overall repair work of the Hanshin Expressway in Kobe is the planned use of isolation bearings in the repaired expressway whenever possible as determined by available clearances and analysis (Raufaste, 1995).

Seismic retrofit of rental housing appears to be seldom undertaken, lacking the incentive to recover the investment. This is a phenomenon common to the United States.

It is clear that the Hyogo Ken Nanbu earthquake and subsequent fires underscored the seismic vulnerability of much of the urban environment that was either constructed under pre-1970 building codes or with traditional practices (see description in Seismic Design section below) such as that found in traditional Japanese house construction. Extensive use of combustible materials for residential construction, high building density, lack of fire breaks and limited fire fighting capability point to the need for retrofit technologies that can provide seismic resistance and passive fire protection.

4. Seismic Design

Japan's exposure to earthquakes and typhoons has produced a society that is aware of the need for earthquake and wind resistant construction. Development of seismic design provisions of their building code (Building Standard Law) have generally paralleled those in the United States and, like the United States, their seismic codes underwent a major revision upwards in the 1970s and again in the 1980s. Today, their codes are generally comparable to those applicable in California. Much of the built environment, however, was constructed under earlier less restrictive versions of the code, or is made up of non-engineered buildings, with little resistance to strong earthquake shaking.

Despite Japan's seismic history, houses throughout the country have traditionally been built to withstand not earthquakes but typhoons, which are far more common and frequently more destructive. Despite the fact that one of the MoC's six priority areas in construction technology R&D is safety from natural disasters (MoC, 1995), little has changed in the construction practices for the traditional Japanese house. It has a heavy tile roof to withstand high winds, supported on wooden columns resting loosely on boulders or shallow spread footings and pegged at the top into the horizontal roof supporting beams. There are no interior shear walls, and unreinforced stucco is generally used for exterior walls (Comartin, 1995). Although the design is not specially adapted for earthquakes, it provides protection only for modest ground shaking. Normally, following a small earthquake the repairs are limited to replacing missing roof tiles and replastering cracked walls. No one in living memory had experienced such strong earthquake shaking in a large urban area in Japan as on January 17, 1995. Ground motions were reported to be about twice as great as those experienced in the Kanto earthquake of 1923. In the Hyogo Ken Nanbu earthquake, over 90% of the victims died in their sleep, crushed by collapse of the heavy tile roofs of their houses (Valery, 1995).

Seismic vulnerabilities of structural systems, in addition to single family traditional houses, include older commercial and multifamily, residential buildings of non-ductile frame construction. Soft first story buildings are also a hazard. In Japan these buildings commonly fill a combination of commercial and residential uses. (In Northridge, they were apartments over garages.) Collapse of a number of police and fire station buildings was a serious setback to emergency response capabilities.

The Hyogo Ken Nanbu earthquake demonstrated failures of bridges and buildings constructed under previous non-ductile provisions of the building code. Ground failure (large soil movement and liquefaction) resulted in unexpectedly large foundation displacements which caused bridges (both old and new) to fall off their supports. This is clearly a potential problem for new bridges (Comartin, 1995) and is the subject of study to establish design methods that consider this hazard (MoC, 1995). In addition, some new bridges suffered significant damage, suggesting a need to re-evaluate the design basis for highly destructive, albeit very infrequent earthquakes (Buckle, 1995a).

Studies of these failures as well as the good performance of older structures that had previously been seismically retrofitted will undoubtedly influence seismic design and retrofit standards in the future. The impacts on issues of policy, retrofit and seismic design practice will not be known until the research and analysis of the earthquake damage are completed. At the time of our visit, 5 months after the Hyogo Ken Nanbu earthquake, it was reported that the seismic provisions of the building code were undergoing a re-evaluation, scheduled for completion the end of 1995.

It should be emphasized that the "modern" buildings in Kobe that collapsed were in fact not modern, but older buildings and transportation structures. Most of the severe damage was to non-ductile steel, concrete, wood and composite structures built prior to the implementation of requirements for ductile detailing. With respect to modern buildings, it should be emphasized that those designed according to the 1981 Building Standard Law, which mandated ductile detailing for the first time, generally performed very well (Wrentmore, 1995). Obayashi Corporation reported that 36% of 223 major buildings it erected before 1971 either collapsed or were unsafe to enter, while only 6% of the buildings completed after 1981 were unsafe, and none had collapsed (Normile, 1995).

One noteworthy, unexpected failure in the Hyogo Ken Nanbu earthquake was the brittle fracture of steel columns of the Ashiya-hama high-rise apartment complex in Ashiya City. Several of the 40 megastructure buildings, constructed in 1975, were damaged in this earthquake. At least one experienced brittle failure through the entire cross section of several of the steel box column sections which were made up of plates measuring more than 50 cm wide by 3-5 cm thick. The failures occurred in an open staircase structure which permitted the failures to be readily seen. No apparent attempt has been made to look for other failures in building locations hidden from view. Preliminary investigations indicate the causes of the failure may be attributed to low notch toughness, weld damage or high strain rate. The damaged buildings have already been temproarily repaired. A special committee will be organized to investigate whether the temporary repair can be used permanently or not. MoC will initiate fundamental scientific research on brittle failure in 1996.

In general, recent earthquake experience, both in Kobe and Northridge, demonstrates that modern homes, workplaces and public facilities, including single family residences in Japan built using contemporary, framing, materials and details, including prefabricated housing, perform very well in strong earthquakes and experience only slight, repairable damage without threat to the safety of occupants (Valery, 1995 and Comartin, 1995).

In view of the enormous damage to structures that the Hyogo Ken Nanbu earthquake caused, the Japanese civil engineering profession believes it is of vital importance to ensure greater functional redundancy in urban lifeline systems (especially transportation facilities) and take steps to ensure that certain critical facilities are built with greater earthquake resistance so as to ensure minimum functionality to serve the community during the emergency. An earthquake-proof berth in the port of Kobe was cited as an example of such a critical facility. A functioning port could receive help from outside the community and thereby avoid a complete breakdown of urban activity.

Professor Hideo Nakumura, President of JSCE expressed in 1995 an urgent need to look closely at the type of earthquake forces assumed in the Japanese design standards and to review the criteria presently in use. In response to this call, the JSCE has submitted initial proposals to the MoC and the Ministry of Transportation. JSCE plans to publish a report on the damage and economic and social effects of the Hyogo Ken Nanbu earthquake as well as methods of reconstruction within 2 years.

Significant research and development has been undertaken over the years by Japanese industry and government into technologies to control the dynamic response of buildings and bridges in order to reduce earthquake losses and increase occupant comfort. Japan has been regarded as among the world leaders over the last 2 decades in developing and applying innovative seismic resistant technologies, notably in isolation and active displacement control. Izumi (1993) summarizes seismic mitigation technologies, ranging from conventional fixed base design to active displacement control systems. Base isolation, mass effect and energy dissipation are categorized as passive systems. Active/hybrid systems have automated processing that adds another dimension of complexity. Design guidelines are in place for passive isolation systems, but not for active or hybrid systems; these latter technologies are still in the research phase.

Seismic base isolation permits a designer to decouple the supported building from the input ground motion. It does so by reducing the first mode period of the structure causing the response acceleration to be substantially reduced in exchange for increased displacement which occurs largely across the isolation plane and is accommodated by the isolation units. These units commonly are laminated rubber bearings (most often used in Japan) or low friction sliding bearings (planar or curved). To be effective, isolation also requires added damping to control potentially excessive displacements and a means for re-centering for friction-only systems. Added damping may be supplied by the rubber isolation bearing, for example, through shear distortion of the rubber itself or the introduction of a cylindrical lead plug embedded in the bearing, or by other means such as the use of additional metallic elements that bridge the isolation plane and absorb energy through repeated plastic deformation as the building vibrates.

Japan leads the United States in the development and implementation of seismic isolation systems for buildings, as well as most kinds of added damping and active displacement control. These latter systems reduce displacement for wind or moderate earthquake or both. Further, the Japanese have pioneered the development of advanced passive isolation systems that exhibit controlled displacement-dependent stiffness and energy dissipation. These systems promise to provide consistent levels of isolation for both small, medium and large earthquakes, something that earlier technology can not do. (Note, however, that because of the acceleration-displacement tradeoff involved, passive base isolation is not effective for structures taller than about 10 to 15 stories or for wind-caused displacement control.) Most of the major Japanese construction institutes have developed their own systems and have built experimental structures as well as a few prototype structures with these devices (Housner and Masri, 1993 and Hanson, 1993).

Proposals for seismic base-isolated buildings must be approved by the MoC based on Article 38 of the Building Standard Law. Since the first such approval in 1982, the PWRI reports that 83 approvals were granted, and nearly 70 buildings have been constructed with seismic base isolation in Japan (Buckle, 1995b and Raufaste, 1995); an additional 40 buildings are under review. This compares to 29 isolated buildings completed or under construction in the United States (Mayes, 1995). Seismic isolation has recently increased dramatically for both new and seismic retrofit projects in the United States (Kelly, 1993).

Base isolation and addition of restrainers has also been utilized on bridges in the United States and Japan. There are 23 isolated bridges, either existing or under construction, in Japan (Kawashima and Unjoh, 1994) compared to more than 30 in the U.S. (Kawashima *et al.*, 1993). The United States has led Japan in the implementation of seismic isolation of bridges. The first isolated bridge was constructed in Japan in 1991, 6 years after the first bridge isolation retrofit in the United States. There are 3 isolated bridges in the Osaka area which were reported to have performed as expected in the Hyogo Ken Nanbu earthquake. A report of their performance is expected in 1996 (Raufaste, 1995).

The Japanese approach to bridge isolation differs from U.S. practice. The need to lengthen the period of vibration is not so important (in Japan) as is the requirement to keep joint clearances small. Other issues include joint design, displacement restraint devices and durability of isolation hardware in the field (Kawashima, 1993). Further, the Japanese practice is to only isolate the bridge deck in the longitudinal direction to protect the weak axis bending of the bridge piers. This is called the Menshin Design and typically uses rubber isolator bearings that are guided laterally to prevent isolation in the transverse direction (Kawashima, 1994).

However the approaches differ in detail, base isolation is now accepted as an almost standard technology for seismic structural safety in both the United States and Japan. Surprisingly, building codes in both the United States and Japan do not give full credit for reduced seismic forces when designing buildings with base isolation. In Japan, the design for a new base-isolated building must be reviewed and approved by the Japan Building Center. Because base isolation is not covered by the Building Standard Law, each new technology innovation submitted to the MoC for approval must be supported by comprehensive experimental testing and verification of performance. The expense of such research tends to discourage small- and medium-size contractors from introducing this technology, and the smaller companies are reluctant to seek use of isolation technologies developed by the major contractors at their research institutes.

Both country's building codes and code bodies do recognize the need to consider testing innovative isolation systems as a step to defining appropriate design criteria. Shimizu Corporation estimates an added construction cost (for the foundation, structural shell and utilities) of about 10% for the use of seismic base isolation over conventional fixed base design (Raufaste, 1995). Kajima Corporation believes there is no cost increase for the use of base isolation for a typical 5-6 story apartment building measuring 25 m by 30 m in plan. The isolation increases the foundation and utility costs by 1% which is offset by a 1% structural savings. The net benefit is to the owner and occupants in reduced seismic damage risk.

Other methods of response control: mass effect, energy absorption, active control and hybrid systems, have been implemented on at least 36 buildings in Japan since they were first introduced in 1984. The more advanced response control systems have been used for research, demonstrations and for actual use, in addition to several large-scale tests performed at Japan's universities and industry research centers. The applications have been made to buildings varying in height to over 100 m. Further, the objective of the response control system generally appears to be nearly equally distributed between solely for modest earthquakes, solely for wind or for both purposes (Izumi, 1993). In some instances the energy absorption system has been specifically designed for maximum earthquake conditions and is expected to achieve response reduction of the order of 80% (Hanson, 1993). Mass effect systems have been in use in the United States even longer, since 1978, to provide occupant comfort, but not as a safety device (Morgenstern, 1995). Energy absorption systems have seen use for building application to control wind vibrations in the United States since their application to the 110-story World Trade Center towers in New York City (Hanson, 1993). Extension of these systems to seismic design has occurred only recently.

Forms of mass effect response control include a liquid type of system developed by Obayashi installed on tops of buildings to reduce the movements of steel frame high-rise structures loaded by wind or earthquake. The system is a type of tank with a bi-directional period adjustment device for tuning with the x and y bi-directional natural vibration modes of the building, respectively. The system was applied to three steel frame buildings and experimental and analytical studies on system effectiveness made. Good results were reported (Obayashi, 1995).

Kawasaki Heavy Industries, Ltd., has developed a similar tuned mass damper to suppress vibrations of long-span bridges and high-rise buildings. Their Tuned Liquid Column Damper is extremely simple, comprised of a U-shaped tube filled with water. To date it has been installed on two tall bridge towers to suppress swaying during construction and for normal operation.

A recent survey of trends of advanced response control R&D in Japan reported that at least 30 systems were under development, 10 (four active, one semi-active and four hybrid) are near the commercial stage, 12 (four active, two semi-active and six hybrid) are in the experimental stage, and the remaining eight in the conceptual stage (Okamoto *et al.*, 1993). Currently, most of the Japanese implementation of active and hybrid systems has been made for new construction seeking to improve occupant comfort (Housner, 1993) against excitation such as small and medium earthquakes and strong winds. Research in the United States has moved from theory in the 1980s to experimental research in recent years (Kobori, 1994).

Japan and the United States have had a particularly close working relationship, especially in the area of active and hybrid control of structures. These efforts have significantly advanced the state-of-the-art of the theory and the technology (Soong and Hanson, 1993).

The control of potentially damaging motions from earthquakes by active structural control has not yet been developed, but continues to be studied (Inoue *et al.*, 1993). Some U.S. and Japanese engineers have reservations about the use of active control for these situations because of uncertain reliability of needed power sources to operate these systems and (more recently) concerns regarding control limits, maintenance and adaptability to inelastic structural response (Tagawa, 1993). Based on observed performance of full-scale active control systems, steps have been taken recently to address critical implementational issues having direct impact on wide-scale use of active and hybrid control. The uncertain performance of systems integration, particularly of components that operate only intermittently with long dormant periods, is a barrier to wide acceptance of these promising systems (Housner, 1994).

Active control has been limited to wind and erection related vibrations. It should be noted, however, that the first building in the world to have an active control system was the Kyobashi Seiwa Building, constructed with an active mass driver system in 1989. It has experienced several moderate earthquakes and strong winds during which structural response was measured. Measured and calculated responses compare well, and comparisons of actual response with simulated response of an uncontrolled structure confirm a significant decrease in amplitude due to the active control system (Inoue, 1993).

Recent implementation of this technology in Japan involves combinations of a variety of add-on devices. Mass dampers include tuned mass dampers, active mass dampers, hybrid mass dampers, multiple stage mass dampers and hybrid multiple mass dampers. Active stiffening or bracing systems, energy dissipation/absorption dampers and hybrid isolations have also been used.

A tuned active damper (TAD) system was used for the control tower at the Kansai International Airport in order to reduce wind-caused vibrations. Construction was completed in November, 1992 by Mitsubishi Heavy Industries, Ltd. Tests indicate a reduction of one half of the level without the TAD (Hirai *et al.*, 1993).

Kajima Corporation has developed a hybrid control using an active tuned mass system, which they call a Hybrid Mass Damper System, or DUOX. It is a combination of an active mass damper system and a passive tuned mass damper. The system was installed as part of the Ando Nishikicho Building in Tokyo and is intended to control both earthquake and wind disturbances. Construction was completed in July, 1993 and system performance is being monitored. Response vibration at the top of the building is estimated to be one-third that of a non-controlled building (Sakamoto and Kobori, 1993).

D. Field Operations and Construction Equipment

1. Introduction

This section deals specifically with the team's observations of Japanese construction companies and equipment manufacturers' field operations and fielded technologies. The contents are a fusion of observations gathered during the team visit to Japan and information gathered from conversations, presentations and selected papers created by other experts in the United States, Japan and Europe.

As noted earlier, some characteristics of Japanese construction are significantly different from those of their U.S. counterparts in the following areas:

- Japanese construction firms are often dealing with terrain and site conditions different from U.S. contractors.
- Japanese construction includes a much higher percentage of demolition/rebuild sites than greenfield sites.
- The cost of the land is extremely high.
- The number of skilled workers willing to work in construction is dwindling.

2. Field Operations R&D

Section II presented a discussion of the numerous motivations for R&D in the Japanese construction industry as a whole. There are specific aspects of these that drive new technology in site preparation.

Environment. About two thirds of Japan's land mass is mountainous and as a result, most of the 130 million people live in the remaining area, which is about the size of Pennsylvania. Because living space is crowded, the Japanese public is concerned about the impact of construction on noise, dust, traffic and other environmental issues. Construction research focuses on how to be more efficient without being disruptive to the surrounding area.

Tunneling Technology. In 1990, the total length of all types of tunnels under contract in Japan was approximately 1300 km with a total cost of around $17.9 billion. Tunneling remains a major source of revenue for Japanese contractors today, and they are developing more effective techniques to complete tunnel projects.

Safety. Construction work in Japan, like the rest of the world, is perceived to be hazardous, and the need for safer as well as more efficient methods is a driving force in their R&D programs.

Labor Issues. As mentioned earlier, because of the "3 Ks:" *kitanai* (dirty), *kiken* (dangerous), and *kitsui* (physically demanding), most of the younger work force seeks jobs that are more comfortable and less strenuous. The development of technologies, such as automation, and machines that can make construction easier and more efficient is an R&D focus.

Natural Constraints. In addition to the often-mentioned frequency of earthquakes, approximately 10% of the world's active volcanoes are in Japan. R&D programs are in place to improve working conditions in hazardous locations.

Based on these factors, the impetus is for the Japanese, relative to the United States, to:

- demonstrate a higher level of technology in field operations,
- demonstrate a higher visibility for research on field equipment.
- purchase larger quantities of smaller machines to accommodate work in tight quarters.

3. Current Construction Equipment and Practices

Equipment Sales and Field Population. Recent unit sales of construction equipment in Japan by type are shown in Table 4.2. In general, most greenfield construction is accomplished with equipment and crews similar to those in the United States, including excavators, loaders, trucks and dozers. Their demolition/rebuild industry utilizes smaller equipment than the United States primarily due to space constraints and the need to keep traffic congestion to a minimum.

Construction Equipment Trends. Observations on this trip revealed several trends that have emerged since 1990; those include the introductions of semi-automated equipment cycles, mechanized material handling, and global positioning systems. Tunneling technologies identified in the 1991 report continue to advance, while automated building construction systems have not yet demonstrated the practical efficiencies necessary to gain widespread acceptance in the field.

Semi-automated Equipment. In pursuit of safer, more efficient working conditions, the Japanese continue to look for ways to supplement human skills with technology. Since the JTEC report (Tucker *et al.*, 1991), automation has been aggressively pursued, particularly in hydraulic excavators. Excavator models with automated work modes have been introduced by Hitachi and Komatsu. Other manufacturers are expected to capitalize on this trend by introducing more excavators with automated features into the construction market. Typical automatic features include: auto-slope, digging depth control, bucket hold, auto-grade, ditch finishing, and high/low limit settings. These systems are also capable of adding to operator comfort through dynamic linkage damping and controlled approaches to hydraulic cylinder limits.

Table 4.2. Field Operations Equipment Sales in Units (¥ million)
[Data from the Public Works Research Institute (Japan)]

Type	1990	1991	1992	1993	1994
Tractors	212 170 371	171 123 294	133 117 250	124 115 239	130 126 256
Backhoes	579 188 767	510 134 644	472 168 640	456 178 634	513 196 709
Cranes	359 51 410	400 50 450	305 35 340	238 26 264	212 25 237
Road Equipment	75 18 93	67 23 90	63 20 83	61 14 75	63 12 75
Concrete Equipment	77 7 84	78 6 84	77 6 83	62 5 67	60 6 66
Tunnel Equipment	44 1 45	49 2 51	53 9 62	69 4 73	86 4 90
Foundation Equipment	58 2 60	64 2 66	54 3 57	42 3 45	38 3 41
Other	113 27 140	124 28 152	92 32 124	81 24 105	101 22 123
Totals	**1518** **454** **1972**	**1465** **367** **1832**	**1251** **391** **1642**	**1134** **368** **1502**	**1204** **393** **1597**

The three numbers in each box denote domestic sales, sales overseas, and total sales, respectively. Slight differences in the column totals result from rounding the figures above.

Automated technology once perfected on hydraulic excavators will likely be integrated into other machines like track-type tractors, wheel loaders and others. Hitachi, for example, has developed a new type of pile driving machine that uses a computer-assisted guidance system for semi-automated H-steel-piling and sheet-piling work.

Automated technologies successfully applied in Japan are easily exported to the industry worldwide. The Japanese have ample R&D funding and capability to compete globally.

Mechanized Material Handling. High construction costs and tight quarters at construction sites are driving industry practice toward more pre-fabricated construction. New low-rise residences, for example, are using pre-fabricated panels, modules and structural elements. Pre-fabricated materials are heavier and bulkier than conventional construction materials, and new equipment is being introduced to meet these needs. Examples include a variety of Komatsu machines:

- LT300 Reach Tower Crane, used to lift material from the street,
- LC08M-1 Crane, a smaller crane for inside use,
- LS300 Material Handler, a small unit for positioning pipes for welding, glass sheets and similar applications, and
- CZ50 Material Handler, a compact, rubber belted unit for lifting and transporting heavy loads, such as pre-cast concrete beams.

A related product group, mobile crushers, has been recently introduced by Komatsu for use at demolition/rebuild sites to process scrap concrete and other hard materials for disposal or use as fill. Similar equipment is probably available from other manufacturers in the Japanese market.

Global Positioning Systems (GPS). Global Positioning Systems are being used in Japan, as well as elsewhere, for site surveys and integration with site planning software tools. For example, the GPS Navigation-Type Surveying System is being used by Mitsui on 12 different construction projects to establish the coordinates for piles, topographical surveying, cross- profile surveying, and plane-table surveying. Mitsui results to date indicate that GPS surveying is accurate within a few centimeters, and cuts surveying time by as much as 90%. The general consensus from interviews on this trip was that Japan is still lagging the United States in the integration of GPS with site planning tools, but will close the gap within the next few years.

Tunneling. Over the last 25 years, the Japanese have focused major R&D efforts in the area of tunnel-boring equipment for use in the construction of railroads, subways, and underground structures; they continue to advance this technology. Komatsu, for example, recently introduced a demonstration version of a soft rockbed, sharp-curved tunneling machine for the MITI Geo-dome Project. The machine can excavate continuously in sharp curves with a minimum radius of 7 m. Electromagnetic sensing radar is used to detect buried objects approximately 1 m from the cutting head. In 1994 Hitachi and Mitsubishi Heavy Industries completed construction of the world's largest shield tunneling machine (14.4 m diameter). Both Komatsu and Hitachi have developed automatic segment assembling robots for use with tunneling machines. These systems have been used in tunneling construction in Tokyo and surrounding areas, as well as in the tunnel under the English Channel.

Automated Building Construction. In the 1991 JTEC report (Tucker *et al.*, 1991), automated building construction was expected to expand rapidly in commercial construction. The results of this trip indicate that such technology has not yet proved to be more efficient or cost effective than conventional methods. Several buildings have been completed using this technology, and planning is underway for several more. The experience gained is being used to further develop these systems, but automation is not expected to have a dramatic impact on commercial construction in the next 10 years.

These observations make it clear that the Japanese have a strong commitment to automate and mechanize the construction industry wherever possible. While they have successfully implemented some methods and technologies which allow them to do so, automation technologies are still immature. Advancements in all phases of construction, including surveying, site planning, computer design tools, pre-fabrication, and material handling, have high priority. Current practices, while targeted at the growth of automation, still include many conventional methods, and until more sophisticated technology performs reliably in the work place, this will continue.

4. Technological Innovations and Trends

These trip observations, as well as other relevant research, indicate that the Japanese will continue to develop products that incorporate advanced technology. In doing so, they expect to utilize more effectively a smaller work force with fewer specialized skills and reduce construction costs.

National Projects and National Labs. The MITI-sponsored Geo-Dome project is a good example of government participation in technological development. MITI is putting up $154 million over a 7-year period for the development of design and construction technologies required to build underground infrastructures. The cavities will be constructed by remote-controlled equipment in soft saturated rock at depths of more than 50 m below the water table. This project (Figure 4.1) is unique in that it involves many new construction systems being developed simultaneously:

- a tight spiral tunnel excavated outside the planned dome contour from the access shaft,
- installation of rock reinforcement from the small diameter tunnel to prestrengthen the rock,
- remote underwater excavation of the dome to its planned shape,
- remote underwater installation of a concrete lining to the dome, and
- removal of the internal water only after completion of the lining.

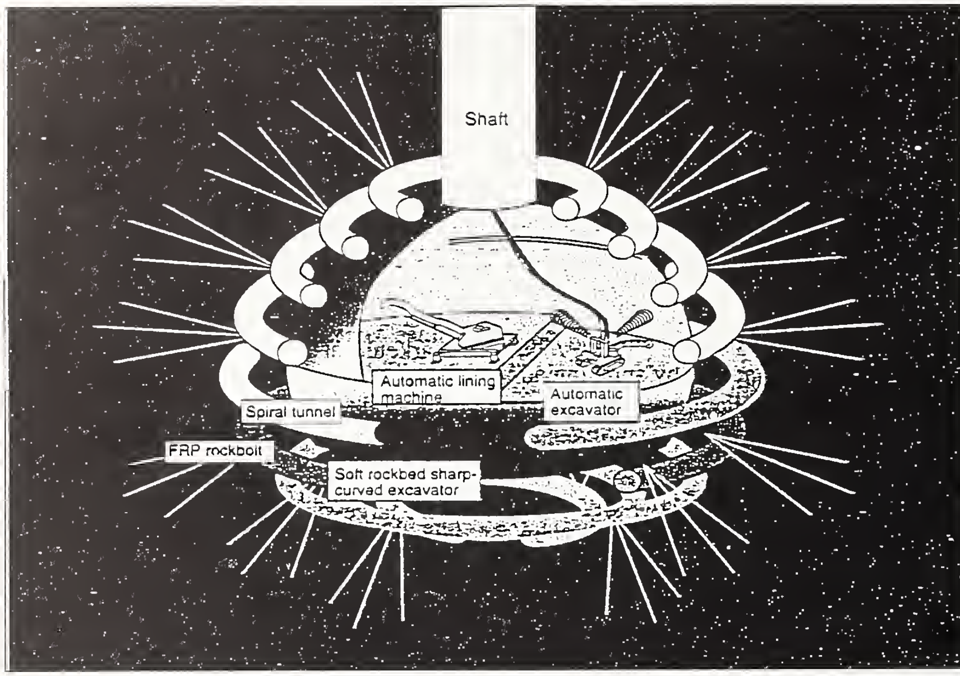

Figure 4.1. Construction of Geodome.

The MoC is developing new remote control technology at their Mt. Fugen-dake Restoration Project. Remote controlled equipment (bulldozers, hydraulic excavator, rock breakers, and off-highway trucks) is operated by radio control in the danger zone around an active volcano. All the equipment is remotely monitored by cameras, and viewed from a stationary control center. Large boulders are crushed by remote controlled rock breakers and debris is transported out by off-highway trucks (Figure 4.2).

Equipment Manufacturers' Technology. The Japanese continue to develop robotic technologies not only to upgrade their image, but to help create work methods that rely less on a large and skilled work force. Unfortunately, interviews on this trip yielded little information with regard to the status of long-term R&D projects. In general the trend is to respond to the market by developing fully automated and unmanned equipment using electronic controls, artificial intelligence, sensors and actuators. Multi-function fully autonomous robots are still in the earliest stages of development. In order to make this generation of robots an effective construction tool, control technologies will have to become much more sophisticated.

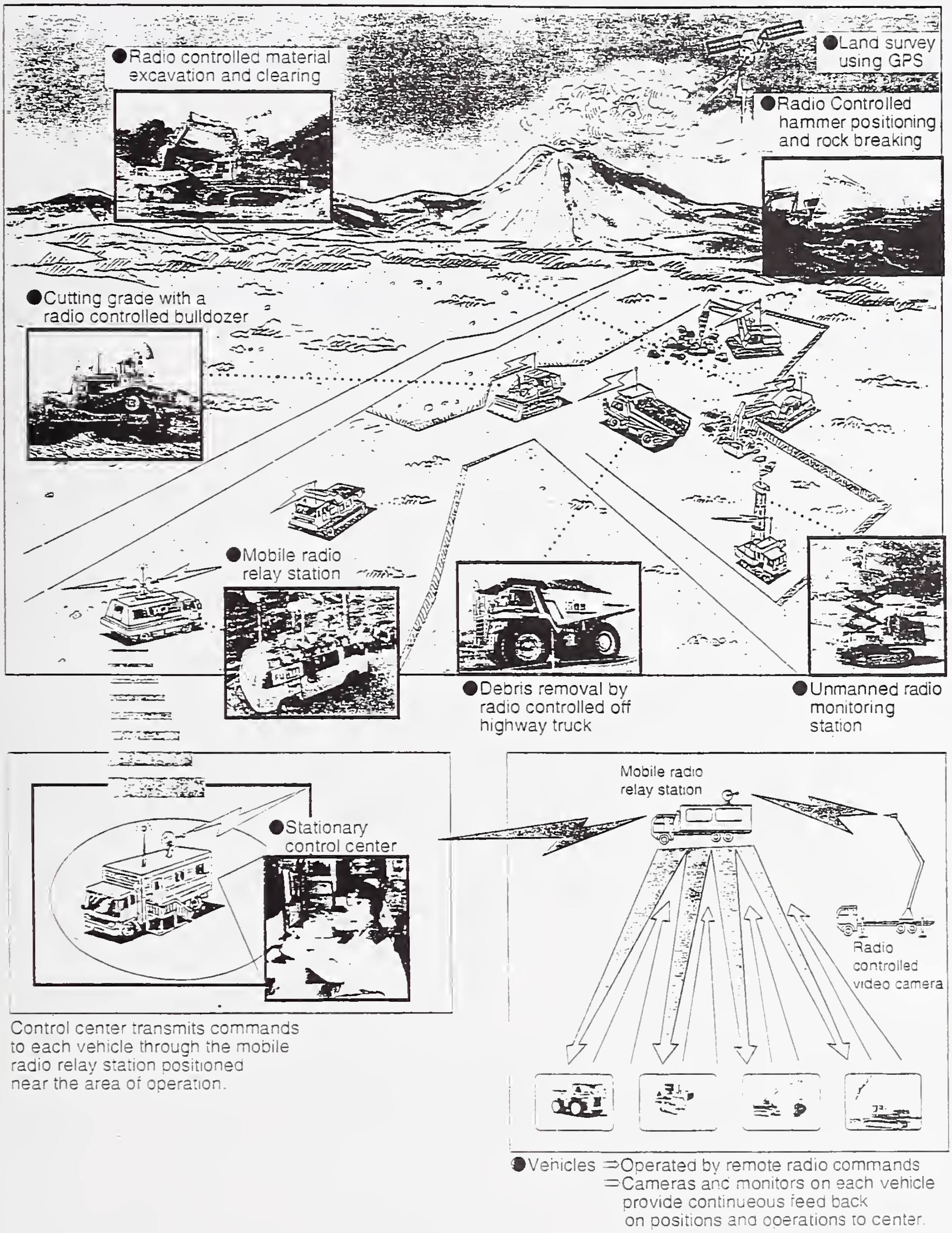

Figure 4.2. Radio Controlled Operation System.

Computer Aided Engineering (CAE). This is covered in some detail in Section III. Of importance to note here are general comments from construction companies that site planning and operations are potential components in a CAE system.

5. Summary

The Japanese continue to make significant, rapid advances in their field operations. They have historically invested heavily in a variety of technologies directed at becoming more effective and cost efficient. This strong foundation of research and technology may take them to a leadership position in the future. Specific advances are:

- new and more extensively-used smaller field equipment, useful in those world-wide applications where, as in Japan, construction involves demolition and earth moving in tight quarters;

- technology and machinery for soft-ground tunneling;

- development of commercial tele-operated machines for field operations in areas where conditions are too dangerous to allow operators on-site; and

Other key facets of field operations where the Japanese are investing resources include:

- fully autonomous machines, where the United States probably leads the way in terms of technological development due to aggressive university research programs and advanced space and military applications; and

- application of CAE tools to automated site planning.

E. Fire Protection

1. Introduction

The Japanese have a far better fire loss record than does the United States, with about half the death rate and an even smaller fraction of total cost per capita. This is especially noteworthy, given the old style of Japanese residential construction, where houses were made of paper and wood and built close together. This vulnerability led to a social consciousness of the risk of fire unlike any other in the world: the Japanese became extraordinarily careful about fire. As a result of this history, it is not surprising that Japanese buildings contain less active fire protection than is common in the United States.

Advances in fire safety are pursued primarily at two government Institutes. The Building Research Institute, part of the Ministry of Construction, has domain over practices and products used during the fabrication of constructed facilities. The Fire Research Institute, part of the Fire Defense Agency, has a broader mandate in prevention of, response to, and control of fire. Both also have testing and certification authority. Under the Panel on Fire Research and Safety, the work at both locations is familiar to U.S. counterparts. There are few true innovations under development.

There are two major factors which may change the Japanese approach. The first is a new product liability law that went into effect on July 1, 1995. This may force either building/furnishing components or the assembled structure to be more overtly fire resistant. The second is a recently-implemented protocol for performance-based fire safe design, described below. In conjunction with this, the BRI staff are considering a new set of standard fire tests.

A description of the current status of the components of fire safe construction technology follows.

2. Fire-Resistant Construction

Fire-resistant construction came to Japan with the American occupation in the latter half of the 1940s. The principles had been developed and implemented in the United States and had had an excellent impact on containing both fires within buildings and spread between buildings. As the Japanese rebuilt their war-damaged buildings and constructed the new buildings indicative of an emerging modern industrial country, they emulated this U.S. practice. This means that walls, door assemblies, etc must perform well in a furnace test. There, one side of the assembly is subjected to a time-varying high temperature. In response, the assembly must not be perforated, nor must the temperature on the other side exceed a mandated level.

Older homes have interior partitions made of thin wood and paper. These have no resistance to even a small fire. Newer multi-unit residences generally have walls made of concrete, and newer detached homes are similar to those in the United States - stud and plate construction. The interior walls are mostly faced with gypsum wallboard. Institutional walls often are made of cast-in-place concrete, gypsum wallboard, or (less commonly) metal panels. All possess a conventional degree of fire compartmentation capability.

Exterior residential construction is often lath with a moisture barrier. The wire grid holding the mortar has little fire resistance and the mortar falls off, enabling fire penetration. Thus, there is a premium on non-combustible interior finish.

There appears to be a moderate amount of wired glass used in windows in order to resist fire-induced breakage. This reduces the likelihood of an influx of air which would exacerbate an already growing or ventilation-limited fire.

In summary, there do not seem to be any innovations in this area, merely growing into conventional technology.

3. Fire Detection

Most public buildings have conventional fire detection systems, as in the United States. These consist of appropriately located, dispersed detectors (heat, photoelectric or ionization) whose signals are connected to a central indicator panel.

The residential detectors are mostly heat detectors, a step behind the United States in implementation. While the Japanese recognize the slowness of such detectors to respond to a fire, allowing it to get quite large, they are also unaccepting of the high nuisance alarm rate of the current smoke detectors. Since house fires are rare, false alarms are unacceptable. Even the late alarm presumably still protects the neighborhood or surroundings.

Under development are a new generation of detectors that will detect fires early, but discriminate against nuisance signals, such as showers, overheated cooking pans, etc. The Fire Research Institute and Matsushita Electric demonstrated the concept over 3 years ago. These are multiple sensors contained in a single unit. They track carbon monoxide, smoke particles, and heat. The signals are then interpreted using pattern recognition techniques, separating the spurious event from a real fire. In the former case, no alarm sounds. Unfortunately, due to the expected high cost and low durability of the carbon monoxide sensor, research has ceased.

4. Active Suppression

In the United States, most office buildings, public occupancy buildings, and commercial residences are now protected by automatic sprinklers; and the trend is toward retrofitting the remaining ones. In Japan, due to the short water supply, very few buildings are protected by sprinklers. There are no quick-response sprinklers in use; not even the idea is discussed. Further, incorporating sprinklers in a building design has not formally allowed relaxation of other design requirements, thus further discouraging their use. One exception to this rule are the underground/within-building parking garages. These have both automatic sprinklers and manual foam suppression capability. The team also heard that a high-rise residential project in Tokyo, the Harumi-1-chome District Redevelopment Project, will be protected by an automatic sprinkler system, apparently a first in Japan.

Halon 1301 systems had previously been used in Japan for protecting critical facilities. With the ban of production of the chemical, the Japanese have just mounted an effort to find alternatives. This seems to be a far smaller effort than in the United States and a few years behind. No solutions are on the horizon.

5. Egress

The Japanese have been pioneers in aiding people in leaving a burning building more effectively. They conducted extensive work on egress signs, developing a sense of optimal colors and location - near the floor. For institutional construction, they have also implemented automatic smoke doors to keep egress pathways free of smoke from other parts of the building. For office buildings greater than 5 stories, certain hinged "egress" windows are designated with red triangles; and escape ladders are located nearby.

6. Furnishings

The United States is just beginning to consider inclusion of furnishing regulations in building codes, although there has been extensive regulation of furniture, bedding, etc. at the point of sale by the Consumer Product Safety Commission. The Japanese have done little here, either on ease of ignition or on flame spread/rate of heat release. There appears to be no public research on chemistry to make materials less flammable. To the best of our knowledge, there is little research in this area.

7. Performance-Based Fire Codes

The Japanese are ahead of us in this area. Most U.S. fire safety requirements are prescriptive - each building component or product must pass a specific test. Since tests are added as new insufficiencies in fire safety are identified, the accumulated list of requirements becomes burdensome. It also stifles the introduction of new products.

The Japanese have now implemented a prototype performance-based design system for buildings, which evolved from a 5-year (1982-86) research project at BRI, funded by the Ministry of Construction. The initial version works within the current provisions of the Building Standards Law, enabling the evaluation and approval of code-equivalent designs for fire safety. Since its completion, approved alternate designs have increased markedly. Before 1986, approvals averaged about 2 per year. From 1987 to 1984, the numbers rose from about 20 to 140. The allowances included all types of large buildings, where design costs were large and the initial expenditures were feasible to reduce the total cost of construction. MoC is now pursuing a self-reliant performance-based fire safety design system, that is independent from existing regulations. This system will also produce a degree of safety equivalent to the current Building Standards Law. BRI is evaluating existing and developing new fire tests for use in such a system. These include ignitability, loaded structure performance, flame spread, heat release, smoke generation, and smoke toxicity.

8. Summary

Within fire protection, there are active teams at both the Building Research Institute and the Fire Research Institute working to understand fire better and to develop means for its control. From this work has come a prototype performance-based design system for buildings. This may well provide a significant flexibility in design and concomitant reduction in the first cost of construction. In other areas, the Japanese have implemented little new technology in the past 5 years, relying on the social consciousness of the people to maintain their current fine record of low fire loss.

V. INNOVATION BY CONSTRUCTION SECTOR

A. Industrial Construction

The design and construction of industrial facilities differ from public works and buildings in a number of significant ways. Some of these differences are:

- Industrial facilities have typically little architectural content, as they are primarily designed around the requirements of machinery rather than for human occupancy (they are occupied only by relatively few workers) or visibility.

- Mechanical, electrical, and either industrial or chemical engineering play large roles in the design of these facilities, civil and structural engineering proportionally less, compared to public works.

- Industrial facilities are built around manufacturing processes, which may be proprietary to the owner or to the engineering firm performing the process design. In many cases, the ownership of proprietary process technology may be the governing factor in awarding the process engineering work. Detailed plant design is often performed by a separate engineering firm from that which does the process engineering (the owner may often perform the process design if he has the technology).

- The plant equipment is typically a very large proportion of the total plant cost, and procurement of equipment is accordingly a major part of the detailed engineering effort. Often, integrated (containing all design and construction disciplines) engineering-procurement-construction (EPC) firms perform all these activities, usually on a lump-sum, turnkey basis.

- Industrial, power, and process plants are typically very congested, placing a high value on prevention of physical interferences and on coordination of the various engineering, design, and construction disciplines.

- Industrial plants are frequently retrofitted, renovated, or changed over for new products or models, new processes, higher efficiency, etc.

- Total project development time is an important consideration, due to the high value attached to earlier time to market of industrial products. This is particularly true of plant changeovers and retrofits, in which the entire productive value of the plant may be in abeyance until the outage is over.

In the industrial area, Japanese firms typically use joint ventures to accomplish complex projects. "In plant engineering and construction (E&C) projects, tasks are divided into several sub-tasks such as plant design, component design, and construction. The sub-tasks are shared among joint venture partners, equipment manufacturers, and subcontractors. This multi-company task-sharing scheme for Japanese E&C firms has become increasingly internationalized during the last decade under fierce market competition for lower costs. Because engineering activities require close coordination and collaboration, especially under strong market demand for shorter project periods, efficient organization and management of international multi-company collaborative engineering work is critical to such E&C firms." (Kano *et al.*, 1994)

On the other hand, Mitsubishi Heavy Industries (MHI), a giant equipment manufacturing company that furnishes engineering and construction services along with process and power plant equipment, has the internal capacity to design and construct complete chemical process plants anywhere in the world. Indeed, MHI in 1993 was the fourth largest of all international construction contractors and the second largest in Japan, with orders booked of $13.7 billion. It received 21.5% of its work outside Japan, a far larger percentage than any of the Japanese general contractors (JFCC, 1994). MHI may participate in some joint venturing with local in-country engineering or construction firms, but such partnering was not emphasized during our discussions. It was emphasized, however, that MHI uses its powerful financial resources to develop and become equity partners in industrial projects around the world, thereby assuring that MHI will be selected to provide plant equipment, engineering, and construction services.

In the international plant market, which is rapidly expanding in China, Southeast Asia, the Pacific Rim, and other developing areas, Japanese engineering-construction firms do not have the protection afforded by the MoC in the domestic Japanese public works and buildings markets, although they may receive assistance from MITI. The R&D institutes of the Japanese general contractors, which are essential to obtaining business in Japan, provide no competitive advantage in the international plant design market, in which awards are winner-take-all, based on lowest price. Unlike the situation with general contractors inside Japan constructing public works and buildings, "the surge in new technology and the advent of a global economy motivate [Japanese] E&C firms to assign work to companies with the lowest quotations in the free market, even with no previous work relationship and on an individual project basis" (Kano *et al.*, 1994). Thus, in the plant market, there is no difference in the approach taken by Japanese, U.S., or other advanced nation E&C firms; all must be price-competitive or be out of business.

There are some areas in which technological superiority does provide a competitive advantage. Clean room technology is very important in many electronics, precision machinery, semiconductor, biotechnology, pharmaceuticals, hospitals, and other high technology industries, and several of the Japanese general contractor research institutes have been active in developing energy efficient air purification technology for Class 1 clean rooms. In the United States, clean room design and construction technology is typically provided by specialist consultants and contractors rather than general contractors. Regardless of these organizational differences, the panel saw no evidence that Japanese their clean room technology is greatly different from or superior to U.S. technology in this area.

Robotics for use in manufacturing is another area in which technology has been used to support business development. Industrial robots are intensively used in Japanese manufacturing plants, and Japanese industrial robots are widely exported to the United States and Europe. Experience with industrial robotics in the 1980s led to the development of prototype construction robots by Japanese firms. However, we observed little research in construction robots (or even industrial robots) in the R&D institutes. That which was seen was in the Komatsu research institute, was concerned with automatic welding, and was not highly advanced.

The most important area of industrial plant construction in which competitive advantage can be secured is chemical process technology; *i.e.*, the process by which feedstocks are transformed into products. Processes which give greater yield, use less energy, use less expensive catalysts, generate less waste products, or are otherwise more efficient provide the source of design and construction business for engineering firms. These processes are proprietary and are protected by patents or as trade secrets. For example, the U.S. engineering firm M.W. Kellogg holds many process patents and receives much of its engineering work as a consequence of its technology.

In the area of technology development for proprietary chemical process improvement, Japanese engineering and construction firms do not appear to be different from or ahead of comparable U.S. firms. However, large, vertically integrated manufacturing, engineering, and construction companies such as Mitsubishi Heavy Industries have inherent advantages due to economies of scale, financial resources (manufacturing firms are heavily capitalized whereas engineering firms are typically not), vertical integration, and interior lines of communication. For these reasons, companies such as MHI should be compared with other manufacturers such as Asea-Brown-Boveri (ABB) rather than engineering and construction firms.

The industrial construction business is driven by the state of the market for the products made by the plants. Due to economic fluctuations, there is typically overbuilding in times of high product demand, followed by periods of depression. In the chemical process business, product demand and hence plant expansion or new plant construction are often driven by the price of feedstocks, such as oil. These business cycles place severe demands on engineering and construction firms. U.S. firms typically hire and lay off engineering and design personnel as business conditions change. However, Japanese firms have traditionally stressed lifetime employment.

> "Because of difficulties in recruiting and laying off a competitive workforce that can respond to the changes in workload, Japanese E&C [industrial engineering and construction] firms have focused instead on: (1) geographical market expansion, (2) product family expansion, (3) arranging finance for clients, and (4) outsourcing work, including engineering and design.... Japanese E&C firms [unlike MHI] typically own neither manufacturing facilities nor assembly factories; they purchase equipment and construction material from outside suppliers. Because equipment manufacturers (vendors) possess rapidly evolving equipment design/manufacturing technology and often share the engineering work of customizing their equipment for a particular project, E&C firms are motivated to enter into multicompany [collaborative engineering] relationships with vendors." (Kano *et al.*, 1994)

Due in part to the appreciation in the yen, Japanese engineering fees are considered to be the highest in the world. The following comparison represents 1993 data. Presumably 1995 engineering rates in Japan are even higher, relative to the United States, due to changes in the exchange rate.

Table 5.1 Comparison of 1993 Engineering Rates
[Data from The Engineering Business, 1993; quoted in Kano *et al.*, 1994]

Country	**Engineering Rate $ U.S. per hour**
Japan	120
Germany	110
United States	91
United Kingdom	55
Netherlands	55
Taiwan	36
Ireland	32
Korea	27
Peoples' Republic of China	27
Poland	14
Philippines	9

Of course, the obvious conclusions in these numbers affect not only Japanese firms; the industrial, chemical process, and power markets have become international. The worldwide decline in chemical process plant construction in the decade of the 1980s, and the consequent increased competition between international engineering-construction firms have led U.S. firms as well as Japanese to outsource engineering work to countries such as India and the Philippines. Both Japanese and U.S. engineering-construction firms are forming joint ventures, establishing subsidiaries, and buying local firms in developing countries with cheap engineering labor. "The JGC Corporation, for example, established a new engineering subsidiary, Technoserve International Co., Inc., in The Philippines during 1989, and Toyo Engineering Corporation set up Techno Management Co. in Korea, in 1988." (Kano *et al.*, 1994)

The leading Japanese as well as U.S. engineering firms thus have come to regard engineering and design as a commodity that can be outsourced to the lowest cost country. Neither country seems to have considered the impact that this will have on their engineering employment, engineering salaries, engineering educational systems, and long-term domestic competence. This is not the place to propose alternate solutions to those being adopted by Japanese and U.S. firms, but there are alternate models to outsourcing and hollowing-out of engineering and design functions that have not necessarily been considered.

Computer-aided Design (CAD) systems have become prevalent in the United States, particularly for plant design. However, although CAD originated in the United States and many commercial CAD systems are made here, these capital-intensive tools for design automation provide no competitive advantage to U.S. engineering companies. We observed the same U.S.-made CAD systems in Japanese firms as are present in U.S. firms; moreover the same CAD systems are present in the developing nations. The capital cost is no barrier, as the costs are often subsidized by the national government to support local engineering jobs; the cost of a graduate engineer *including a U.S.-made CAD workstation* in the Philippines or India has been quoted at $15 per hour, which is about the cost of ownership of the CAD station alone in the United States.

Thus, the internationalization of the engineering-construction market has been a boon to the business of U.S. CAD vendors, if not to U.S. engineering firms. The advanced industrial nations are in the 1990s in a process of exporting engineering jobs and hollowing out their engineering-construction firms, just as occurred in manufacturing in the 1970's and 1980's. Although this process is driven by the necessity to be cost competitive in the international marketplace, because all firms are using the same strategy of outsourcing, none can achieve a sustained competitive advantage, and at the end of this process they will all arrive at the same point.

The competitive evolution in the plant engineering-construction business will, if continued, lead both Japanese and U.S. engineer-constructors to be managers and coordinators of engineering and design, outsourced to third-world countries; of equipment procurement, similarly acquired internationally on the basis of price; of worldwide logistics management and delivery expediting; and of construction management in host countries. That is, they will become <u>virtual companies</u> managing project developments around the globe. Success in this arena will go to the firms that can best coordinate information and minimize the inefficiencies of this distributed process.

In 1988, it was reported that "Japanese contractors are beginning to shift some of the management responsibilities of the main office to their overseas subsidiaries and affiliates." [Hasegawa, 1988] However, even six years later, "almost every service, except for a part of detailed engineering, construction, and operation & maintenance (O&M), is located in Japan where Japanese E&C firms have a major technology base. From a business viewpoint, services will need to be located near clients or near the local market, while the best technology remains at its centers of excellence around the world; in other words, the technological base of Japanese E&C firms needs a drastically enhanced global perspective." (Kano *et al.*, 1994)

However, the "flow and coordination of information becomes difficult and costly in an international scenario because of the greater distances involved. The difficulties in coordination across both company and country borders have occasionally resulted in design changes and rework at the construction site as well. Although engineering accounts for only 9% to 15% of the total project costs, engineering work determines most of the overall project costs. So, each factor that impacts engineering quality, engineering time, or costs is critical to the overall competitiveness of E&C firms." (Kano *et al.*, 1994)

Some of the information technologies that have been identified by leading Japanese as well as U.S. engineering-construction firms include:

- three-dimensional CAD design,
- integrated project databases,
- standards for exchange of product data (*e.g.*, PDES/STEP),
- worldwide, high-speed, high-bandwidth telecommunications,
- construction simulation (four dimensional modeling),
- virtual reality and virtual plant modeling,
- risk reduction,
- knowledge-based systems for design and construction, and
- project management systems.

No engineer-constructor has put all of these pieces together, or even most of them, into an integrated coherent system. Some parts are being developed, however. For example, Raytheon Engineers and Constructors recently announced the development of a proprietary virtual reality system for use in plant visualization.

In 1988, it was reported that "most computer systems used by contractors are intended to automate repetitive office work and stop short of providing simulations that would help to draw up the optimal construction work plans" (Hasegawa, 1988). It would appear that the situation has not greatly changed in 1995. None of the Japanese general contractor research institutes showed any research projects in or use of three-dimensional design or virtual reality. In response to questions, they typically replied that CAD systems are in use at their design offices but are not considered a subject for the R&D institutes. Of course, the research institutes are really engineering experiment stations engaged in physical testing and design verification, rather than general research establishments, so that R&D of software might be more appropriately carried on elsewhere, such as in corporate information technology departments.

At a building construction site in Tokyo, Mitsui Construction Company is providing on-site plotters connected by Local Area Network (LAN) to CAD stations in its off-site design office; CAD design is two-dimensional only. No firm contacted regarded design and construction information as an asset to the ultimate owner-operator of the facility and no one provided design and construction database access to others.

At the most advanced firm visited, Mitsubishi Heavy Industries, MHI stated that it uses commercial CAD systems and not a proprietary CAD system. MHI has not standardized on any CAD system: when a client requests delivery of documents in some particular CAD format, MHI's policy is to use in production whatever CAD system the client specifies. Three-dimensional CAD systems are available but three-dimensional design is not used unless the client explicitly requires it, as it is considered too expensive; conventional two-dimensional CAD drafting is the standard practice.

This response is not unusual; a similar response would be obtained from any average contractor in the United States. If an integrated equipment manufacturer, engineer, and constructor such as MHI does not realize benefits from three-dimensional design, interference detection, quantity takeoffs, construction sequencing, and other applications, it is doubtful that general contractors would.

In 1988, it was reported that "a large number of contractors have entered...the sales of construction database services and construction software for CAD and small business computers]" (Hasegawa, 1988). At this time, Kajima, Taisei, Takenaka, Obayashi, Shimizu, and other general contractors all reported that they were engaged in sales of construction software (Hasegawa, 1988). However, no evidence of this market was visible 7 years later. Apparently, Japanese general contractors see little competitive advantage in CAD; in the use of three-dimensional computer models throughout design, procurement, and construction; or in the use of CAD models after construction for facility management, operations, maintenance, and renovation. (In spite of a 1988 prediction that "more efficient construction of higher-quality facilities will become possible by linking a new CAD system with the CAD units used on construction sites and with a building repair-maintenance information system." [Hasegawa, 1988]) In this they are not unlike the majority of U.S. contractors.

Japanese general contractors appear to see little need for new technology for project coordination and management, as they unanimously agree that they deliver projects on time and on budget. Mitsubishi Heavy Industries asserted that they complete process plant projects earlier than the schedules, but receive no incentive fees from the clients for so doing. With the exception of the automated building erection systems, which were developed in part to reduce construction times for high-rise office buildings, Japanese general contractors are satisfied with their budget and schedule performance.

Firms in both Japan and the United States use identical commercial CAD systems that have evolved from drafting systems and merely replace manual drafting functions. None of the Japanese firms we visited appear to be developing systems for true computer-integrated construction. Japanese firms treat their engineering and design people resources as corporate assets, and therefore avoid the layoffs prevalent in U.S. engineering-construction firms, but neither country treats design and construction knowledge as a corporate asset that can be captured and retained after people inevitably depart. We saw no development of new methods for project management and control and no Japanese (or U.S.) firm that has reorganized its design and construction process to exploit information technology. In the area of integrated information systems to support global, distributed operations by engineer-constructors, neither Japanese nor U.S. firms have progressed far enough to be considered to have a lead.

B. Large Commercial, Residential and Institutional Buildings

1. Introduction

The construction of a large building in urban Japan is inherently similar to that in a U.S. city. However, there are subtle cultural, physical, and technological differences that affect both the construction process and the completed product. Certainly, with resistance to natural disasters a principal motivator in Japanese building design, structural issues are especially important for large buildings. These facets and recent innovations in the Japanese industry were discussed in Section IV.C. The focus in this section is on other technological aspects of the construction and the building.

We were frequently reminded that space is extraordinarily valuable. The construction site may cost five times the construction costs, leading to the erection of ever-taller buildings as inner city locations become more in demand. "Elbow room" around the site is often so limited that it determines the construction process.

In the United States, most buildings of this type are designed for flexibility of use; it is common to build speculative buildings and to reuse existing buildings for new purposes. The percentage of buildings designed for special purposes is small. In Japan, it appeared that the projects were more purposeful and less speculative, perhaps due to the limited space and the Japanese emphasis on careful planning. The internal layouts were precise, resulting in a much less adaptable working environment. This, together with what appeared to be a generally lower level of luminous and thermal environmental standards, must have some impact on the productivity of the building users. This should be evaluated in the future.

2. Examples of Current Construction

Shimizu Manufactured System by Advanced Robotic Technology (SMART). Shimizu recently completed a 20-story, steel-structure, commercial office building in Nagoya that integrates a number of recent technologies. The structure is 80 m tall, with a footprint 24 m x 30 m. Following completion of the site preparation and a 2-story basement, the roof and "top hat" were constructed under computer-controlled cranes. The 38 m high "top hat" included a jacking and lift system of four towers, each with 300 ton lift capacity, and served as a manufacturing plant. Two operators in a control room maneuvered cranes and hoists to bring prefabricated columns and beams up the building exterior and set them precisely into position. A robot welder then united the structural steel components. Curtain walls and HVAC components were installed, and the unit was then jacked to the next story. All work was performed in an enclosed environment, protecting the workers and the work surfaces from the weather. The total construction time was 24 months, 14 for underground work and 10 for the superstructure. Completion of each floor took 8 days. At the conclusion of the job, the "top hat" and the jacking/lift system were removed, and the roof was lowered to the top story to complete the building. While there was significant cost for the new installation techniques, development of the system, and first-time acquisition of the manufacturing hardware, Shimizu believes the technologies will be applicable in other areas where laydown and queuing of materials isn't possible.

Mitsubishi Heavy Industries (MHI) "T-UP" Building. Taisei and Shimizu designed and constructed a similar, 34-story building for MHI. The "top hat" completes five stories in each step of the frame erection. A laser measurement system scans the position of and plumbs each steel column. An information system controls the process, although it does not store the placement information for use during the service life of the building. Taisei expects to save over 30% of the normal construction costs and one quarter of the project time, once this method is perfected.

Interestingly, when we talked with representatives of the contracting companies about the viability of jack-up construction, nearly all were pessimistic about its future. Several companies had constructed or were in the process of constructing a single building using this method, but none had plans to construct a second. While very successful as a technological experiment, its re-use could not be justified when measured economically.

Tokyo Rinkai Hukutoshin Project. We visited this conventionally designed, 29-story hotel when it was well along in its construction. One modification in the structural erection was the use of 4-story columns, a process designed for improved safety during construction. Another interesting structural feature was the use of deep steel beams with specifically designed reinforced openings, each precisely taken by an assigned utility or service. This is an example of a single-purpose building where the usage plan, which was developed at the outset, will not be easily modified, *e.g.*, for advanced communications or changing space requirements. We were impressed with the striking cleanliness and the general quality of the housekeeping on the job site.

MHI Yokohama Building. At the MHI Yokohama building, we saw a modern office building with full services and raised floors, enabling future added power and communication lines. However, it appeared that, in tightly accommodating current needs, the flexibility to adapt the work space (*e.g.*, by changed the location of lighting and HVAC panels) to future uses was compromised.

Harumi-1-chome District Redevelopment Project. This 50-story apartment building will be the tallest residential complex in Japan. It will incorporate accelerographs to gather seismic response data and will be protected with an automatic fire sprinkler system, the first for residential construction in the country. As with other modern urban high-rise buildings, such as the Tokyo International Forum, Glass Hall project, the basement excavation is proceeding concurrent with erection of the structural system. Mitsui, the general contractor, said that they are completing the project on schedule with about half of the normal complement of workers.

3. Other Aspects

A feature that has become common in this type of construction is the just-in-time (JIT) delivery and installation of materials. Accompanying this is an applied technology used extensively on the Japanese construction site, but is barely in the infant stage in the United States - bar coding. JIT delivery is necessitated by the lack of storage space at the typical job site and in turn requires close tracking of materials. Bar coding and hand-held computers (and sufficient staff to collect the data) make the JIT concept a reality. Clearly, for tall buildings constructed with little surrounding space, such a system is put to the test, but it seems to be working.

In constructing these buildings, there appeared to be little overt emphasis on environmental sensitivity, greater use of recycled and recyclable materials, or expanded recycling of construction waste material. Perhaps, having started higher on the environmental "kindness" scale, the Japanese contractors do not seem to be as pumped up in their quest to redeem themselves for prior environmental "sins" as some elements in the United States. This does not imply that they are doing less, it does mean that what they are doing is done with a lot less fanfare.

When construction research staff were asked about research activities for hospitals and educational facilities, the limited cases where there was any activity were related solely to life safety issues. Kumagai Gumi, for example, was utilizing base isolation in the design and construction of a hospital. The Building Research Institute and Fire Research Institute are performing a variety of projects aimed at improving life safety (*cf.* Appendix A of this report). However, in general, such topics as ventilation requirements for asepsis control, and services for education which can support the new introduction of information technology as well as more traditional teaching methods, were not addressed by the staff that we visited. The only comments which emerged from our sessions were to the effect that these were design issues handled in design offices. If such research is being done at universities or in design offices, the ability to translate research findings into practice would not necessarily be easy.

In the completed buildings we visited, some built within the last few years, there seemed to be little emphasis on the interior environment. Lighting and thermal control were issues not well-addressed either in the buildings we visited or in the research we saw. As an example, in only one conference room that we visited on the trip were the bare fluorescent lamps not visible. The glare was sufficient to produce, *e.g.*, considerable ghosting of the light fixtures on a computer screen.

In Japan, as in the United States, there are cost-effective showcase buildings with energy intensities about half of the norm. These buildings are well-designed, so they typically also have better than average lighting (artificial and daylighting), better air quality, and in general better comfort and slightly increased worker productivity. However, while the "know-how" is available in both countries, the implementation on a broad scale is less impressive.

In both countries there are engineering studies of the potential for cost-effective retrofit and improved design of new buildings. A survey (Sezgen and Schipper, 1995) of energy consumption in service sector buildings in five industrialized countries shows that Japanese buildings use about 3/4 (per unit floor area) the energy of American buildings (Figure 5-1). Most of the difference is in the Americans' far higher use of energy for air conditioning. In the United States there are several "conservation supply curves" for commercial buildings showing that it is cost effective to improve efficiency by 40-50% (EPRI 90; NAS, 91; Koomey, 94). A similar Japanese "supply curve" (Nagata, 1995) shows a potential savings of 12% at 2-year payback time, and a life-cycle optimum saving of 33% (compared with the above 40-50% for the United States). Since Japanese office buildings already use only 3/4 as much energy/square meter as ours, it appears that both of these supply curves suggest that an optimum building today in either country would use about half the current U.S. intensity, or 2/3 that of Japan.

4. Summary

The Japanese construction industry has been highly successful in producing structurally sound large buildings under highly constrained conditions, although we saw comparatively little that had not been reported by the 1990 teams. The sites we visited were mainly concerned with civil engineering and accordingly showed a research emphasis on structural systems rather than on coordinated building systems design.

C. Residential Construction

1. Introduction

In the other parts of this section, we have had the benefit of benchmark documents from JTEC (Tucker *et al.*, 1991) and CERF (Hampton *et al.*, 1991). However, neither of these documents provides background on home building. Therefore, this subsection goes into considerably more detail to provide the reader with both a sense of direction in this sector and understanding of the context of recent technological changes.

Japan has one of the highest population densities and some of the highest land prices among the advanced countries of the world. It is no surprise therefore that its inhabitants place a premium on living space and that the size of housing units has become a principal factor affecting their quality of life and a primary issue defining the quality of housing in Japan. This is especially true in congested metropolitan Tokyo and to a lesser extent in the urban regions centered on Osaka and Nagoya, all magnets for migration from rural areas since World War II. These urban areas, with larger population growth, increasingly have lower proportions of single-family and attached houses for home ownership, larger shares of multi-family apartments for rent, fewer structures of wood construction, and a much lower average size of unit than the rest of Japan. Problems with congestion, long commute times, and environments incompatible with residential use are particularly serious in Tokyo with its mix of apartments, condominiums, and extensive areas of low-rise, densely built housing often intermingled with commercial and industrial uses (BCJ, 1992). The average size of Japanese houses is less than two-thirds that of dwellings in the United States; and, on a per capita basis, they have half the living space. Moreover, their current standards and future targets with regard to floor space are modest compared to U.S. current standards (JFCC, 1994).

The ideal Japanese lifestyle of ordered, peaceful tranquility takes place in an uncluttered environment where material possessions are at a minimum and essential functions are exposed and unadorned. The traditional Japanese home reflects this image, which is one of openness and light, with a minimum of furniture and other clutter (BCJ, 1992). In consonance with this vision, the typical wood home had been built with post and beam construction, without nails, and with the wood structural members unpainted to expose their texture and grain, which is highly valued in Japan. The rooms tend to be open and, with the aid of sliding and removable partitions (*fusuma* or *shoji*), are multifunctional, capable of adapting to changes in the daily routine of the family and its members. Direct access to the outdoors through a porch is desirable. The principal room of the house is the *tatami*, named after the 0.9 m x 1.8 m (3 x 6 foot) woven straw floor mats; and the size of rooms is measured by the number of such mats required to cover the floor.

This image, however, is gradually fading. Rooms are becoming more functionally specialized with solid walls, doors and windows defining rooms (Construction Review, 1989). Although most newly constructed houses attempt to maintain one room where traditional customs can be observed, Western lifestyle is becoming the rule and even furniture in some tatami rooms is in the western style. Similar to other advanced countries, the Japanese have their complement of modern material possessions: automobiles (67.4%), stereos (59.9%), color TV (99.1%), air conditioning (52.3%), and microwave ovens (42.8%) (BCJ, 1992). The average 1990 Japanese family income of about $58,000 (BCJ, 1992; based on a 1990 conversion rate of ¥120 = $1.00) is high by any standards. The quality of life, however, as represented by the amount of living space remains below that of other advanced nations. According to a "Housing Demand Survey" conducted in 1988, over a third of Japanese households expressed dissatisfaction with their housing, with higher rates of dissatisfaction expressed in major metropolitan areas (BCJ, 1992). Lack of storage space, the level of insulation against sound and heat, and durability were issues of concern. A Survey of National Needs for Construction Technology in February, 1992, indicated that the almost half of the Japanese general public (47.4%) and over two thirds of the experts (67.4%) desired more investment in social overhead capital, in which construction and housing in particular play a significant role (RICE, 1993).

2. The Government Role in Housing

Research and Development. The Japanese government plays a key role in encouraging and providing direction to Japanese housing R&D. The MoC, its Building Research Institute (BRI), and the Housing and Urban Development Corporation (HUDC) are the government agencies most directly involved in the residential construction research. Some examples of themes that pertain to residential construction are development of wood-frame housing technology (1986-1990); development of improved housing for the elderly (1987-1991); development and application of new materials for construction (1988-1992); and development of new construction method technologies such as prefabrication (1988-1992) (Paulson, 1991). In 1987, Japan was said to lead the United States in the implementation of state-of-the-art construction materials technology and continues to gain leadership in structural steel, high-performance concrete, high-performance composites, and geotechnical materials (Wright *et al.*, 1991).

The Japanese Science and Technology Agency (STA) oversees government R&D and ensures that the national drive for technology advancement receives continuous support and attention from the highest government authorities (NAHB, 1994). The STA supports the Research and Development Corporation of Japan and directs placement of R&D in various industries, encouraging the Ministry of International Trade and Industry's (MITI) 16 research establishments to work closely with industry on a variety of industrial problems.

Incentives for Housing Investment. The Japanese government has also played a major role in stimulating housing construction. From the end of World War II to 1990, about two-fifths (40.4%) of the housing in Japan had been built with public funds (BCJ, 1992). In 1990, privately built housing accounted for 70% of all housing starts while publicly assisted housing comprised the other 30%. The MoC promotes housing and social capital to achieve goals in key time periods as set forth in its Sixth Housing Construction Five Year Plan (FY1991-1995). This is one of eight plans formulated by MoC under the overall guidance of The Public Investment Basic Plan approved in June, 1990, for public investments amounting to a total ¥430 trillion between FY1991 and FY2000. Within this framework, the housing plan, among others, was revised in 1993 to set more stringent goals and to facilitate the pace of development. This plan projected construction of 7.3 million housing units, of which 3.7 million units or over half of all units were to be publicly subsidized housing, a 12% increase in public housing investment over the previous plan (RICE, 1993).

About 87.3% of the planned subsidized housing has been constructed from between FY1991 and FY1994 (RICE, 1994). The MoC's FY1993 allocation to housing in urban areas was later revised and increased 6.8%. In FY1994, however, in line with decreases in the national budget, the MOC's total budget was decreased and its allocation for housing in urban areas was reduced by 26.4% compared to the 1993 revised allocation (RICE, 1994).

Government assistance usually takes the form of financial incentives such as low-interest loans, tax incentives, and attractive pricing on government contracts. The three principal actors in the publicly assisted housing supply system in Japan are the Government Housing Loan Corporation (GHLC), the 53 local housing supply corporations in prefectures and municipalities, and the HUDC. The GHLC was established in 1950 to provide long-term, low-interest loans for persons intending to acquire their own homes; loans to local housing supply corporations and builders for construction of housing; and loans to individuals who intend to build rental housing. The local housing supply corporations construct and manage rental housing as well as supply housing and sites for sale with the aid of loans and subsidies from the central government. The HUDC, established in 1955, supplies middle class workers in urban areas with houses and housing lots to eliminate the shortage of housing in congested areas. It also engages in urban renewal and new town development.

3. Historical Trends

Japan has invested a much greater share of total GDP than the United States in residential construction. [These trends will be in current dollars unless otherwise indicated; the data for Japan is by fiscal year unless otherwise indicated.] In the period from 1960 to 1987, the proportion invested in new housing and additions and alterations of existing housing averaged 6% compared to 4.3% in the United States (Villanueva, 1988). Increases in Japanese housing construction in the 1960's and early 1970's averaged 9% a year.

Summary of Trends. A close examination of historical trends indicates five distinct stages of growth during the period from 1960 to the near-present (RICE, 1993):

> ***1960 -1973***: This early period was characterized by high growth in which the Japanese economy grew at an average rate of 16.2% and construction's share of the GNP increased from 15.1% in 1960 to 24.6% in 1973.
>
> ***1973 - 1979***: The worldwide oil crisis began to have an impact in 1973, affecting the Japanese economy and private construction investment. Construction investment as a whole increased 8.9% during this period, but was lower than the 11.6% increase occurring in the GNP (RICE, 1994). Private non-housing investment experienced a very low average growth rate of 3.5%, compensated for by government investment in construction at a steady rate of 13.7% to stimulate the economy.

1979 -1985: A second oil crisis occurred in late 1978, precipitating what was, until 1990, the longest recession of the postwar period of the Japanese economy. Construction investment declined in real terms and slipped to a low 15.4% of the GNP.

1985 -1990: After the Plaza Accord of 1985, the yen appreciated rapidly, negatively affecting the Japanese economy. Export-led expansion temporarily ended. Government-stimulated domestic demand, financial deregulation, and expanded consumer spending helped end the recession and the economy began to grow again at the end of 1986 and beyond. The main impetus for this growth from FY1985-FY1990 was a considerable increase in construction of rental housing, typically small apartment-type units in non-wood, concrete/steel, multifamily structures. Although the number of housing units and total floor space increased during this period, the size of individual units declined. In this period, the 10.3% increase in construction investment exceeded the 6.0% rise in the GNP. Construction's share of the GNP increased from about 15.4% in 1985 to 18.8% in 1990.

1990 to Present: The Japanese home building industry is among the world's largest, exceeded only by the United States. During the last half of the eighties, housing starts per capita began to exceed that of the United States and other advanced nations. In 1993, for example, Japan constructed 12 housing units per 1,000 persons compared to comparable ratios of 5.1 in the United States and 7.9 in Germany (JFCC, 1995). The upgrading of the standard of living in Japan has been a byproduct of the affluence brought about by strong economic growth during the past 30 or more years. Reaction to the poor quality of housing construction built after the war, combined with the desire for a better living environment comparable to that of other advanced nations, has provided some of the impetus for new construction.

Housing Investment. The economic prosperity or "bubble" of the previous era burst in the 1990's, and the Japanese economy returned to recession because of excess inventories, negative stock exchange cycles, an unstable banking industry saddled with bad loans, and general asset deflation. Private investment in construction stagnated while the government proposed substantial increases in investment in construction, particularly housing, with a so-called Package of Economic Measures.

Housing responded to the recession much more quickly and severely than construction in general. Investment in housing experienced annual declines of 9.1% and 1.4% in 1990 and 1991 compared to small increases of 1% and 3.8%, respectively, in the same period for general construction. In the 1992 to 1993 period, however, the trend in housing investment was more favorable than the overall economy and construction in general, increasing by about 7.4%.

Japan still spends a greater proportion of its GDP in housing construction than the United States, even though investment in housing grew at a slower pace (Tables 5-2 and 5-3). Japanese housing construction amounted to ¥25.8 billion in 1993, accounting for about 5.5% of its total GDP and almost a third (30.3%) of the investment in all construction. The United States, on the other hand, invested only 3.9% of its GDP in housing construction in 1993, but it accounted for 44.3% of the value of all construction put-in-place. Investment in housing in the United States increased about 10.8 (based on construction put in place) or 13.1% (including the imputed value and rents accruing to housing as an investment good). The lingering effect of the recession in the United States was still being felt in the commercial sector, exaggerating the importance of housing investment.

Table 5.2. Japanese Gross National Expenditures (GDP) for Housing and Total Construction, Percent of Total GDP and Percent Change, 1992 and 1993 (Current Prices) (Seki, 1995)

	(¥Billion)		Change 1992-1993	
	1992	**1993**	**No.**	**%**
GDP	464,191	466,763	2,572	+.055
Total Construction	84,583	85,020	437	+.520
% Total GDP	18.22	18.21		
Housing	24,008	25,789	1,781	+7.420
% Total GDP	5.17	5.53		
% of Total Construction	28.38	30.33		
Private	22,662	24,198	1,531	+6.780
% of Total GDP	4.88	5.18		
% of Total Construction	26.79	28.46		
% of Total Housing	94.39	93.83		

In summary, the most recent trends indicate that Japan and the United States are in different stages of their economic cycles. The Japanese are still in the midst of a recession while the United States has recovered and experienced substantial growth in housing. Despite its stagnant economy, Japan has made a concerted effort to improve its infrastructure and social overhead. The impetus is two-fold. Government investment in infrastructure was designed to counter the effects of the recession. Also, some pressure was exerted in the mid-1980's by other nations, particularly the United States, to induce Japan to reduce its trade surplus. As a result, Japan was urged to increase consumption, especially in infrastructure, to provide a market for imports from other nations.

Table 5.3. **U.S. Gross Domestic Product (GDP), Investment in Residential Structures, Housing GDP and Total Residential GDP, in Current Dollars and 1987 Dollars, 1990-1993** (U.S. Bureau of the Census, 1994; Table 690)

	1990	1991	1992	1993
U.S. GDP (Current)	$5,546.1	$5,722.9	$6,038.5	$6,377.9
Investment Res. Structures	$214.6	$188.5	$222.5	$251.6
% GDP (Current)	3.9	3.3	3.5	3.9
% GDP (1987 $)	3.9	3.5	3.9	4.1
Housing U.S. GDP[1]	$454.2	$477.6	$505.5	$520.4
% U.S. GDP (Current)	8.2	8.3	8.4	8.2
% U.S. GDP (1987 $)	8.1	8.2	8.1	8.0
Total Residential GDP[2]	$668.8	$666.1	$728.0	$772.0
% U.S. GDP (Current)	12.1	11.6	12.1	12.1
% U.S. GDP (1987 $)	12.0	11.7	12.0	12.1

4. Factors Influencing Trends

It is important to understand the factors behind the impressive growth in housing investment. Growth in investment must be related to a larger context of trends in the economy and construction as a whole and to shifts in government management of the economy and related monetary and fiscal policies. Exorbitant land prices, especially in major urban areas, demographic factors, changes in real income levels, the amount of available public financing, level of interest rates, as well as rising labor costs, appreciation of the yen, and worldwide recessions were all factors in influencing housing investment during the past thirty years (Construction Review, 1989). Of these factors, five merit more detailed explanation here. Three factors (economic growth, replacement of substandard

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[1] The Housing Gross Domestic Product is the value of output or of services (shelter) provided by renter and owner occupied housing minus expenditures to intermediaries such as insurance, etc. The biggest component is provided by owner-occupied housing; the value of which is quantified as an imputed rent for owner-occupied houses.

[2] Total of Investment in Residential Structures plus the value of housing services as defined by the Residential GDP.

housing, and demographic characteristics) have a positive influence on growth, and two (high land prices and construction costs) operate to restrain growth.

Economic Growth. Growth in housing demand was spurred, first, by a strong and rapidly expanding economy. From World War II until 1980, Japan's GDP often grew at double-digit annual rates and generally exceeded 9%. Since 1985, Japan's per capita GDP has exceeded that of the United States. For example, Japan's per capita GNP in 1991 was $27,300 compared to $25,550 for the United States (U.S. Bureau of the Census, 1994). This has translated into rising real incomes, a higher standard of living, and demand for new housing. The annual growth rate in the GDP moderated a bit from 1985 to 1991, however, ranging from 4.4% to 7.5%. In ensuing years, the "bubble" burst, resulting not only in the lowest rates of growth of the postwar period, but in a real decline in GDP.

Replacement Demand. Second, there was a need to alleviate the housing shortage resulting from an estimated 4.2 million units severely damaged during World War II. Much of the housing construction initiated to alleviate the housing shortage has, in hindsight, proved to be of relatively poor quality, especially when compared to current higher Japanese standards and aspirations for a better quality of life. By 1968, the number of housing units exceeded the number of households and there was no longer any shortage of housing, but as Japan's economic growth took off and its standard of living rose, a desire to replace inadequate post-war housing added to and helped sustain housing demand. Interviews indicated that, perhaps because of dense utilization of the land, improvement of housing has occurred through wholesale replacement rather than additions. Despite efforts by the government to stimulate remodeling, only 8.3% of total investment in new housing construction in 1993 was for additions.

Demographic Changes. Third, growth in households has been a major demographic factor contributing to high housing growth rates. The baby boom and low death rates following World War II contributed to the population growth. Population continued to grow but at diminished rates. More important, however, the size of households has decreased from an average 5 persons per household in 1955 to 2.99 persons in 1990, resulting in an increasing rate of household formation (BCJ, 1992). Contributing to the trend of smaller households is the rapid aging of the Japanese population. In 1990, persons 65 years and older comprised 12% of the population, slightly below that of the United States and substantially below other Western nations such as France, Germany, and Sweden. The elderly, however, are expected to account for over a quarter of the population after the year 2000, much higher than the shares projected for other advanced nations (BCJ, 1992; RICE, 1993).

The increase in number of households combined with the constraints imposed on the availability of land have led to the promotion and development of so-called multi-generation homes, usually of three stories. In such houses three generations of a family can live together with some redundant, separate bath and/or kitchen facilities to provide a measure of independence and privacy, but also with common rooms to encourage communication among family members. The Misawa Model "O" home, for example, is a three-story wooden home designed for multi-generation use (Misawa, undated). Many of the concept demonstration homes sponsored by utilities, prefabricators, and universities are multi-generation and some with three stories have elevators to accommodate the elderly (Energy International, Inc., 1995). In the Tokyo Gas concept house called EXALT 95, for example, the three-story house is designed with the first floor for the grandparents and the second and third floors for parents and children (Energy International, 1995). Thus, three generations will live together in one house, with each generation maintaining its privacy and space.

Land Costs. Fourth, Japan's land cost for housing is the highest in the world, a factor, along with high construction costs, that acts as a restraining influence on demand. According to a study by The National Land Agency, "As of January 1994, a square foot of land for housing in Tokyo cost an average of 560,000 yen -- about $510 at 1994 exchange rates ... By contrast, a square yard of housing land went for $45 in Honolulu, $19 in San Francisco, $16 in Los Angeles, and $9 in New York (Staten Island)... Building a house and buying 2,200 square feet of land for it would cost a typical Tokyo resident about 13 years worth of paychecks." (Washington *Post*, 1995)

Much of the price and/or value of the Japanese home is in land rather than structure, and this may thwart efforts to reduce the cost of housing through advances in technology. Inflated land prices may not only have a detrimental effect on incentives to innovate, but are beginning to affect the number of housing starts. The supply of land for housing, after peaking in the early seventies, was relatively stagnant in subsequent years, resulting in a steady rise in land prices, especially in the booming years of the late eighties (RICE, 1994). Even though land prices remain comparatively high relative to other nations, they have declined significantly since the onset of the recession. Land prices for urban residential land have declined by a third since their 1991 peak. For many Japanese, the value of their homes has sunk below the amount they borrowed to purchase them (*The Economist*, 1995). As a result, about 15% of the households are unable to trade up for larger homes, and housing starts in May of 1995 were 11% below a year ago.

Housing Costs. Housing construction costs in Japan are considerably higher than in the United States, but the increasing value of the yen relative to the dollar clouds the true extent. One source asserted that housing prices in Japan are five times annual family income and that to be affordable, the ratio should be only a multiple of three. Low productivity due to inefficient management and institutional rigidity is said to be one of the factors responsible for high housing prices. Moreover, residential housing costs have escalated faster than construction as a whole and all types of building construction.

Our first-hand inspection of demonstration houses indicated that a house (without land) that today costs about $650,000 in Japan would likely cost $150,000-$200,000 in a typical suburban location in the United States. The cost of all dwellings has risen 26.1% since 1985, or 7.3 percentage points from 1991 to 1994, compared to increases of 24.6% or 5.8 percentage points for all buildings in the same time periods (Oishi, 1995). The cost of wood housing construction in 1994 was 24.3% greater than in 1985 and 9.3 percentage points higher than in 1991, while non-wood housing hardly increased at all (0.57 percentage points). Steel frame construction was the lowest in cost compared to steel reinforced concrete, reinforced concrete, and block in 1994.

The Japanese housing industry reveals many of the features of the Japanese distribution system in regard to the size and number of builders or retailers, length of the distribution channel, manufacturer's domination of many of the channels, and symbiotic relationships (Fahy and Taguchi, 1995). These characteristics have the effect of adding cost to housing because pricing is often rigid, based on private institutional arrangements rather than competitive factors.

The housing industry is composed of three main components: large housing producers or prefabricators, building material wholesalers who control many small builders, and independent small builders. The small builder who wants to obtain a steady supply of good materials often affiliates with a material wholesaler who, as a result, exerts control over the builder. The wholesalers, in turn, are controlled by very large trading companies such as Sogashosa, Mitsubishi, Mitsui, Kadatsu, etc.. It will be noted that many of these firms are also large scale prefabricators of housing, indicative of a high a degree of horizontal interaction in what is known as the *gurupu system*. These manufacturer-wholesalers influence product range, pricing, and marketing to their affiliate builders. One method of enforcing control is through the common use of the *tegata* or promissory note (Fahy and Taguchi, 1995). In the housing industry, if the builders do not have enough cash, the wholesaler will allow them 210 days to pay the remainder of the bill. The builder thus avoids cash flow problems if his house sells slowly. Wholesalers can also recommend to their affiliates *tatani* or prices that incorporate fixed margins for each intermediary in the production chain and these are not always based on competitive pricing. Like the U.S. production chain, the Japanese production chain is long and varied, but another actor, the "sub-sub" who allocates work among the subcontractors but does not manage, complicates production and adds to cost.

Aside from the economic factors contributing to high costs, many factors associated with the technology of construction add to the cost. Inefficient site assembly, involving management and coordination of many subcontractors, is said to increase the cost of construction for many small builders that predominate in the Japanese home building industry. Standard fees for architects, that range from 15% to 20% and are based on total project cost rather than actual performance of actual work, also escalate costs. Post and beam construction preferred by many small builders still accounts for about a third of new starts and is more expensive because of requirement for skilled labor, larger amounts of man-hours, and use of larger quantities of expensive wood. Home builders in outlying areas are said to be more skilled and reliable than newer builders in urban areas and have closer ties with their local market based on tradition and family relationships.

5. The Status of Japanese Housing

Housing Starts. The number of new housing units constructed each year in Japan increased steadily after World War II, reaching a record of 1.86 million starts in 1972 (BCJ, 1992). Housing starts declined markedly in 1974 due to the recession-induced energy crisis and declined again in the early eighties as a result of a second oil crisis. Subsequently, over 1.1 million units were constructed annually until 1983. Spurred by the construction of rental units, new housing starts continued to increase during the remainder of the eighties, reaching 1.73 million units by 1987 and stabilizing thereafter until 1990. Steel frame, reinforced concrete, or steel-framed reinforced-concrete construction accounted for almost 60% of new units, an increase from a 30.2% share in 1970.

A severe recession depressed housing starts sharply in 1990, and starts fell by 19.3%. By 1993, however, in response to a series of economic measures and low interest rates, new units increased substantially at a rate of 6.3% to 1.51 million (RICE, 1994). Also, recession-induced lower land prices and relatively small increases in construction costs were responsible for lower prices for apartments which increased 42.1% from the previous year. About 19% of new units consisted of additions to existing units, amounting to about 8% of the total amount invested in construction (Table 5.4).

Table 5.4. Housing Starts and Cost in Japan, 1993 (Seki, 1995)

	Units	% Total	Cost (¥ Billion)	% Total
New Construction	639,210	77.50	20,052	88.85
Additions	157,848	19.14	1,867	8.27
Alterations	27,707	3.36	650	2.88
Total	824,767	100.00	22,569	100.00

Interviews and data indicate, however, that recent public efforts to rejuvenate the economy through construction of housing may have a limited effect irrespective of favorable, lower interest rates offered by the government. Some long-term investment in technology or institutional reform to reduce construction costs may therefore be necessary to stimulate demand. Declines in land costs, although still high, have begun to have a negative effect on starts, while housing costs continue to increase faster than construction as a whole. When combined with stagnant real incomes caused by the recession, these factors may result in lackluster demand for housing in the private market and act as a barrier to pump-priming efforts. These trends may be exacerbated by substantial declines in MoC's budget allocated to urban housing in FY1994 compared to the increased allocations in FY1993.

Tenure. The rate of home ownership in Japan is about comparable to that prevailing in other advanced nations of the world. Aside from a high home ownership rate of 71.2% in 1958, the rate appears to have fluctuated in a narrow range from 59.2% to 62.4% (BCJ, 1992). Declines in ownership are the result of migration of the population from rural regions to more crowded major metropolitan areas, which have greater economic opportunity and low potential for home ownership. Although the rate was only 59.8% in 1993, the low interest rate loans offered by the HDLC attracted many customers into owner-occupied housing in that year. As a result, owner-occupied housing sales increased 11.7% from the previous year to an annual total of 537,000 units. In 1993, 38.5% of new units were rented. The significant growth of rentals, particularly in the eighties, was not only the result of high land prices, but was due to large tax deductions given to land owners who constructed rental units. Land owners could receive a 75% reduction in local property taxes and lower inheritance taxes (Construction Review, 1989).

Building Types. Despite a marked increase in construction of multifamily units, almost two-thirds of the housing stock in Japan consists of single-family detached structures. Consistent with the decline in owner tenure, single-family detached housing's 72% share of total housing in 1963 declined to an average of 65% for several years, and then decreased to 59.2% in 1993 (Table 5.5) (BCJ, 1992). Similar to home ownership, the increased migration to urban areas was a major factor explaining the decline in detached housing and the concurrent rise in apartments. So-called tenements or terraced housing of one or more stories, which were 15.1% of the housing stock in 1963, comprised only about 5.4% of all housing in 1993, while apartments, formerly 12.5% of all housing in 1963, comprised over a third of all housing units in 1993. As might be expected, congested urban regions with scarce land and high land prices have fewer detached units and more apartments than rural areas.

Housing Structure and Materials. The Japanese have a definite preference for wooden housing despite significant decreases in wood construction since World War II. Wooden houses have declined steadily from 95.3% of the housing stock in 1963 to 68.1% of all housing in 1993 (BCJ, 1992; RICE, 1994). Since 1970, however, wooden housing's share of total starts has declined from 70% to about 41% in 1988 (Construction Review, 1989). Only slightly less than a third of the wood structures in 1988 were "fire preventive," *i.e.*, the framework was wood, but the roof and outer wall surfaces were covered by fire-preventive materials such as mortar- or zinc-coated sheet metal (BCJ, 1992). Non-wood structures, on the other hand, have increased from 4.7% in 1963 to 31.9% in 1993, with most of these houses in 1993 constructed with reinforced concrete and few of block (Table 5.5).

The declining use of wood for the exterior of Japanese houses has been accompanied by sharp increases in smaller apartment units constructed of steel and concrete and a rise in prefabricated homes, particularly those constructed of steel. Material substitution was largely due to higher material costs and restrictive building codes. Since the Korean War, Japan has experienced shortages of wood, escalating its price. In 1987 the codes forbade the use of wood in the construction of three-story multi-unit buildings in urban areas (BCJ, 1992). As the costs of traditional housing rose, pre-fabricated housing became more cost competitive. Low-interest mortgage rates tended to favor larger homes that used non-wood construction.

Table 5.5. Dwellings By Type Structure in Japan (Thousands), 1993 (Seki, 1995)

		Wood		Non-Wood					
				Total		Ferro-Concrete		Block	
Total	40,853	27,823	68.14%	13,012	31.86%	11,847	29.01%	353	2.70%
Detached	24,183	22,685	93.80%	1,498	6.19%	1,093	4.52%	117	0.48%
% Total	59.22	81.53		11.51		9.23		33.14	
Tenements	2,205	1,720	78.00%	484	21.95%	276	12.52%	165	7.48%
% Total	5.40	6.18		3.72		2.33		46.74	
Apartments	14,253	3,328	23.35%	10,925	76.65%	10,385	72.86%	71	0.45%
% Total	34.90	11.99		83.96		87.66		20.11	
Other	195								
% Total	0.48								

The MoC is considering approval of light gauge steel framing for residential applications. Such approval depends on the ability of steel to meet strict guidelines that have been established by Japan for approval of new materials. The Japanese, through the Kozai Club, a steel association, have expressed an interest in obtaining information on light gauge residential steel framing from the American Iron and Steel Institute (AISI). Specifically, they would like to obtain technical data on the seismic performance of steel-framed houses from AISI. This inquiry has expanded to include the discussion of potential cooperative seismic research with concerned parties in the United States and could include dynamic tests using a large "shake table."

Type of Housing Construction.

Post and Beam Construction

In 1987, the latest year for which comparable data is available, 37.9% of housing starts were wood post and beam construction compared to 57.3% in 1973 (Construction Review, 1989). Although such housing is increasingly using plastic, metal, and other non-wood materials for walls, ceilings, doors, and floors, large quantities of smooth-grained wood is still required for exposed interior trim. The decline has occurred because traditional post and beam construction is more labor intensive and requires more skilled labor and wood, both of which have become increasingly scarce and expensive.

2x4 Construction

The new Japanese building code first permitted 2x4 construction in 1974. Consequently, the Japan 2x4 Home Builder Association was formed in 1976 to promote the 2x4 method of construction in Japan. Starting from a few hundred units in 1974, 2x4 housing was estimated to be about 52,000 units or 3.1% of all starts in 1988 and 60,000 units or 3.9% of all starts in 1993, a growth rate of about 15.4% in the 5-year period. The completion in 1986 of the Summit House, a 5,400 square foot structure demonstrating 2x4 construction sponsored by the American Plywood Association, had received considerable attention. Several advantages are claimed for the 2x4 platform method of construction and it is expected to increase further in the future because of greater resistance to earthquake and fire, cost savings in materials and labor in construction, and shorter construction cycle-times (Construction Review, 1989). 2x4 housing, for example, performed better than other types of residential construction in the Hyogo Ken Nanbu earthquake. The reasons for the slow adoption of 2x4 construction can be ascribed to inertia or tradition favoring the post and beam technique; lack of harmonization between the size of U.S. and Japanese wood building modules; problems in inspection, reinspection, and grading of U.S. lumber needed for 2x4 construction; and, differences in wood quality requirements between U.S. and Japanese builders (Construction Review, 1989). Mitsui Home Company is a leading proponent of 2x4 construction. Eighty percent of the lumber used for its 2x4 homes is imported, chiefly from North America (Mitsui, 1986).

The Housing Institute of Complete Project Management (HICPM) was established in June of 1995 as non-profit subsidiary of the ABC Development Corporation that does a significant amount of housing development in Japan. The mission of the HICPM is to foster development of advanced housing systems from abroad for application in Japan, particularly the U.S. 2x4 method of construction. The fundamental assumption is that Japanese productivity is low and that the Japanese housing industry must catch up with the United States if its housing is to become affordable. HICPM is seeking to establish a close relationship with NAHB, setting up an exchange of information to help transfer and promote U.S. 2x4 construction technology and management techniques in Japan. The OM Institute has formed an association to advance construction technology among small builders, with the objective of improving their competitiveness. Solar-related technologies as well as a Japanese modification of the 2x4 (2x3) housing construction are among the advances being promulgated.

Prefabricated Housing. Prefabricated housing units comprised about 10% of housing starts in 1973. Starting with a sharp drop in the demand for housing in 1974, prefabricated housing's share of new dwellings declined below 10% during the mid-seventies and early eighties. At this time, Japanese policy shifted away from prefabricated housing toward a flexible system of building components, emphasizing quality in an attempt to satisfy consumers' desire for more diverse housing. In the process, officials and firms evaluated the trade-off between economies of mass production and the desire for variety of design and attempted to emphasize the central role of traditional builder, advances in wood technology, modern management techniques, and rehabilitation of the housing stock. By 1982, new prefabricated dwellings' share of all residential construction increased markedly, achieving 15% of housing starts in the latter portion of the eighties (JFCC, 1995; Construction Review, 1989). In the early nineties its share rose to about 20% of the total housing stock due to increased cost-competitiveness.

The prefabricated segment of Japan's housing is a heavy user of steel which favors large scale investment in capital equipment and automation. Steel frames have traditionally accounted for 62% of all prefabricated houses while wood panels and concrete systems have accounted for 22% and 16% respectively (Mathieu, 1987). In the interests of trade policy Japan apparently urged the use of steel in prefabricated housing (Construction Review, 1989). In 1987 practically all of the 5 largest prefabricated producers used steel frames, requiring an average of 4 to 7 tons of steel per house (Construction Review, 1989). In 1987, only a little more than one-quarter of the prefabricated housing starts were of wood construction. Multifamily units' share of the total prefabricated housing market has been diminishing while semi-detached share has maintained steady at slightly over half.

In general, Japanese factories are highly automated, using computer controlled production processes. Some use computer aided design (CAD) and many use computer-aided-manufacturing (CAM), but in 1987 integration of the two was still being explored. Labor accounted for about 15% of total cost for prefabricated wood houses, but was slightly higher for concrete and steel houses (Mathieu, 1987). Cycle-times for prefabricated homes ranged from 35 days to 50 days compared to conventional housing, which could take as long as 6 months. Although the Japanese could manufacture housing in a short period of time, site work was more time consuming because most plumbing and electrical work was done on-site rather than in the factory, and as many as 36 trades could be involved in work at the site.

The production of prefabricated housing is concentrated in large firms. The top five firms produce 80% of all units, while the top ten produce 94%. Sekisui House, Misawa Homes, Daiwa House, National House, and Sekisui Chemical have consistently been the leading firms and are large, diversified corporations. Only Misawa devotes its production exclusively to the housing industry. Sekisui House, Daiwa House, and National House each produce metal frame units with precast concrete composite exteriors, Misawa Homes produces both modular wood panels systems and a ceramic modular system, and Sekisui Chemical produces a modular box system.

Misawa claims it is difficult for factory-produced housing to break into the Japanese housing market because small builders predominate and have extensive family and local relationships (Carlson, 1995). The structure of the Japanese residential construction industry, with a large number of small, traditional firms and a few large diversified corporations, is similar, in part, to the United States. According to one estimate, about 170,000 small building firms averaging eight units per year account for more than half the total housing market (Mathieu, 1987). This compares to the structure of the U.S. housing industry, in which small builders producing less than 25 units per year accounted for 81% of all units produced in 1993, compared to 58% in 1969 (Ahlwalia, 1994). Despite the adverse structure, factory-produced homes have risen steadily over the past 30 years.

Misawa Homes is said to have produced more than 45,000 housing units in 1994 (Carlson, 1995), but in interviews they acknowledged a production of only about 20,000. It is still one of the five top prefabricators in the world based on volume (Carlson, 1995). Misawa now has 19 factories, of which 17 produce panelized wood homes and components while two produce steel-frame modulars with precastable autoclaved light weight ceramic skins (PALC).

Misawa was the first firm to abandon the traditional, heavy post-and-beam construction in favor of stress-skin panels, fitted together with fasteners and adhesives at the site. Materials were chosen for the lightest weight possible in relation to maximum strength and space. This glue-nail, stressed skin lattice panel, although not new to the United States, was quite innovative for Japan.

It is not clear what progress Misawa has made in introducing to factory-built housing the mass customization methods of production originally developed by the Japanese automobile industry. Ten years ago Misawa produced large volumes of similar-sized panels, operating with an inventory on the factory floor. Its new factory is capable of customizing production to suit the tastes of individual customers and maintain large volumes. Whether this was done with minimal, just-in-time inventory procedures is not exactly clear. Its newest plant "turns out 4,000 different styles of wall panels" and is almost completely automated, yet it is still capable of producing "4x8 foot panels about every 60 seconds" (Carlson, 1995). Misawa, however, appears to be dealing with the trade-offs between the uniformity of mass production and the customer's desire for individuality that seemed irreconcilable in the mid-seventies and caused a shift away from factory-produced housing. Misawa may be on a path to solving this dilemma but whether it has completely reached that goal is not clear from available literature or interviews. Misawa also demonstrated sophisticated CAD techniques to help the customer visualize and choose alternative designs, but such designs do not appear to be directly linked to development of a "cut list" of components and parts used in specifying actual production.

Housing Size. Given that Japan has a high population density, it is not surprising that housing size and occupied density or persons per room is one of the most sensitive housing issues in Japan. Despite substantial progress, the size of units and related goals appear modest when compared to those of the United States and other Western nations.

The average number of rooms has been increasing from about 3.9 in 1963 to 4.86 in 1988, while the number of persons per household has declined from about 4.2 to 3.18 in the same period (BCJ, 1992). Concurrently, the average floor area per housing unit has increased from 71 m^2(163 ft^2) in 1963 to 89.3 m^2 (960.2 ft^2) in 1988. The size of both renter- and owner-occupied housing improved during the period. As might be expected, however, owner-occupied housing experienced the greater increases, rising to 6.03 rooms per house and to 116.8 m^2 (1,255.9 ft^2) per unit and the smaller declines to 3.64 persons per household and 0.84 persons per room in 1988. The floor area per unit of rental housing increased only slightly during the period to 44.3 m^2 (476.3 ft^2) in 1988.

Changes in annual average unit floor area of new housing starts showed a more irregular pattern of growth and decline. In almost all the 1970s, there was a steady growth in average floor area of residential units. Due to the large surge in rental housing with lower average floor areas in the 1980's, however, the average floor area of new housing declined with the exception of only two years of slight growth (Construction Review, 1989). In 1993, the average floor area of housing starts increased by 4.2% over the previous year to reach a high of 89.3 m^2 (960.2 ft^2), largely the result of an increase of larger owner-occupied and speculative housing (Construction Review, 1989). Owner-occupied housing decreased slightly in size to 137.1 m^2(1,474.1 ft^2) and size of rental units increased to 51.1 m^2 (549.4 ft^2).

Japan's MoC Sixth Five-Year (FY1991-1995) Housing Construction Plan has targeted an increase of the average floor area per house to 95 m^2 in 1995 (BCJ, 1992). With an average floor area of 92.6 m^2 (996 ft^2) per dwelling and 30.7 m^2 (330 ft^2) per person in Japan in 1993, this goal in the plan appears well on the way to being achieved. These latter figures compare to 154 m^2 (1,647 ft^2) and 61.8 m^2 (664 ft^2) for all housing in the United States (JFCC, 1994).

Home Automation. Japan is one of the most active international players in the home automation (HA) market. Many Japanese companies including Matsushita, Toshiba, Sony, Sanyo, NEC, Sharp, Hitachi, Mitsubishi Electric, Nippon Telegraph and Telephone (NTT), NHK (Japan Broadcasting Corporation), and Oki Electric offer house-automation systems for the Japanese market (Wood, 1988). The objective of the Japanese approach to HA systems is to integrate entertainment, security, telephone, and sometimes television. Toward this end, the level of Japanese public and private investment in HA reached about $145 million in 1988. After resolving some differences in point of view, the Ministry of Post and Telecommunication (MPT) and MITI, in cooperation with the Kensai Industry Electric Industry (KEC) trade group, defined a standard for a home electronic bus (HEB) (Kotch, undated). The HEB refers to the transmission lines or media installed in the home to transmit information to and from various input devices, sensing monitors, and appliances. The standards refer to the system of control designed to maintain compatibility in communication and degrees of intelligence among various devices. The HEB, therefore, was not intended to support specific products, but was to embody standards that could accommodate all types of future technologies, similar to the CEbus standards developed by the Electronic Industry Association in the United States (Kotch, undated). Japan actually became the first country to define such a standard, in which top priority was accorded rules for hard-wired connections to allow information exchange in the house.

Originally, the Home Bus Standard (HBS) was based on four twisted pair wires and two coaxial cables. The Electronic Industry Association of Japan (EIAJ), reconciling the proposals of MPT and the Radio Engineering and Electronics Association (REEA), defined the communication protocol for HBS in 1987 (Kotch, undated). Some claimed, however, that the protocol was limited as it covered only the lowest three layers of the International Standard Reference Model of the Open Systems Interconnection (OSI) established by the International Standards Organization (ISO) of the United Nations for intercompatibility of communication and therefore dealt only with the processing of information independent of its meaning. Moreover, the proposed single connection was expensive and used a bulky plug. Others wondered why so many wires were needed, since technological trends usually favor simplification (Egis Group, 1988).

Individual manufacturers have been cautious about adopting the HBS standard. Most manufacturers of consumer electronics and electrical appliances have at least one HA system in their product lines. In many cases Japanese product manufacturers have developed HA systems around the security entry access communication systems (door phone) and rely on modular additions to the relatively simple security systems. Only Toshiba immediately adopted the HBS. KEC supported a single coaxial cable for HBS, which was highly expensive.

NTT is aggressively marketing its Howdy SX-Series home telephone system and is said to have sold 1.2 million units in 1989 (Egis Group, 1990). NEC has developed a home power line system called Spectrum Ac that uses spread spectrum technology to control noise on the wires by sending data on several frequencies at once. A government/industry group called the Electric Power Line Information Transmission Research Committee has investigated and established specifications for this technology. SECOM, the largest security company in Japan has backed a multifunction system that combines dedicated phone lines, customized mobile equipment, and various sensors. Matsushita Electrical Industrial Co. (MEI) is said to be the top-ranked HA equipment supplier in Japan (Egis Group, 1990). While supporting the official HBS and its own High Amenity Life (HAL) system, MEI has also sponsored, with Philips, a Domestic Digital Bus standard called D2B. Originally developed by Philips for control of audio and video systems, it has been reluctantly adopted as part of the Japanese HBS and has been recognized as an international standard for audio and video systems. MEI's Savtec system is a relatively complicated system that accesses television and electric power lines while sending digital data over coaxial cable, as well as over electric and telephone lines (Egis Group, 1990). In 1989, Matsushita Electric Works, Ltd. separately from MEI constructed the Intelligent House System (IHS), an experimental house capable of testing new products and systems (Energy International, 1995).

The University of Tokyo, in cooperation with about 18 companies, sponsored a $7 million house to demonstrate a computer-networking concept called TRON, or The Real-time Operating system Nucleus. It integrates independent appliances and HVAC systems using sophisticated sensor and monitoring systems, using a 32-bit microprocessor to control the flow of information and allow it to be processed in real time -- instantly as it is generated. The Japanese government has also subsidized TRON. The house is intended to be a setting for experimental home automation systems rather than a prototype house for commercialization (Energy International, 1995). Other demonstration houses that incorporate HA systems are the Ideal NEXT House (includes security of house, operation of appliances, information gathering, and monitoring of air quality) and the NEXT21 (monitors energy use in a multi-residence complex) house in Osaka sponsored by Osaka Gas, the Experience of Amenity Life in Tokyo (EXALT) 95 house in Tokyo, sponsored by Tokyo Gas (monitors lighting, equipment usage, sliding shutters, and centralized meter system for gas, electricity, and water), and the Energy Management House (EM-House) an all electric house sponsored by Kyushu Electric Power (KEP) (automated blinds, lighting, home security, and an electricity load control system) (Energy International, 1995).

6. Residential Energy Conservation

Japan imports 80% of its primary energy and, as a result, energy conservation has become an important issue. Electricity prices in Japan at 17.2 cents per kwh are 2.5 times higher than the U.S. average price of 6.9 cents per kwh (Energy International, 1995). Consequently, paybacks for residential energy conservation are much shorter than in the United States, presuming a similar initial price. The disparity between the cost of electricity and gas is not as great as in the United States. The electric heat pump, therefore, has found wide acceptance, and the gas industry has been impelled to become more proactive in promoting new technologies, such as the gas engine heat pump. From the first energy crisis in 1973 until 1986, total energy consumption showed little growth despite the expanding Japanese population and economy. Energy consumption increased markedly as prices stabilized and the Japanese government's economic policy shifted away from export, devoting more attention to the domestic economy.

Instead of prescriptive energy codes, Japan relies on suggested standards and guidelines, but these appear to be observed as enforceable regulations. The Japanese government originally published a "Decree of Energy Conservation" in June of 1979, designed to encourage better use of insulation materials, control of air infiltration, waste heat recovery systems, and zoned heating and cooling. These regulations, revised by the MoC in February, 1992, now consist of two components: "Standard for Builders Judgement of Energy Conservation for Housing" and "Guide for Energy Conservation for House Designers and Builders." "The standard specifies heat loss factors, insulation levels, and solar radiation incidence factors that builders and manufacturers are encouraged to achieve on a best effort basis. The standard also includes an airtightness guideline." (Energy International, 1995) Loans are offered as incentives to those who comply with the guidelines.

Japan's research program on energy technologies was first organized in 1974 with the initiation of the "Sunshine Project." New emphasis on energy conservation was provided by the "Moonlight Project" in 1978. By 1989, an environmental technologies program was added. In 1995, all three efforts were consolidated into a "New Sunshine Program" with the objective of generating sustainable growth through the solution of energy and environmental issues (Demand-Side Technology Report, 1995). One project calls for the development of a stationary high-efficiency lithium battery in the 20-30 kW range that could be used for load management. This battery would have an energy density three times that of a lead-acid battery and a service life of 10 years, with immediate research focussing on electrode materials and stable electrolyte solutions. Other research projects will focus on the uses of waste heat in four areas: heat recovery technology, heat transportation and storage technology, heat supply and use technology, and overall system design strategy. The project will consist of 36 R&D contracts funded at a level of about $500 million. The program also includes research efforts in renewable energy including solar.

Renewable Energy: Solar Technologies. In 1994, the Japanese government issued for the first time basic guidelines for renewable energy policy and implementation. Japan's declining share of the world photovoltaic (PV) module production was the impetus for this effort. From 1986 to 1994, the U.S. share of world module production increased from over one-quarter (27.3%) to over one-third (35.2%) while Japanese share of production decreased from just under half to a bit over a quarter. At the same time the total volume of production increased by 180% (Photovoltaic Insider's Report, 1995b; Photovoltaic News, 1993). Although PV power generation is not a major priority area, the national government is increasing the amount of direct subsidies for PV applications.

The program to install PV systems on residential rooftops is doubling from 600 systems valued at ¥2 billion in 1994 to 1200 systems valued at ¥3.3 billion in 1995 (Photovoltaic Insider's Report, 1995c). The government will pay up to one-half the price of the PV system (rated at up to 3 kW peak power) or $27,000 per house and this subsidy will remain in effect for the first 3 years of the program and then step down to zero after 7 years (Arthur D. Little, 1995). It is said that by the year 2000 MITI desires to have 60,000-70,000 such units installed, generating 200 megawatts of power (The Quad Report, 1993). Under this subsidy program, Solarex Corporation, a U.S. PV producer, is working with its authorized distributor in Japan, MSK, to supply PV panels for 100 to 300 homes constructed by Misawa (Photovoltaic Insider's Report, 1994). A typical installation is illustrated in a demonstration called Eco-Energy House which features a PV roof employing custom glass-superstrate polycrystalline PV modules to create an integral PV sloped residential roof deck. Despite these government efforts, a recent study by a Japanese research group concluded that PV systems would have to be subsidized up to 75% for as much as 40 years before PV would have an even marginal impact on power generation (Photovoltaic Insider's Report, 1995a).

Other innovative Japanese residential PV projects include two amorphous silicon PV modules developed by Sanyo that are integrated into the building by being directly mounted on the roof deck Arthur D. Little, 1995). One, consisting of curved tile modules about 305 mm^2 designed to blend with traditional Japanese ceramic roof tiles, is very expensive to produce and install. The second module is a flat-panel shingle about 1.1 m by 0.54 m, with an active area of about 0.5 m^2 which did not integrate as well with the typical Japanese roof style. This module has been modified to amorphous silicon on a glass superstrate with different dimensions and small plug-in connectors that integrate better with the roof. It has been installed at a PV test site at Rokko Island operated by Kansai Electric. Kandenko Co., Ltd., has developed large-area, single-and poly-crystalline PV modules 1.3 by 0.650 meters as a stand-off mounting system above the existing roof.

In other experimental houses, PV is used as an ancillary system to provide electricity support and is not a main feature of the house. The Energy Management (EM-House), an all-electric experimental designed and built by Kyushu Electric Power Company is supported in part by 2 kW output PV system on the roof. The Ideal House NEXT sponsored by Osaka Gas uses a PV panel to power a fan in the attic that exhausts circulating cool air in a unique ventilation system. In Osaka Gas' NEXT21 multifamily house a photovoltaic panel is used with a gas-fired fuel cell generation system for electricity support.

Many of the experimental Japanese innovations in residential energy conservation involve low-tech, passive solar systems either operating independently or in combination with more active and exotic technical systems such as PV, fuel cells, and ground or water source heat pumps. The OM Solar Association has patented a passive solar system used in combination with PV that is said to be complicated compared to conventional systems. The system uses a glass surface on the roof to collect heat which is transferred via air in a channel under the roof and a rooftop semi-circular duct to an air regulating unit or OM handling box. The air regulating unit is the principal mechanical portion of the system and consists of dampers, a fan, and a heat exchange coil for hot water, that controls the flow of air into a vertical duct, providing heat to a concrete slab and fan convector under the floor or to an exhaust vent during the summer. The PV provides power for the air regulating unit and other applications in the house. On hot humid nights the system does not bring down the temperature but reduces the humidity. In such situations it might be more effective to use PV generated electricity to power an air conditioner. The association has patented software that conducts computer simulations that detail and forecast the energy efficiency and thermal requirements of houses based on their site, construction, and local climate characteristics.

Other Energy-Efficient Technology in Demonstration Homes. Manufacturers and utilities have incorporated a number of hardware oriented energy conservation innovations related to heating and cooling into their construction of concept houses (Energy International, Inc., 1995):

- The NEXT house sponsored by Osaka Gas uses a unique thermal well system for heating and cooling consisting of a series of underground heat pipes well below the home backed up with a gas engine heat pump. Cooling of the interior spaces is achieved by circulating cold air from the wells through the outer walls. A multi-hole concrete floor in one room is cooled by a thermal well in the summer and heated directly by the sun in the winter.

- Osaka Gas' NEXT21 multifamily house uses a fuel cell system to supply an absorption heat pump air conditioner in the first residential application of a fuel cell in Japan. Waste water heat is recovered through a waste water pool.

- In the Tokyo Gas house, HVAC consists of a gas engine heat pump with a duct distribution system, a hot water wall and floor heating system, and unique "Amenity" air conditioners. These units prevent overcooling by first dehumidifying the air and then warming it with a water heat exchanger. The roof is constructed in two layers separated by an air chamber to improve insulation and release hot air in the summer.

- Matushita's IHS house emphasizes lighting using new generation flourescent lamps and vocal control of lighting in one room.

- The Kansai Electric house incorporates a desiccant-type dehumidifier that uses solar heat for desiccant reactivation. A PV panel powers the ventilation for the desiccant system in the summer. Kansai in cooperation with the Sharp Corporation has developed solar-powered inverter air conditioners with a PV array for generating electricity and an indoor unit for cooling. Waste water is collected and filtered for use in bathrooms and sprinklers and waste water heat is absorbed in a restoration tank which maintains the hot water supply.

- The E-M house sponsored by Kyushu Electric Power uses a multi-split heat pump system combined with a boiler for both HVAC and the hot water system, achieving a coefficient of performance (COP) of 3. COP is the ratio of the net heat output (or net heat removal for cooling) to the rate of total energy input under designated rating conditions as specified by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE).

Appliances. Japan has six climate zones and its weather is almost as variegated as in the United States. For example, central Honshu's weather is very similar to the climate in the U.S. Northeast, Mid-Atlantic, and Midwest states. Much of Japan is a good candidate for cooling. It is not surprising, therefore, that some of their innovations, especially those devoted to export, have been devoted to air conditioning. Matsushita, for example, ranks fifth in the U.S. market for room air conditioners, garnering 6% of the market in 1991 compared to 3% in 1988 (Appliance Manufacturer, 1992). Japanese expertise in microprocessors, electronic controls, and associated miniaturization has been applied in Mitsubishi's ductless split air conditioning system, with its slim outdoor and indoor units and remote control. Such a system adapts to variation in comfort requirement in various rooms of the house instead of being governed by rigid structural requirements of a ducted system.

Appliances tend to be smaller in Japan and use fuzzy logic for control. The preference is for variable speed heat pumps. As a result of national policy, zoned heating and cooling is standard, constraining the market for central air conditioning. The term room air conditioner in Japan is used to denote small split-type air conditioners and heat pumps for residential use. As in the ductless systems described above, an outdoor compressor, fan, and air coil unit is connected to several fan coil units, each serving a room. Such air conditioners more nearly approximate what is called unitary air conditioners in the United States. Following the recession in the early eighties, heat pumps experienced a 90% growth in a 5-year period while the growth of cooling only air conditioners declined and stabilized. In 1990 heat pumps comprised 71.5% of total sales and over half of these were variable speed heat pumps driven by inverters (Energy International, Inc., 1995).

In Japan, the quality-conscious consumer chooses the HVAC equipment, in contrast to the builder or HVAC contractor who are the key decision makers in the United States. The consumer appears more willing to bear the higher first cost of the inverter-driven variable speed heat pumps. Such heat pumps are seen to have the advantages of quiet operation, better comfort through more uniform temperatures, the convenience of excellent Japanese electronic controls for modulation, and the ability to operate at the different power line frequencies that are found in various cities of Japan (Energy International, Inc., 1995). The kerosene heaters and under-the-carpet resistance heating that is acceptable in Japan would not be considered innovative or acceptable in the United States.

Home appliances such as washing machines and refrigerators are also much smaller and use less energy in Japan compared to the United States. The energy use of refrigerators, for example has decreased by over a third since the first energy crisis in the mid-1970's (Energy International, Inc., 1995). Fuzzy logic control, originally conceived in the United States, is becoming very important in many of these appliance, including vacuum cleaners. Fuzzy logic uses artificial intelligence data and rules to vary control of the appliance to suit changing conditions.

7. Summary and Conclusions

The people of Japan today are still largely housed in single family wooden houses and have a definite preference for post and beam construction, but trends in annual housing starts reveal that the number and proportion of multifamily houses of concrete and steel, prefabricated steel houses, and rental units have increased markedly with increasing urbanization and escalating housing prices. U.S. 2x4 wood construction is still in the incipient stages of growth due to inertia, differences between United States and Japan in regard to size of modules, wood quality, and inspection requirements.

On a per capita basis, the market for new housing in Japan is larger than any of the advanced industrial nations. Factors favoring growth in new housing and investment in new technology have been the substantial economic growth, ample government funding, and rising standards of living coupled with the need to replace housing destroyed and built after the war, increased rates of household formation, and an aging population. On the other hand, the high cost of land and construction has hindered further growth and challenges the Japanese to redirect research and development toward producing more cost-effective, affordable housing.

Rising housing costs and the large volume of housing demand in Japan, combined with a more cohesive and geographically concentrated market for housing, have provided a more favorable economic climate for a large and increasing investment in, and acceptance of prefabricated housing in Japan, compared to the United States. As a result, Japan is probably ahead of the United States in the scope and variety of off-site housing production technology. House manufacture is still relatively expensive, however, and the potential for further improvement exists in improving assembly productivity on-site, linking customer-oriented design to production specifications, and instituting mass customization production techniques. Eventually, however, the fact that much of the value of Japanese housing is in the land limits their capability to reduce the cost of housing through advances in technology.

Japan is often cited as being an energy-efficient country characterized by a low per capita energy use or low ratio of energy use to GDP. Although the increasing per capita energy use for travel induced by growing urban sprawl and car ownership belies this image, the Japanese have made some impressive achievements in the adoption of residential energy conservation technologies. They have encouraged and embraced solar and other renewable energy technologies, zoned heating and air conditioning, and the use of smaller, more efficient variable speed heat pumps and other appliances that incorporate energy-saving fuzzy logic controls. Japan still lags behind the United States, however, in the production of PV and in research and innovation in the growing area of amorphous PV technologies. Because of Japanese expertise in electronics hardware and control, they have been pioneers in the adoption of uniform standards for home automation. Despite these efforts, the large number of applications of home automation in Japan have been piecemeal and incremental adaptations of existing proprietary systems. U.S. proficiency in computer hardware and software technology is responsible for more innovation in home automation, but it may lag behind the Japanese in volume of applications

D. Public Works

1. Definition

Under the Japanese definition, public works construction is composed of five broad categories:

- national land conservation (erosion control and flood control),
- primary industry (agriculture, forestry and fishery),
- industrial infrastructure (road and others),
- community environment infrastructure (*e.g.*, sewer systems, parks, schools, hospitals, libraries), and
- housing and other accommodations.

The category "community environment infrastructure" accounts for about one-half the total public works expenditure and the sub-category "roads" accounts for another one-quarter. Around one-quarter of the public works investment is funded by national government authorities such as central agencies and quasi-public corporations and the remainder by regional authorities.

2. Scope

The contracted volume for public works has seen a healthy expansion in recent years, some of which reflects a deliberate decision by government to overcome the decreased construction investment by the private sector as a result of the lagging economy. In 1993, the public sector accounted for 44% of the total construction investment of ¥85 trillion ($770 billion at a 1993 exchange rate of *ca.* ¥110 = $1.00) and the remaining 56% by the private sector. On the other hand, in the United States with a 1993 construction investment approximating 60% that of Japan in 1993, the public sector accounts for about 28% and the private sector 72% of the investment. Of the total construction investment in Japan, 55% went into building projects and 45% into civil engineering works. The ratio in the United States is approximately 67% buildings and 33% civil engineering works and reflects the higher degree of infrastructure development in the United States. The private housing market in Japan accounted for about 28% of the total construction investment as contrasted with about 44% in the United States. In the case of public civil engineering works and public non-housing building, Japan expended about 42% of the construction investment as compared to 28% in the United States. Private expenditures for civil engineering works amount to roughly 9-10% of the total construction investment in both Japan and the United States (JFCC, 1994).

Despite the higher proportional and absolute investment by Japan in public works activities, there are areas where the infrastructure development lags those of other developed countries. Sewerage is probably the most notable in that existing systems serve less than one-half the population. Roads are another area where additional development is needed; the percentage of miles paved is about 20% less than in the United States. The percentage of the Japanese population having an adequate water supply lags that of other developed countries. In urban park area, New York and London provide about 10 times more area per capita than is available in Tokyo (JFCC, 1994).

3. Government Role

The Ministry of Construction (MoC) plays a centralized role in the public works arena. There is no counterpart organization in the United States; equivalent responsibilities are distributed between various agencies of the federal government, state governments and municipalities. The MoC has jurisdiction over private as well as public sector construction and oversees the nation's public sector public works projects.

Another major function of the MoC is the jurisdictional responsibility for approving the incorporation of new technologies developed by private contractors into public as well as private work. Once approved, those technologies become public domain information. Unlike the United States, Japan has a national building code, which is developed and administered by the MoC. This in itself promotes a wider use of new technology, once instituted. On the other hand, if the focus of the MoC were not oriented toward promoting technology advancement, the centralized building code could prove to be a handicap to other jurisdictions with an advanced outlook.

The MoC's sponsored research is directed toward resolving problems. In this connection, the MoC operates two research laboratories: the Building Research Institute (BRI) and the Public Works Research Institute (PWRI). Although government-sponsored, these laboratories work in close partnership with contractors, consultants, institutes and academe.

In addition to the MoC, the Ministry of International Trade and Industry (MITI) develops an environment for the creation of wealth (including the construction industry) with jurisdictional responsibility for technological development. Under this aegis, MITI sponsors research usually on the basis of 100% for basic research and 50-67% for near-term product development. For the latter, the remainder is usually funded by private contractors. It is evident that the Japanese government plays a heavy role in regulating the construction industry as well as making a substantial investment in advancing technology. In making research investment decisions, there does not appear to be a distinction as to whether the benefits accrue to the private or the public sector, mainly because there is so little separation.

Although it may be construed that MoC and MITI have overlapping responsibilities in regulating the Japanese construction industry, it appears the two organizations maintain a close working relationship thereby avoiding interface conflicts. Their authorities apply equally to public and private construction.

There is also a Ministry of Transport (MoT) which controls ports and harbors and operates its laboratory, the Ports and Harbors Research Institute (PHRI). While the MoT is responsible for transportation planning, the standards for tunnels, highways and railroads are controlled by the MoC, and the related research is conducted by the PWRI.

4. Procurement Practice

Traditionally, the larger Japanese construction firms maintain a design capability, and most contracts in the private sector are design-build. Design-build has not been used in the public sector. Also, the firms have aligned themselves with specific private sector clients. To a certain extent, such alignments also prevailed for public sector work through the designated competitor system. As a result of the scandal in public sector construction procurement, large contracts being obtained by central government entities will be procured through an open competitive system (See Section II.C.2.). Although the prefectures have been enjoined to follow similar rules, they are not obligated to do so. This open competitive process will likely have an effect in altering the approach Japanese contractors take in seeking work and may level the playing field for participation by other and smaller contractors. It also could have a negative effect with respect to fostering innovation, as the opportunity for obtaining enhanced quality and incorporating advanced technology will be diminished by virtue of the tendency to focus on the lowest bid price with its consequent lowering of the profit margin. With the difference in procurement practice between the public sector and the private sector, it would appear that potential profitability would further favor the large contractors preferring to do work for the private sector.

Although billed as an open competitive bidding procedure for construction contracts in the public sector, there is a prequalification evaluation requirement to participate in the bidding. This includes such factors as business capacity, past record on similar projects, availability of engineers with requisite qualifications and experience, and disqualification criteria. These qualification requirements are published in an objective and specific manner for each project. The same procedure prevails for selection of design and consulting services above ¥73 million ($880,000) if price is the only criterion. In conjunction with the reformed bidding and contracting procedures for public works, foreign firms are not to be discriminated against in any aspect, although the qualification requirements might be more difficult for non-Japanese firms to meet.

In the United States public sector, especially the Federal sector, incorporating new technology has been hampered by various procurement rules, and in some cases statutes, which largely dictate open competitive bidding. This tends to diminish the opportunity for government officials to incorporate innovations, as the principle of sharing risk is difficult to define in such contracts. It may be of value to track the Japanese experience under their new rules to determine whether there will be a marked difference from the previous history of adopting advanced technology and methodology. Preliminary indications from the contractors are that they can live with the system and do not see that the reformed system in itself will reduce their dedication to investing in new technology. However, should profit margins indeed decline, there will be a test of the companies' resolve to maintain their R&D institutes.

5. Contract Payment

Under Japanese public sector contracts, 30-40% of the scheduled contract work for the year is paid at the beginning with the remainder, except for retainage, being paid at the end of the year. This approach to payments is quite different from government payments in the United States, which are usually monthly based upon the value of the work completed with a specified percentage being retained. On the other hand, private sector contracts in Japan generally follow a rule similar to that for U.S. Government contracts.

6. Public Works Research

Research and innovation in the public works arena covers a wide range of diverse activities: environment, river and coastal hydraulics, dams, water quality and sanitation, roads and bridges, and earthquake disaster prevention. Japan has a long history of adapting technology for these applications from abroad to its particular conditions. Research and development were actively undertaken by the central government and local entities both as a means of catching up and favoring domestic companies. Private sector R&D also grew in conjunction with the contracting of public works projects. This interest in R&D, mostly directed toward development, is deeply inculcated in the fabric of the MoC and private contractors.

A sampling of the types of research are described in Sections IV and V of this report and in Appendix A. The most notable efforts have been in the following areas:

- Underground construction. This is a subject of heavy investment because of restricted land availability and soft ground conditions in much of the country. The Japanese companies have also been highly innovative in refining shielded tunnel boring machines (TBM) (Section IV.D). In addition, the government is making a major investment over an extended period to develop design and construction systems pertinent to underground structures.

- The use of various carbon fiber reinforced plastics has received much attention, with a number of products tested and approved. These are especially useful for retrofitting damaged concrete structures and strengthening existing structures (Sections IV.B and IV.C).

- A unique process was developed for controlling corrosion in the splash zone of the bridge piers of the Trans-Tokyo Bay Highway Project by hot bonding a titanium alloy to the steel member (Section IV.B.4).

Other innovations mentioned as under development, but for which the panel had no further information, included:

- pressurized or vacuum sewage systems in lieu of gravity,
- monitoring techniques to forecast landslides and pyroclastic flows,
- porous asphalt surface layers to add drainage to pavement surfaces, and
- techniques for seismic isolation and control of infrastructure.

VI. CONCLUSIONS

The Japanese construction industry is large, solid, and progressive, driven by national expenditures on infrastructure and construction in general that are twice the percentage of their GNP as is spent in the United States. The Japanese lead the world in the modernity and quality of their constructed facilities, in the size and quality of their physical research laboratories, and in their private and public construction R&D investments whose sum is an order of magnitude greater than that in the United States.

While the government research institutes contribute substantially to generic construction technology development, the majority of construction research is performed by industry using its own funding. The corporate R&D institutes are made possible by a close relationship between the construction companies and the government Ministry of Construction (MoC), which assures that those companies with R&D establishments that support the Ministry's 5-year plan for R&D will gain access to the vast public works program. Other forces driving investment in R&D are its use as a competitive marketing tool in the domestic market, improvement in public health and safety, the need to construct facilities underground and in constrained spaces, the need to make production more cost-effective, a conviction that the development of new, more refined products and services is the only way to expand the domestic market, and the maintenance of an active, highly-employed, and productive work force. Direct profit on intellectual property from research investment, surprisingly, is not a common motive.

Research and development by the Japanese engineering-construction firms has no counterpart in the United States. The large Japanese firms have laboratories of a scale larger than the government laboratories of Japan or the United States. However, the work in these laboratories is not equivalent to that in U.S. government or university laboratories. The work appears to be aimed at improving their designs and construction practices, more at developing capabilities, improving quality, and testing of materials or specific applications of products or processes than at producing new or unique knowledge.

The domestic recession and the strongest yen in history are having a large, harmful effect on the construction industry in general and on the R&D institutes in particular. Although public works investments have been increased to offset private sector declines in contracts, the R&D institutes are currently largely understaffed and underutilized due to budget reductions. Some products noted in visits five years ago have migrated out of the Japanese laboratories into the market-place, few if any new research initiatives are underway. The panel saw no totally new construction technologies or innovations during this visit. Rather, the large Japanese contractors are refining those introduced earlier and applying lessons learned, including holding off on some high visibility innovations as costly and unproductive in today's circumstances. A prolonged recession could extend the hiatus in R&D advances and, in the worst case, might render the R&D institutes unaffordable in their current role.

Two additional factors may change conditions for research and innovation in the Japanese construction industry from those observed in the 1990 predecessors to this study. First, procurement scandals in 1993 have led to a revised, more competitive and transparent procurement system in the public sector and may subject engineering-construction firms to competition from contractors who don't invest in R&D. Second, the catastrophic Hyogo Ken Nanbu (Kobe) earthquake in 1995 has revealed needs for improving construction practices and for retrofitting existing constructed facilities.

The JTEC and CERF reports found the Japanese industry surpassed the U.S. industry in most construction technologies. This panel observed that the relative strengths of the two countries have not changed since those 1990 appraisals. The Japanese have built an integrated approach toward incorporating new technologies into their design and construction projects and lead in such areas as large-scale bridges, tunnels, soft-ground construction, congested area construction, high performance construction materials, automated "jack-up" erection techniques for high-rise buildings, and computer visualization of residences for prospective buyers. Operating under a different set of cultural and economic circumstances, the United States leads in computer integration of design and construction, the economy and flexibility for evolutionary use of constructed facilities, and global positioning systems.

The Japanese have developed the advantageous ability to get more out of a given technology - to expand the capability of an existing technology, but not necessarily develop a new technology. We should remember that it is part of the Japanese culture to extract the most from their resources - be it land, food, energy, technology or knowledge - and that is both highly commendable and a warning to less aggressive competitors.

The Japanese MoC has responsibility for regulations for private and public construction and provides mechanisms, often multi-year in length, for assessment of innovations and for their acceptance by regulators. Since the United States lacks a formal process recognized by federal, state and local regulatory authorities, nationwide acceptance is generally slower in the United States.

The Japanese industry has taken strong measures to increase the pace of its internationalization. Should the yen return to the higher exchange rates of recent years, Japan is well-poised to increase it's currently few successes in the international competition.

The panel observes that construction R&D in the United States is also poised at a type of turning point, the possibility of a turn for the better. The economic challenges brought about by the re-sizing of the defense industry, the growing concern for the environment and the need for adherence to the principles of sustainable development are forcing new alliances between previously unacquainted industry segments. This is creating a healthy breaking down of old paradigms and is helping forge new R&D partnerships between diverse groups from government, industry and academia. It remains to be seen whether the Federal political climate will continue to support this, conceptually and financially, and whether the relatively few U.S. construction firms with R&D commitments are able to maintain them.

The United States and its construction industry can benefit from the practices and innovations developed by the Japanese. While a direct transfer of the Japanese R&D approach and even the emerging technologies may not always be feasible, the opportunities for modified application and the potential value of increased U.S. investment in construction R&D should not be overlooked. The panel also suggests the establishment of a U.S. public/private sector program both to conduct multidisciplinary R&D and to efficiently disseminate evaluated technology focussed in the construction field. Modeled on the functions of the Japanese Advanced Construction Technology Center and funded jointly by government and private industry, this program could be organized under, *e.g.*, the Manufacturing Extension Partnership of the Department of Commerce's Technology Administration, working with the existing public and private construction-related organizations.

Finally, construction technology must be proven on construction sites, and the future leadership in construction technology will go to the nation that performs the most construction and builds the most ambitious projects.

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APPENDIX A:

SITE VISIT REPORTS

Table of Reports

Schedule of Site Visits

Date	Morning	Afternoon
Friday, June 9		Fire Research Institute
Monday, June 12	Japan Federation of Construction Contractors, Inc. Advanced Construction Technology Center Misawa Home Co., Ltd.	Takenaka Research and Development Institute Kajima Technical Research Institute
Tuesday, June 13	Deep LNG & LPG Storage Tanks Construction Site Japan Society of Civil Engineers	Trans-Tokyo Bay Highway Construction Site Tokyo Rinkai Hukutoshin Project Harumi-1-chome District Redevelopment Project
Wednesday, June 14	Tokyo Terminal Renovation NKK Corporation OM Solar Association	Tokyo International Forum, Glass Hall Project Nippon Steel Corporation
Thursday, June 15	Mitsubishi Heavy Industries, Chemical Plant Engineering and Construction Center Kawasaki Heavy Industries, Ltd., Noda Works	Komatsu Research Institute Hitachi Construction Machinery Co., Ltd., Tsuchiura Works
Friday, June 16	Public Works Research Institute Kumagai Gumi Technical R&D Institute National Research Institute for Metals	Building Research Institute Hazama Technical Research Institute National Institute for Research in Inorganic Materials
Saturday, June 17	Housing Institute of Complete Project Management	

Building Research Institute

Date and Time: Friday, June 16, 1995, 13:30-16:30

Participants:

U.S. Panel Members: Thomas L. Anderson
Lloyd A. Duscha
Burton Goldberg
Richard G. Gann

Japanese Hosts: Dr. Tsutomu Shimazaki, Deputy Director General
Dr. Hideo Fujitani, Senior Research Engineer, Structural Engineering Department
Dr. Hiroshi Fukuyama, Senior Research Engineer, Structural Engineering Department
Dr. Yuji Hasemi, Head, Fire Safety Division
Mr. Akiyoshi Mukai, Senior Research Engineer, Structural Engineering Department
Dr. Shinsuke Nakata, Director, Production Department
Dr. Ichiro Nakaya, Testing and Evaluation Department
Dr. Isao Nishiyama, Coordinator for International Research Cooperation
Dr. Takeyoshi Tanaka, Head, Smoke Control Division

Summary of Technical Visit:

The Building Research Institute (BRI) was founded in 1946 as part of the Ministry of Construction. It is the only national laboratory concentrating on housing, planning, and building sciences. The BRI moved to modern, world-class facilities in Tsukuba Science City in 1979. In 1995, the BRI staff is 170, with about 15 in fire research and the rest distributed among the 10 Departments, Institutes and Centers. The operating budget is ¥2.7 billion ($30 million). NIST and BRI have a long history of research cooperation, mostly deriving from the participation by both organizations in the U.S.-Japan (UJNR) Panel on Wind and Seismic Effects and the Panel on Fire Research and Safety.

The visit began with an introduction to BRI by Drs. Shimazaki and Nakata. This was followed by a video describing the various BRI activities and facilities.

Dr. Fukuyama then talked about BRI work on the use of high-strength (carbon, aramid or glass) fibers to repair and strengthen structural members. The approach is to wind concrete columns with high-strength fibers, using an epoxy resin to hold the windings in place. Aramid and glass fibers

have about the same performance, with the glass fiber being 2-3 times less expensive. The retrofit process is faster (full cure in 2-3 days) and less costly to implement than a steel jacketing system, requires no machines or skilled welders, and adds little weight. At least 10 companies have the capability to do this, although only one is now licensed. This approach is already being applied to columns
and piers damaged in the Hyogo Ken Nanbu earthquake.

Dr. Nishiyama presented a progress report on a U.S.-Japan joint program on composite and hybrid structures. The work began about 12 years ago, with a focus on 4 applications:

1. Concrete-filled steel tubes. The issues here are synergism between the tube and the filling and stress-transfer mechanisms in column-beam connections. Prediction methods have been extracted from a literature survey. Full-scale test samples are under fabrication for testing the modeling.

2. Reinforced concrete (RC) columns with steel girders. The issue here is the ultimate strength and ductility of the beam-to-column joint panels. Experiments have demonstrated good agreement with computer models.

3. Reinforced concrete core walls with exterior steel frames. This type of construction is not common in Japan, so the purpose here is to gain experience leading to possible design implementation. Full-scale testing is underway. In addition, a 12-story model building has been designed according to the general Japanese method and alternatively using a coupled-shear wall approach used in New Zealand. Investigation of the comparative earthquake performance is underway.

4. High performance materials.

    a. Effective utilization of fiber-reinforced plastics (FRP). This will develop evaluation methods for high-performance FRP-RC panels, methods for repair or strengthening of existing RC members, and use of FRP on electrical facilities. The participants are mainly from industry, and the program runs from 1994-1997.

    b. High performance concrete. This is mainly an information exchange about what these materials will look like and how to use them effectively.

Dr. Fujitani presented a prospectus of a project for a performance-based structural design framework. This 1995-97 project will clarify the true structural requirements, enabling the use of new designs and advanced materials.

Mr. Mukai described a new Japanese standard for rolled structural steel. He also discussed brittle failure of steel buildings in the 1995 Hyogo Ken Nanbu earthquake. About half of the 40 high-rise buildings along the fault line suffered structural damage. They were typically of 1975-type construction. Possibilities for the cause of the damage included weakening of the columns from heat from the weld, direct high strain rate from the earthquake, and the use of materials that (we know today) would not withstand such a severe stress.

Concurrent with these presentations, Drs. Tanaka and Hasemi discussed current key projects within the fire research program. Of prime importance is the success of the prototype performance-based design system for buildings, which evolved from a 5-year (1982-86) research project at BRI, funded by the Ministry of Construction. The initial version works within the current provisions of the Building Standards Law, enabling the evaluation and approval of code-equivalent designs for fire safety. Since its completion, approved alternate designs have increased markedly. Before 1986, approvals averaged about 2 per year. For 1987-1984, the numbers rose from about 20 to 140. The allowances included all types of large buildings, where design costs were large and the initial expenditures were feasible to reduce the total cost of construction. MoC is now pursuing a self-reliant performance-based fire safety design system, that is independent from existing regulations. This system will also produce a degree of safety equivalent to the current Building Standards Law. BRI is evaluating existing and developing new fire tests for use in such a system. These include ignitability, loaded structure performance, flame spread, heat release, smoke generation, and smoke toxicity.

We then toured the excellent facilities of the Institute. Their large-scale facilities are world-class: a large reaction wall and 5-story test structure, a new 3-D motion machine, and a multi-story apartment simulation for smoke control studies. They also have a variety of conventional small- and intermediate-scale test facilities. There appear to be few staff, and most of the facilities were idle.

Summary of Significant Findings:

Recent BRI research has led to significant innovations in building design and construction, *e.g.,* the prototype performance-based fire safety design system. This is already giving builders some additional design flexibility, especially in larger, costlier buildings. This performance-based approach is also in evidence in a similar project for structural systems. The other projects represent useful work, but not significant innovations.

Follow-Up:

More specific presentations of the fire-related projects will take place at the forthcoming 13th UJNR Panel on Fire Research and Safety meeting in Gaithersburg. The evolution of new test methods and the construct in which they are to be used should be followed so that U.S. manufacturers are able to pursue selling their products in Japan. The construction-related work was presented at the recent meeting of the UJNR Panel on Wind and Seismic Effects and will likely be of continuing visibility in that forum.

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Mukai, A., *A New Industrial Standard for Rolled Steels for Building Structure ans the Brittle Failure of Steel Buildings Damaged by the 1995 Hyogo Ken Nanbu Earthquake*, Building Research Institute, 1995.

Nishiyama, I. And Yamanouchi, H., *U.S.-Japan Cooperative Research program on Composite and Hybrid Structures - Research Plan and Progress*, Building Research Institute, 1995.

Fire Research Institute (FRI)

Date and Time: Friday, June 9, 1995, 13:30-17:30

Participants:

U.S. Team Member: Richard G. Gann

Japanese Hosts:
Dr. Nobuo Jiromaru, Director General
Dr. Kimio Sato, Deputy Director General
Dr. Asamichi Kamei, Chief, 3rd Research Division
Mr. Daisuke Kouzeki, Chief Research Member, 3rd Research Division
Mr. Haruki Nishi
Dr. Naoshi Saito, Chief, Extinguishment Section, 2nd Research Division
Ms. Yuko Sasu, Extinguishment Section, 2nd Research Division
Dr. Kohyu Satoh, Chief, Alarm and Communication Section, 3rd Research Division
Dr. Ai Sekizawa, Chief, Section of Fire Data & Analysis, 3rd Research Division
Dr. Tokiyoshi Yamada, Chief, Fire Physics, 1st Research Division
Dr. Kunimiro Yamashita, Chief, 1st Research Division
Mr. Eiji Yanai, 1st Research Division

Summary of Technical Visit:

The Fire Research Institute was founded in 1948 as a division within the Fire Defense Agency (FDA), now part of the Ministry of Home Affairs. It is the only national laboratory for scientific and technological research in support of the fire service. They are located in Mitaka on the west side of Tokyo. In 1993, the FRI staff was 103, divided among 3 Research Divisions and a General Affairs Section, and the operating budget was ¥658 million (•$8M). FRI is currently implementing a $40M facilities construction program. NIST and FRI have a long history of research cooperation, mostly deriving from the participation by both organizations in the U.S.-Japan (UJNR) Panel on Fire Research and Safety.

This visit was arranged by Dr. Sekizawa. After an opening conversation with him and Drs. Sato and Kamei, we watched a 30-minute FRI video, updated from the version shown at the last meeting of the UJNR Panel. At present, four new buildings are under construction. This large influx of funding is part of the government's support for the construction industry which has been hard hit by the domestic recession.

Following this discussion, I visited three principal research projects:

1. Detection

Dr. Satoh and Mr. Kouzeki have been performing research jointly with Matsushita Electric Co. to develop a fire detector that would sense real fires reliably, yet not be subject to nuisance alarms from overheated cooking pots, shower mist, cigarette smoking, etc. Their multi-sensor detector, which had been successfully demonstrated at the 12th UJNR Panel meeting in 1992, uses a thermistor for sensing heat, a photoelectric detector for particles, and a sensor comprising a DuPont polymeric film over a platinum base for measuring carbon monoxide. The unit knows the typical nuisance signals and uses "fuzzy logic" and pattern recognition to discriminate against alarms from such events. While the first two components are inexpensive and durable, the last has an expected life of 3 years and is expensive. They estimated the market cost of the sensor at ¥20,000 ($250). It appears that no commercialization is at hand, and the project has been completed.

They are also working on other approaches to improved alerting of people and thus improved evacuation. For instance, in a hotel, if a central computer thinks there is a fire, it can automatically call the room to see if anyone is there and, if so, to check whether there is a fire before raising an alarm. An infrared detector in the room could both detect the presence (or absence) of occupants and also serve as another fire sensor. They also have devised a door lock that "knows" if the door has been locked from the inside or the outside as an additional means of determining whether a person is in the room. If there isn't anybody in the room, the system goes into alarm. Handicapped people wear a fire alarm around their neck, similar to the U.S. medical alert amulets. The alert rings at the fire department. They do not expect this technology to make it to market in the next 5-10 years, primarily because of cost issues.

2. Smoke Movement in Underground Structures

Dr. Yamada is working on modeling the air handling in multi-story underground parking garages. They have built a 1/10-scale, 5-story mock-up, as shown in Figure a-1. At one end, the floors can be connected by ramps, a stairwell, or a shaft. They use a small heptane or methanol burner to generate heat. They measure temperatures at several locations and carbon monoxide with a single CO sensor near the burner at present. They use video to estimate smoke density from the heptane flames. They will soon begin to use the various zone models (*e.g.*, CFAST, BRI-II) to determine if they can predict the temperature patterns in the system. A fire in a lower floor will heat that floor's ceiling and thereby the floor of the next story. Thus the upper story will have a warmer floor than its ceiling, creating a temperature inversion. This should provide a stiff test of these models. At present, the Science and Technology Agency is funding this work.

3. Advanced Fire Truck

During the 1992 UJNR visit, we saw an automatic system that FRI had developed for making sure an extendable ladder truck sent the top of the ladder to the desired location relative to the fire. Apparently this system is too expensive for commercial use at present. They have now devised a ladder truck that can operate in very small spaces, such as on side streets or in older towns. Such a truck might also reduce the need for wide streets and setbacks in new housing areas. Mr. Nishi said that the ladder can extend 30 meters, with up to 110 degrees of angle. Morita Co., the leading manufacturer of fire trucks in Japan, has made a prototype, as shown in Figure a-2.

4. Suppression

I did not visit this work, which is focussed on alternatives to the now-unavailable halon fire suppressants, although I discussed it briefly with Dr. Saito. They have presented work on an improved cup burner as a means for measuring fire suppressant efficiency. Dr. Saito thinks that the opposed flow burner is a major improvement. A materials flammability test based on the Cone Calorimeter was not adopted as a national standard.

5. General

The visit continued with a round table discussion with Drs. Sekizawa, Kamei, Yamashita, Yamada and Kamei, Ms. Sasu (who is going to Princeton for a year to work with Prof. Ed Law), and Mr. Yanai (who is performing their work on fire retardants). We discussed the possibility of regulation of furnishings in homes. FDA has no such regulations, except for curtains and carpet in hotels. Their rationale is that there are many combustible materials in older Japanese housing, including shoji screens, and there are relatively few chairs, tables, etc. Therefore, regulating the latter is less important than in the United States. They noted that the new product liability law goes into effect in July 1, 1995 and that this could change everything. [A copy is attached as Appendix C.] Dr. Yamada has written a paper on equivalency as a preliminary to a performance-based fire code. This was presented at a recent Mini-Symposium (see reference below).

My visit concluded with a brief discussion with Dr. Jiromaru. He urged us to go to Kobe to view the earthquake damage, and we discussed the outcome after viewing a high-definition video tape of the damage on their new wide-screen high definition television receiver. The fires generally began with ruptured gas mains. Their extent was limited by the availability of contiguous fuels, typically older wooden structures, and by water and other natural boundaries. The mechanisms of flame transport were similar to those in the Oakland Hills fire, but without the presence of any significant wind. There apparently had been some internal ignition of houses by flame radiation entering through the windows.

Summary of Significant Findings:

There is research at FRI that could well lead to advances in construction conditions, *e.g.*, advanced fire detection and evacuation methods, and improved firefighting in close quarters. However, none of these have yet come to market, and the prognosis for implementation in the next 5 years is unsure. The Japanese have implemented the first form of a performance-based fire code (see mini-symposium reference and the BRI site visit summary), and this is already giving builders some additional design flexibility, especially in larger, costlier buildings.

Follow-Up:

More specific presentations of these and other projects will take place at the forthcoming 13th UJNR meeting in Gaithersburg.

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Kouzeki, D. *et al.*, *Study of Evacuation Assisting System Incorporated into Intelligent Fire Detection System*, AUBE '95, Duisburg, Germany, April 4-6, 1995.

Mini-Symposium: Fire Safety Design of Buildings and Fire Safety Engineering, Building Research Institute, Tsukuba, Japan, June 12, 1995.

National Institute for Research in Inorganic Materials

Date and Time: Friday, June 16, 1995, 14:00-16:30

Participants:

U.S. Team Members: Steven J. Bomba
Edward E. DiTomas
Noel J. Raufaste, Jr.

Japanese Hosts: Satoshi Kishimoto, Senior Researcher, 5th Research Group
Chitoshi Masuda, Dr. Head of 4th Laboratory, Failure Physics Division
Dr. Mamoru Mitomo, Supervising Researcher
Dr. Norio Shinya, Supervising Researcher, 5th Research Group

Summary of Technical Visit:

NIRIM was established in 1966 within the Science and Technology Agency as a national institute to conduct special research in the creation of inorganic advanced materials with refractory, super hard, electronic, magnetic, optical and super-conducting properties, as well as biomaterials and intelligent materials. The Institute has a 1995 budget of ¥3.65 billion ($43 million) and a staff of 165, including 118 research staff and 17 technicians. NIRIM operates 14 Research Groups and three Research Centers. NIRIM is made up of six laboratories: Extreme Technology, Advanced Materials, Ion Beam Applications, High Voltage Electron Microscope, Quake-free and Clean.

The research done at NIRIM is very basic, often at the crystal surface, molecular and atomic levels. This resulted in a visit that was extremely interesting, but was too basic to relate directly (in the near term) to the implementation of new products and technologies in the construction industry. Research projects currently underway at NIRIM are:

- cubic boron nitride films and single crystal diamond films, with an emphasis on their use for the next generation of semiconductor devices;
- super-conductive materials using new materials, single crystal growth and crystal structure analysis;
- intelligent structure materials such as zirconia and intelligent glass that changes its light transmission according to changes in air temperature; and
- diamond embedment in ceramic in lieu of metal to withstand higher heat levels and the use of cubic boron nitrite for metal cutting.

The team visited their ultra high pressure generating apparatus used to characterize artificial diamonds and cubic boron nitrate. These findings contribute to improved cutting surfaces for hard materials. Work using their 30,000 ton press and high pressure apparatus of 10^{10} Pa range was described. We heard a briefing on development of superconductive materials and analysis of materials using transmission microscopy and neutron diffractions. We viewed their transmission microscope rated at generating acceleration voltage of 1,300 kV.

In Japan's ailing economy, fundamental research at universities and industry has been reduced and less interest is being shown in these areas.

All STA-supported NIRIM research findings are published and distributed to colleagues and customers; have 675 patents and application for an additional 388 patents, host and participate in multilateral and bilateral cooperations and international conferences, conduct workshops and technical meetings; participate in standardizing activities; accepts and provided guest researchers. Our host's earlier work had led to a patent, and commercialization for use in Toyota turbochargers, with potential application to ceramic scissors and knives.

Summary of Significant Findings:

NIRIM is a leading government laboratory in ultra-high pressure and ultra-high temperatures. They were the first Japanese Institute to start a center of excellence in advanced materials. The Institute has capabilities to assist the construction industry with ideas and test methods leading to better processes and methods. For example research on diamonds and cubic boron nitrate could enhance cutting heads on tunnel boring machines, and portable saws. This type of research is essential for building a scientific infrastructure, but is appropriately too basic to have a near-term bearing on construction products and technology.

References:

Mitomo, M., Nishimura, T., and Kim, Y.W., *Fracture Resistance of Engineering Ceramics*, Extended Abstracts of Asia - Pacific Workshop on Intelligent Materials, 1995.

National Institute for Research in Inorganic Materials, Science and Technology Agency, (NIRIM), 1994.

NIRIM COE Research Program, - Striving to Be a COE in Advanced Materials Research - Advanced Materials Research Utilizing Extreme Conditions, Science and Technology Agency of Japan, National Institute for Research in Inorganic Materials, (NIRIM).

Large Volume Ultra High Pressure Generating Apparatus, National Institute for Research in Inorganic Materials Science and Technology Agency, (NIRIM), March 1995.

National Research Institute for Metals

Date and Time: Friday, June 16, 1995, 09:00-11:30

Participants:

U.S. Team Members: Steven J. Bomba
Edward E. DiTomas
Richard G. Gann

Japanese Hosts: Satoshi Kishimoto, Senior Researcher, 5th Research Group
Dr. Chitoshi Masuda, Head, 4th Laboratory, Failure Physics Division
Dr. Norio Shinya, Supervising Researcher, 5th Research Group

Summary of Technical Visit:

This Institute was established in 1956 in the Science and Technology Agency. They had just moved to their new facilities in Tsukuba a few months prior to this visit. The staff totals about 400, with about 10 industrial guest researchers and a lesser number of university visitors. This Institute does fundamental research while MITI sponsors the applied complement.

They call "smart materials" those with properties that are engineered for the application. Typical of these are composites, especially ceramics with fracture healing capabilities. They are particularly interested in materials that are self-diagnosing, self-healing, and/or self-adapting. This can be achieved both by material structure design and by built-in sensors and processors. Applications included mitigating the brittleness of ceramics and extending the fatigue life of other materials. Presentations included research on a self-healing mechanism for creep cavities, creation of multi-functional materials using an electron beam, and self-control of fatigue crack growth.

References:

National Research Institute for Metals, Science and Technology Agency, 1993.
The Concept of Intelligent Materials and the Guidelines on R&D Promotion, Science and Technology Agency, November, 1989.

Public Works Research Institute

Date and Time: Friday, June, 16 1995, 08:00-12:00

Participants:

U.S. Team Members: Thomas L. Anderson
Richard a. Cemenska
Lloyd a. Duscha
Burton Goldberg
Noel J. Raufaste, Jr.

Japanese Hosts: Dr. Takashi Iijima, Director General
Dr. Kiyoshi Katawaki, Research Coordinator for Advanced Materials Technology
Hirohide Konami, Assistant Director General
Yasuo Mitsui, Research Coordinator for Construction Management Engineering
Tomonobu Nakaoka, Deputy Director General
Ryutaro Oishi, Head, International Cooperation Division
Dr. Nario Yasuda, Head, Planning Division
Dr. Koichi Yuokoyama, Director, Structure and Bridge Department

Summary of Technical Visit:

PWRI was created in 1922; its 1994 budget was ¥11.7 billion ($138 million); ¥4.1 billion ($48 million for personnel and office expenses, ¥7.25 billion ($86 million) for research expenses, and ¥0.4 billion ($4.7 million) for facilities expenses. PWRI employs 470 persons; 310 are engineering and 160 are administrative. PWRI is made up of 12 research departments, a construction management engineering center, and an experimental research laboratory in Nigata performing research on avalanches and landslides.

The Institute serves as the Ministry of Construction's (MoC) technical arm in leading research for the environment; rivers; water quality; dams; erosion control; roads; materials and construction methods; structures and bridges; and earthquake disaster prevention. PWRI's research findings often serve as the authoritative reference source for civil engineering specifications and standards. PWRI is anticipating research needed for oceans, space, and geofrontiers. For the latter they are considering three projects:

- underground energy storage systems to store compressed air for night-time release to power turbines;

- construct the Kobe City Auditorium within the neighboring Rokko Mountains; and

- use underground rivers for water storage and to reduce flow speed of storm water runoff.

They are conducting pilot investigation to study the feasibility of developing superconducting alloys, fine ceramics, engineering plastics (polyamide, polyacetal, polycarbonate, transformed polyphenylene oxide) as ways to save energy; composite materials as fiber reinforced plastics; environmental friendly energy savings materials; recycling construction materials; high durability paints; and multi-span continuous bridges with base isolation.

PWRI provides the technical data for developing and implementing public works related technologies into the Japan Building Code. We heard about MoC's plan to Reform the Bidding and Contracting Procedures for Public Works. This Plan stresses adoption of transparent, objective, and open competitive procurement procedures. Procurement of design and construction services for public works now mandates open bidding for all bidders worldwide for projects sponsored by the central government valued at more than ¥730 million ($8.8 million) and for work valued at more than ¥2.4 billion ($29 million) sponsored by quasi-government agencies, *e.g.*, Japan Public Highway Corporation and by the Prefecture Governments. Other bids will be awarded as before (based on short list of qualified bidders, as determined by the owner). This revision has been enacted but is not fully operational.

During this visit, the delegation did not have time to visit PWRI's laboratories; however, several NIST staff have visited these laboratories several times in the past. The following is an abstract from their reports. PWRI's Earthquake Engineering Laboratory develops base isolation criteria for bridges. Their Geotechnical Dynamic Centrifuge has a radius of 2 m and maximum centrifugal acceleration of 200 G (static), 90 G (dynamic). Their Earthquake Engineering Laboratory performs vibration experiments on a 125 ton dynamic loading actuator. Their Vibration Laboratory has six shaking tables where bridge structural responses and geotechnical characteristics are determined. Their Structural Aerodynamics Laboratory has three wind tunnels where research led to reducing wind-induced oscillations and forces on bridges. Their Dam Hydraulics Laboratory determines forces acting on dams and optimizes spillways. Their Foundation Engineering Laboratory has three test pits to test piles at vertical loads up to 200 tons and horizontal loads to 300 tons. Their Earth Structure Laboratory has a 20 m by 20 m by 5 m test pit for testing embankment stability. Their Structural Engineering Laboratory with three testing machines capable of subjecting specimens to vertical and horizontal loads. The largest has a capacity of 3,000 tons in compression and 1,000 tons in tension. Their Boundary Layer Wind Tunnel is the largest in the world with test section is 41 m x 4 m x 30 m. This laboratory was built to test a 1:100 scale model of the 4 km Akashi-Kaikyo suspension bridge. PWRI performs extensive research in advanced construction technologies using robots and prefabrication technologies, *e.g.*, lightweight materials for bridges; develops technologies for offshore facilities and for designing and constructing public work facilities 60 to 200 m underground.

All PWRI research findings funded by the MoC are published in a variety of reports and made available to colleagues and customers. PWRI is significantly involved in hosting and participating in multilateral and bilateral cooperations and international conferences. They have effective bilateral and joint collaborations with several countries including the National Institute of Standards and Technology, the National Science Foundation, the Department of Transportation's Federal Highway Administration in the United States. They conduct a wide variety of workshops and technical meetings; participate in standardizing activities; accept and supply guest researchers.

Summary of Significant Findings:

PWRI provides the technical data for developing and implementing public works related technologies into the Japan Building Code. The Panel heard about MoC's plan to reform the Bidding and Contracting Procedures for Public Works. This Plan stresses adoption of transparent, objective, and open competitive procurement procedures.

Follow-up:

The UJNR Panel on Wind and Seismic Effects manifests a long-term relationships with PWRI staff, with whom we can test questions and issues should it be necessary.

References:

Public Works Research Institute, Ministry of Construction, 1994.

Outline of Developments in Construction, PWRI brochure, undated.

Radio Control System For Heavy Equipment, PWRI brochure, undated.

Kiyoshi, Katawaki, *New/Advanced Material, Its Present and Future Application for Civil Engineering*.

Action Plan on Reform of the Bidding and Contracting Procedures for Public Works, (Background and Objectives of the Action Plan).

Construction Investment, Ryutaro Oishi, June 16, 1995.

Hazama Technical Research Institute

Date and Time: Friday, June 16, 1995, 14:00-17:00

Participants:

U.S. Team Members: Ezra Ehrenkrantz
Charles I. McGinnis
Boyd C. Paulson, Jr.
Kenneth F. Reinschmidt

Japanese Hosts: Mr. Hidetoshi Yoichi, Gen. Mgr., R&D Planning Department
Mr. Takashi Inoue, Assistant Manager
Mr. Yochio Ito, Senior Research Engineer, Section 2, Technical Research Department
Dr. Kazushi Shimazaki, Chief, Section 2, Technical Research Department
Mr. Kouichi Higashi, Senior Research Engineer, Section 5, Technical Research Department
Mr. Shuichi Yamaguchi, Chief, Section 5, Technical Research Department

Summary of Technical Visit:

The Hazama Technical Research Institute is located in Tsukuba Science City, a center for 50 government and 150 industry research labs, north of Tokyo. The Research Institute is a new facility, opened in 1992 on the 100th anniversary of the company.

Hazama ranks about number ten, in the second tier after the "Big Five" general contractors, and has about half of their annual volume (about ¥600 billion) and number of employees (5300). It is about 60% building and 40% civil, with dams and tunnels making it one of the largest in the latter sectors. Revenues and profits have declined in recent years and the effects have been felt in the Technical Research Institute, where there have been reductions in staff and budgets.

The Technical Research Institute relocated to Tsukuba to interact with the other research centers in the area, including the two largest government labs. It employs about 100 research professionals, 60 technicians, and 20 administrators, again about half of the largest firms. Its budget runs about ¥4 billion per year, or about 0.7% of sales. This is slightly smaller than the Big Five.

Mr. Yoichi presented an overview of Hazama Corp. and the Tech Research Institute, with supplemental information provided by Mr. Inoue. Mr. Ito presented work on seismic base isolation, Dr. Shimazaki on testing reinforced concrete samples collected from the debris of the Japan Railway structures damaged in the Hyogo Ken Nanbu earthquake, Mr. Higashi on research on establishment of turf grass, and Mr. Yamaguchi on anti-bacteria concrete. The researcher presentations showed some overlap with other labs (most of them seemed to be exploring base isolators and alternative concrete materials), focused on current high-priority problems (the Hyogo Ken Nanbu Earthquake follow-up studies), and had some possibly unique twists. For example, the study of turf grass reflects the importance of golf courses in Japan, and with its work on improved grasses Hazama is seeking a competitive edge in this market. Mr. Higashi, who presented this work in some detail, seemed to have the type of expertise normally found in a university agricultural experiment station in the United States. On the lab tour we also saw experiments to grow coral so that it could be transported to new oceanside resort developments.

They stated that about 20% of their activity is research and 80% pragmatic development (compared to about 40% to 60% at the institutes of the larger corporations). Although their budget is proportionately smaller at 0.7% of sales, there was a high level of activity in most of the research labs, so they may be effectively using the resources at their disposal.

The ensuing lab tour revealed top quality physical facilities for construction research and development, with the standard complement of large, up-to-date research facilities and equipment, *e.g.*, shake table, reaction floor and walls, wind tunnel, hydraulic wave basin, artificial climate room, clean room, biochemical labs, anechoic chamber, soils lab, materials labs. They also has a room isolated from electromagnetic waves. In an adjacent field test area they were developing their version of the automated high-rise building systems recently in vogue in Japan and were conducting experiments on GPS and laser controls for earthmoving equipment. It seems that they are heavily problem focused.

References:

Base Isolation System and Passive Vibration Control System, reprint, undated.

Hazama Annual Report 1994, corporate brochure, September, 1994.

Hazama Corporate Data, corporate brochure, October, 1994.

Hazama General Contractors, Architects and & Engineers, marketing brochure, undated.

Hazama Technical Research Institute, corporate brochure, July, 1995.

Hazama's Anticorrosive Method Against Concrete Deterioration Caused by Sulfur Oxidizing Bacteria," corporate brochure, March, 1995.

Kajima Technical Research Institute

Date and Time: Monday, June 12, 1995, 14:00-17:00

Participants:

U.S. Team Members: Thomas L. Anderson
Richard A. Cemenska
Lloyd A. Duscha
Ezra Ehrenkrantz
Boyd C. Paulson, Jr.
Noel J. Raufaste, Jr.
Kenneth F. Reinschmidt

Japanese Hosts: Dr. Yoichi Nojiri, Director
Mr. Masahiko Nishimura, Manager, Planning Office
Mr. Yoshinobu Nobuta, Chief, Planning Office
Dr. Yasuo Murayama, Manager, Civil Engineering Department I
Dr. Naoto Ohbo, Chief, Earthquake Engr. Section, Civil Engineering Department I
Dr. Choji Tsubota, Chief, Building Structures Section, Building Structures Department
Mr. Kouichi Suzuki, Senior Research Engineer, Building Construction Engineering Dept.
Mr. Tomio Ohuchi, Chief Research Engineer, Building Environment Engineering Department
Mr. Satoru Miura, Senior Research Engineer, Mechanical and Process Engineering Department
Mr. Kikuo Koseki, Assistant Manager, Technical Development Department, Civil Engineering Division
Mr. Kazuo Suzuki, Deputy Manager, Sales Department, Business Promotion

Summary of Technical Visit:

The Kajima Technical Research Institute (KaTRI), located West of Tokyo, has an older facility in Tobitakyu, begun in 1965, and a newer complex nearby in Nishichofu, begun in 1984. This visit began with oral presentations at the Tobitakyu facility and then proceeded to a tour of the new labs at Nishichofu.

Dr. Yoichi Nojiri presented an overview of Kajima's research programs and policies. Mr. Koseki provided an example of market research leading to base isolation systems. Dr. Tsubota discussed base isolation between bridge decks and piers, water jet cutting to help repair columns, sheet-pile rings around the bases of oil tanks to prevent liquefaction of supporting soils, and the use of risk analysis. Mr. Suzuki talked about the construction automation used on "push-up" building construction, composite structures of concrete columns and steel beams. Similar research was seen at other industry laboratories.

Summary of Significant Findings:

Since the 1990 JTEC visit, a new "Concrete and Wind-Tunnel Laboratory" had been constructed at the Nishichofu complex, completing the site build-out with this eighth building.

While some contractors have been cutting back their research staffs, it seems that Kajima's Technical Research Institute is trying to hold steady. The 1991 JTEC report said there were then 270 engineers and scientists on staff. During the current visit, the Director said there are now 330. Presumably some growth took place soon after 1990 and then stabilized as the recession of 1991-94 set in. The budget remains at about 1% of sales. Sales have declined somewhat in recent years, and the budget cutbacks appear to have been taken in supplies and materials rather than in direct salaries (though salary increases and bonuses have probably been cut significantly, as at other companies in Japan). Nevertheless, in view of the severe recession, it is impressive that Kajima continues to give its Technical Research Institute this level of priority.

The Director here, as at other labs, did indicate that their priorities had shifted away from long-term research to short-term development and problem-solving that would more readily enhance the company's revenues. The budget is now prioritized to emphasize fifty core technologies deemed essential to Kajima's business lines. An example is better base isolation of structures for improved resistance of earthquake forces. Even so, we were told that 45% of their budget still goes to "fundamental" research, perhaps meaning that it has no immediate application or project associated with it, and that it is funded from internal corporate funds. Earthquake engineering remains at the top of the priority list, with over 100 of the researchers and 40% of the budget, and will probably remain so given the unexpected consequences of the Hyogo Ken Nanbu earthquake last January. However, emphasis here will shift more to diagnosis, repair, and retrofit rather than designs for new structures.

General Impressions and Need for Follow-Up:

The physical facilities for construction research and development are among the finest in the world, and the research staff is well-educated, experienced, and capable. However, it appears that, relative to their potential, the facilities and staff are underutilized. Some labs appeared almost dormant, with old samples and poster boards reflecting experiments of days past and with little sign of current activity. Even in the areas with experiments being set up, tested or dismantled, there seemed to be no sense of urgency and little sign that the activities had a high priority for completion.

There was considerable duplication of facilities and similarity in activities between Kajima and the company and government labs visited on this trip, . Wind tunnels, shake tables, climate simulation rooms, large-scale reaction walls, anechoic chambers and other impressive facilities and equipment seemed *de rigueur*. The duplication was also indicative of a lack of communication with researchers elsewhere in the world doing similar things. The hosts indicated that they had recently put up a home page on the World Wide Web, but no one said anything about using the Internet to find information or communicate with other researchers working on similar research. Both libraries and the Internet have become fundamental tools to researchers doing cutting-edge research elsewhere in the world.

We are thus left with the impression that these facilities are really used more for testing and demonstrations than for fundamental research. a conversation held in Kajima's wind-tunnel facility and later repeated at other sites is indicative. The models being tested are provided late in the design process and are tested as-is, with no means to vary the shape or size of the models to get some kind of sensitivity analysis to feed back to the designers. It is basically a go/no-go test and is meant mainly to confirm that the structure as designed complies with the building regulations. Findings to the contrary would be unexpected and would probably set back the project schedule.

Here it also seemed clear that the public relations and marketing aspects of these labs were at least as important as their technical research capabilities. It seems that in part they are a form of one-upmanship, or "keeping up with the Joneses," relative to their competitors and would probably not operate at the present levels if justified solely on their research outputs and without the peer pressures from competitors, prequalification requirements from the government, and image benefits for corporate recruiting and public relations.

Since this visit occurred early in the week, before we started looking for libraries, Internet use and other signs of connectivity with the global research community, it would be interesting to have a follow-up visit with these things in mind.

References:

Kajima Technical Research Institute, Kajima Corp., Tokyo, May 95.

Kajima, descriptive company brochure, Kajima Corp., Tokyo, undated.

Exhibits and Laboratory" brochure giving overview of KaTRI, Kajima Corp., Tokyo, August 1993.

Individual Kajima brochures describing facilities and activities of:

a. Environmental Engineering Laboratory, January 1987.
b. Shaking Table Laboratory, October 1990.
c. Soil Mechanics and Foundation Laboratory, October 1990.
d. Structural Testing Laboratory, March 1985.
e. Wind Tunnel Laboratory, March 1995 (only in Japanese)

Kajima Institute of Construction Technology, Appendix in **Construction Technologies in Japan**, Japan Technology Evaluation Center, Loyola College in Maryland, 4501 North Charles Street, Baltimore, MD 21210, June 1991, pp. 176-177.

Kumagai Gumi Technical R&D Institute

Date and Time: Friday, June 16, 1995, 09:00-12:00

Participants:

U.S. Team Members: Ezra Ehrenkrantz
Charles I. McGinnis
Boyd C. Paulson, Jr.
Kenneth F. Reinschmidt

Japanese Hosts: Hideki Abo, Manager, Marketing Group
Riichi Hirai, Manager, Technical R&D Institute
Hisayoshi Ishibashi, Manager, Vibration Group
Takehiko Kato, Deputy General Manager, Architectural Research and Development Department
Kazuhiro Nawata, General Manager, Research Promotion Department
Hajime Okano, Deputy Manager, Structure Group
Takeyasu Suzuki, Deputy Manager, Civil Engineering Group
Kenjirou Tanaka, General Manager, Materials Research and Development Department
Noboru Toshiro, General Manager, Civil Engineering Research and Development Department
Motoh Tsunoda, Manager, Research Promotion section

Summary of Technical Visit:

Kumagai Gumi is a top ten construction company. Their R&D Institute was established in Tsukuba Science City in 1998 and is staffed by 81 people, of whom 60 are engineers. They are organized into five departments: Research Promotion, Civil Engineering R&D, Architectural R&D, Materials R&D, and Environmental R&D. These are further subdivided into 12 sections or groups.

Dr. Hirai provided an introduction and overview. He stated that only the top companies have an R&D facility. Their research supports a full range of construction options from a complete design/build project to construction only. Research provides for improved construction methods and for more jobs and business opportunities. Increased design know-how results in enhanced marketing opportunities. Designing with technology enhances cost control and performance and provides for a comprehensive capability.

Kumagai Gumi does a lot of work on dams and tunnels with the government as its client. Typically the government designs these facilities, but it is advantageous to have good engineering capability to make proposals on how to accomplish the construction. In awarding work, the government estimates cost, time, and technology. Technology is most important and this R&D Institute provides a foundation to help get work. That is why they have high-level research facilities.

Eighty percent of the Institute work supports the requests of people on projects, market research, or positioning the firm for job selection on large-scale projects. The remaining 20% of the work is for outside contracts.

A number of facilities and projects were described and visited:

- There is a search to develop proprietary systems to improve water quality in lakes and swamps, and work is being done on a golf course operation system. The Institute has biotechnology efforts to use microorganisms to remove nitrate and sulfate ions.

- The Class I clean room research facility replaces air 100 times per hour and uses 50 % fresh air. a robot acts as a sensor, counting particles and monitoring temperature and humidity.

- An artificial weather simulator permits testing of roof and wall panels. It is 6.15 m high, with a 10 m x 5 m floor. Temperature and humidity are controlled, and its lamps act as an artificial sun.

- The marine hydrodynamics laboratory permits studies of coastal and island projects, particularly artificial islands. The staff study what shapes should be used to reduce stagnant areas and prevent water pollution.

- The structures and vibrations laboratory works on many projects with facilities such as 3D vibrating panel capacity and a shake table. The technologies include high strength concrete, hybrid structures with concrete columns and steel beams, base isolation and tuned mass dampers. They believe these elements have the capacity to reduce earthquake forces by about 20-90 %.

- a large wind tunnel is used to test completed designs in the urban environment to determine that, for a given design, acceptable wind speeds will be obtained for exterior wall fastenings and for pedestrians at ground level.

- The concrete laboratory is working with fluid concrete used for bridge design and high-strength concrete using admixtures, fly ash, and silica fume.

- Work is underway to repair deteriorated concrete due to hydrogen sulfide attack, and water jets are being used to remove deteriorated material.

- An anechoic chamber is being used to study noise cancellation of stationary sound sources. Typical models of theaters and performance spaces are used for testing designs.

Summary of Significant Findings:

Most of the work at the Institute is being performed in support of specific projects, with less work on predictive tools and innovation. Building safety during and after construction was a very strong concern. The interest in unique building technologies appears focussed on specific solutions, such as base isolation.

References:

Annual Report, Kumagai Gumi Co., Ltd., 1984.

Kumagai Gumi Technical Research & Development Institute, corporate brochure, in Japanese, undated.

Mitsubishi Heavy Industries
Chemical Plant Engineering and Construction Center

Date and Time: Thursday, June 15, 1995, 10:00-12:30

Participants:

U.S. Team Members:	Richard a. Cemenska Edward E. DiTomas Ezra Ehrenkrantz Richard G. Gann Charles I. McGinnis Kenneth F. Reinschmidt
Japanese Hosts:	Mr. Ichiro Araki, Group Manager, Administration Group, Chemical Plant Engineering and Construction Center, Machinery Headquarters Mr. Hitoshi Ariyoshi, Project Manager, Project Group, Flue Gas Desulfurization Plant Department, Chemical Plant Engineering and Construction Center, Machinery Headquarters Mr. Tatsuro Hongo, Assistant Chief Engineer, Construction Engineering Department Mr. T. Nishizawa, Project Manager, Chemical Plant Engineering and Construction Center, Machinery Headquarters Mr. Takahashi, Deputy General Manager, Construction Machinery Department Mr. Jin Yoshida, Group Manager, Construction Group, Project Department, Chemical Plant Engineering and Construction Center, Machinery Headquarters

Summary of Technical Visit:

Mr. Takahashi presented the general capabilities of Mitsubishi Heavy Industries (MHI) through a marketing videotape. MHI is a very large corporation, with FY 1993 revenues of $23.6 billion and approximate 1994 revenues of $30 billion U.S. It is number 60 on the Fortune list worldwide. It has 14 plants and six research and development centers, with its engineering headquarters is in Yokohama. An important characteristic of MHI stressed by Mr. Takahashi is that individual plants compete internally with each other for customers; it was not explained how this is managed.
MHI business is in the following areas:

power	28%
machinery and plants	21%
aircraft	19%

ship building	18%
general machinery	14%

MHI at Yokohama performs turnkey process plant design, procurement, and construction; it stresses modularization and exploits its extensive internal shipyards to fabricate these modules. Plant types include:

- methanol plants
- ammonia plants
- oil refineries
- liquefied natural gas receiving terminals
- desalination plants (flash evaporation and reverse osmosis)
- wet flue gas desulfurization plants
- polyethylene plants
- fertilizer plants

Power plants and general machinery are designed elsewhere.

MHI sells and installs an online, real-time artificial intelligence system for plant diagnosis, (PDIAS) and Electric Power System Intelligent Simulator for power system analysis (EPSIS). Other computer software systems mentioned included:

CAPS: Computer-Aided Project Engineering System
PMIS: Project Management Information System
FES: Functional Engineering System.

Also mentioned was a Computer-Integrated Manufacturing (CIM) system that covers manufacturing to sales (apparently not including post-sales support). Unfortunately, time did not permit any information to be obtained about these systems.

Another marketing videotape described a greenfield methanol plant constructed by MHI on a turnkey basis in Venezuela. This plant, Penquiven East, produces 2,200 tons per day of methanol. Standard Intergraph CAD was used to design the plant. Some construction innovations claimed included reinforced concrete pipe racks (due to the cost of steel in Venezuela) and the use of induction heating pipe bending machines brought from a MHI shipyard to bend pipe in the field. The plant was planned for a 30-month period from start of design to completion; the actual duration was 27 months. No incentive fee was paid for the early completion.

Another marketing videotape described the Mitsubishi All-Weather Automated Building Construction System to construct buildings taller, faster, and with less labor. The building constructed was the 33 story MHI building in Yokohama, in cooperation with Taisei and Shimizu. The roof provided protection from the weather, hydraulic jacks were used in the lift columns, anti-sway devices were used on the cranes, automatically guided vehicles (AGVs) adapted from manufacturing practice provided horizontal materials transport over the floors, and an automatic welding machine was developed to weld square columns together.

The use of this system apparently placed substantial constraints on the design of the building. As with other automated building construction systems, the MHI system has been used only for the developer as the owner; no other buildings have been sold to external clients. In response to a question, MHI stated that they would not use this system on a second building; if another building became available, they would use another (unspecified) method.

In general, according to MHI, the Japanese research and development institutes are primarily used to convince prospective customers to retain the contractor and to accept new technology. In addition to the automated building system, another example cited was MHI's flue gas desulfurization system.

Turnkey design/procurement/construction projects are taken lump sum. In the case of process innovations, which are of particular interest to the MHI Chemical Plant Engineering and Construction Center, pilot projects may be constructed first, also under lump sum contracts. The general contractor assumes all the risk by guaranteeing cost and schedule, a major difference from U.S. firms. (No discussion was given of guarantees on chemical plant performance, yield, quality, etc., which are important factors in the process industry.) If the plant is completed early, there is no additional fee, as in the Venezuelan methanol plant. According to MHI, they never have claims or disputes with clients.

In a tour of the MHI design facility, it was determined that plant design is done as two-dimensional drafting on conventional Intergraph CAD systems. According to MHI representatives, they have not standardized on any CAD system, they use whatever system for which the client requests electronic drawing files. Although MHI has Intergraph PDS (Plant Design System), they do not design in three dimensions unless specifically instructed to do so by the client; otherwise they use two-dimensional drafting, as it is cheaper. This is done in spite of the fact that MHI does all the equipment fabrication and construction under lump sum contract and therefore could benefit from the advantages of three-dimensional design.

Summary of Significant Findings:

MHI is a very large, integrated engineer, equipment manufacturer, and constructor performing turnkey projects around the world. It is therefore significant that it apparently does little innovation in the plant design process. Integrated design and construction information systems that would exploit MHI's vertical integration to achieve higher efficiency are not part of its strategy. This is perhaps because, like other Japanese general contractors, MHI is convinced that it always performs on time and on budget, and therefore no improvement is needed or possible.

The Mitsubishi All-Weather Automated Building Construction System is an impressive and expensive investment in research and development in the building construction process. The experiment will, apparently, not be repeated. It is interesting that many of the major general contractors have developed or, in the case of the second tier contractors, are developing very similar jack-up high rise building systems. These systems are so similar that only specialists could determine the particular advantages and disadvantages of each; this simultaneous development must be more than coincidental. There is no interest as yet by foreign contractors to license any of these systems, so that they will remain for some time a purely Japanese phenomenon.

Follow-up:

MHI is so big that considerably more information is needed to evaluate what it is doing throughout its research institutes and engineering offices (which are said to be internally competitive). More information on the internal information systems CAPS, PMIS, and FES would be desirable.

References:

Presentation, corporate brochure, undated.

Mitsubishi Juko Yokohama Building, corporate brochure in Japanese, undated

Takenaka Research & Development Institute

Date and Time: Monday, June 12, 1995, 13:00-17:00

Participants:

U.S. Team Members: Steven J. Bomba
Edward E. DiTomas
Richard G. Gann
Burton Goldberg
Charles I. McGinnis

Japanese Hosts: Shoichi Kobayashi, Director, General Manager
Kenro Mitsui Assistant Chief Researcher, Construction Technology Research & Development Department
Toshio Nagashima, Manager, Research Planning Department
Yasushi Nakayama, Manager, Research Planning Department
Sadatoshi Ohno, Ph.D., Chief Researcher, Fundamental Research Department
Yoshikazu Sasaki, Dr. Eng., Chief Researcher, Construction Technology Research & Development Department
Matsujiro Tomono, Senior Manager
Yasuhiko Yoshioka, Dr. Eng., Senior Manager, Construction Technology Research & Development Department

Summary of Technical Visit:

As of 1994, Takenaka employed 10,000+ employees, of which approximately 50% are architects. The remainder of the technical staff are civil engineers and a broad spectrum of other engineering disciplines. In addition to the headquarters facilities, branch offices and the Research & Development Institute, these staff members work in approximately 800 to 1,000 field offices.

The Research & Development Institute, located in Chiba Prefecture, is a large, futuristic white building designed to simulate a moon crater, impressive in its architecture and well-maintained. The gross area of the facility is 37,715 m^2 and currently houses 260 staff. There is extensive room for additional staff and projects.

The Takenaka Research & Development Institute's primary functions are:

- Development of advanced technologies to respond to company needs. The identification of these needs comes from within various departments of Takenaka, from Takenaka projects and from Takenaka clients.

- Research testing and consulting services commissioned by other Takenaka departments.
- Provide education of trainees within Takenaka.
- Support and provide technical assistance to academic institutions.

Major research areas include:

- computational engineering,
- acoustics,
- soils and foundations,
- environmental biology,
- indoor environment,
- materials,
- construction automation,
- structural,
- wind tunnel analysis, and
- disaster prevention

All research and development goes through three stages internal to and under the control of Takenaka: planning, execution, and application. The management provided us with a flow chart of their R&D selection process, which is attached.

Research projects currently underway at the R&D Institute are:

- domed structures, especially air membrane roofs similar to the Tokyo Dome;
- control of structures under seismic loading using active mass dampening;
- sound field simulator for the study of sound transmission in structures;
- super clean room construction techniques;
- ground liquefaction analysis system;
- indoor air quality with emphasis on individual environments and needs;
- air flow analysis program, including maintenance of personal environments (precision controlled work space);
- super high strength, 100 MPa (14,000 psi), silica fume concrete; one of the beams of the R&D facility was constructed using 140 MPa (20,000 psi) super high strength concrete;
- green concrete - a very porous concrete that allows the growth of plant life on its surface;
- sealants;
- thermosetting structural sealant glazing systems;
- all weather construction methods such as prefabricated panels that rise as the building is erected to enclose the work area;
- improvement of the design-build process; and
- wider use of computer simulation for design—air flow, acoustics, visualization, vibration control, oscillation damping, seismic, etc.

We were given a guided tour of several of the R&D Institute's many laboratories. While the laboratories were well equipped with conventional technology instrumentation. The researchers had been creative in extending the envelope of usefulness of older equipment technologies. The laboratories visited were:

- Large scale structural testing. The laboratory is equipped with a 2,000 metric ton testing machine and several small machines. Systems currently under construction included composite construction (combinations of steel and concrete) as well as steel reinforced concrete. a substantial amount of the research effort had been redirected into repairing and reinforcing concrete as a result of the Hyogo Ken Nanbu earthquake.

- Fire testing. As with the large scale structural testing laboratory, the lab is well equipped but there were no new technologies evident. The focus of this lab is on flammability testing and includes a convention fire resistance furnace, a •40 MW burn hood with oxygen consumption measurements to determine rate of heat release, and standard flammability test apparatus.

- Green concrete. The green concrete lab is outside the R&D building. The only activity was the development and testing of a highly honeycombed concrete that facilitated the growing of plant life on the concrete surface.

- Chemical analysis of concrete. This laboratory is focused on the micro-structural analysis of concrete to improve its quality and to develop the use of new materials in the making of concrete. The lab is no longer studying the use of polymers in concrete because they cost too much.

- Weather durability testing. This laboratory tests the weather durability of a variety of construction materials, with a focus on metals and coatings, especially aluminum and stainless steel. They also test stone—such as granite, sandstone and limestone—from foreign as well as local sources.

- Curtain wall durability testing. This laboratory's focus is on various curtain wall systems. The tests are conducted on full- and reduced-scale mock-ups of different systems. a reduced-scale sample of a rainshield system with a stone veneer was on display. It was pointed out that the rainshield system was not typically used in Japan.

- Indoor air quality. Studies on individual air quality control and individual environmental control were in progress in this laboratory. In our discussion, we noted that more advanced techniques and procedures were available and offered our hosts access to these resources.

The success of any R&D effort culminates in the profitable commercialization of the product or technology. The Takenaka staff discussed examples of bringing some of their R&D efforts into the construction marketplace. The first example was a large air dome that had neither beam nor column support. This effort required two years to obtain final government support. Two other technological advances that have gone through the commercialization process during the past 5 years are high-strength concrete and a new exterior cladding panel (still in the process).

The effort in high strength concrete research is driven, at least in part, by the need to resist seismic loading. Structures designed to resist seismic loads have a substantially higher density of reinforcing than other structures, translating into a need for a concrete that is highly fluid and high in strength, a need satisfied with silica fume high strength concrete. The use of super-plasticizers is also being studied to further increase the concrete's fluidity. Another facet of high strength concrete being studied is the use of undensified silica fume. Both the United States and Europe use densified silica fume because it is easier to handle, albeit more expensive to produce.

Other research areas include the use of high-strength-concrete-filled structural tubes and their placement by pumping. Pumping heights of 60 m have been reached, and Takenaka is now planning to pump 100 m on an up-coming project. Strengths of 60 MPa (8,700 psi) are becoming more common, while 80 MPa (12,000 psi) is now being achieved.

While most high strength concrete is used in beams and columns, it is sometimes used throughout a structure. Takenaka is now planning a 600 m high structure, TAK 600, using high strength concrete.

Takenaka is doing substantial research in the design and use of two dimensional fiber arrays in Direct Sprayed Carbon Fiber Cement (DSCFC) cladding panels. With the current cost of carbon fiber now at ¥3,000/kg, a cost comparison shows DSCFC panels to be about 30% to 40% higher than standard reinforced concrete panels. However, there are other substantial savings to be considered, such as the reduced weight of the panels, allowing a reduction in the size of the building frame and foundations. Some research has been done on the use of high strength silica fume concrete in DSCFC panels.

Takenaka advised that while they did not have any products or technologies that did not make it through the commercialization process, they did have some experiences where the product or technology did not enjoy the commercial success expected.

The following information was obtained during an ensuing question and answer session:

- *Has the current recession impacted funds for R&D?* Takenaka's 1995 budget is ¥12 billion, 10% less than last year. Next year's budget most likely will go down another 10%. Usually R&D is 0.8% of sales.

- *Has there been any significant advances in the use of robotics since the JTEC study in 1990?* While there is little that is new in concept, there have been many improvements in the machines and their use in a variety of buildings.

- *Is automated welding used to improve quality or save time and manpower?* While automated welding provides all three benefits, the main goal is to provide more consistency in weld quality. There are still some problems to overcome before automatic welding becomes more widespread. The limited availability of skilled tradesmen in the future will further drive the need for automated welding.

- *Is a performance-based fire code now in use?* a performance-based fire code has been completed and part of it has been put to commercial use. It was used in the new Proctor & Gamble building in Kobe and resulted in lower costs.

- *What is the status of the use of computers in the field office and what is the Institute doing to expand their use in the field office?* 80% of Takenaka's branch offices are using computers for planning work, while approximately 50% to 60% of the field offices are using computers. Basic field office use (80%) is for finishing the drawings and making sketches. The rest of the field use is for special Takenaka systems. Drawings are usually sent to the field on paper, however, some parts are sent electronically.

- *Is there any market in the residential area for renovation?* Takenaka expects this market to grow in the future, however the scale of the individual residential projects is very small which reduces the economic feasibility of introducing new and sometimes expensive technologies. Takenaka is looking for ways to capitalize on this market. The market for office building renovation is much larger.

Summary of Significant Findings:

Upon completion of the tour of the Takenaka R&D facilities, two aspects of Takenaka's R&D efforts were clear. The Japanese construction industry's R&D expenditures have been impacted by the current recession and will continue to decline in the near future. Second, the often perceived technological lead held by the Japanese construction industry no longer exists and may have never existed. The advantage the Japanese developed is the ability to get more out of a given technology - to expand the capability of an existing technology, but not necessarily develop a new technology. This advantage, in part, is a result of the culture and structure (organization) of the Japanese construction industry which allows, even demands, large expenditures for R&D, often on technologies that hold little promise for direct and/or short term economical reward.

The Japanese construction industry has entered into an era of significant change brought about by changing economic conditions at home and a need to compete in the world market. We may well see a substantial drop in R&D and a breakdown of existing traditional design-contract-subcontract-supplier relationships by the end of the current decade. While the current construction industry *modus operandi* works well when entrenched in the Japanese culture, it appears it may not be an exportable commodity.

We also heard here, as well as elsewhere, that the maintenance and renovation of aged buildings is a growing component of construction. This includes diagnosis, planning, design, and execution.

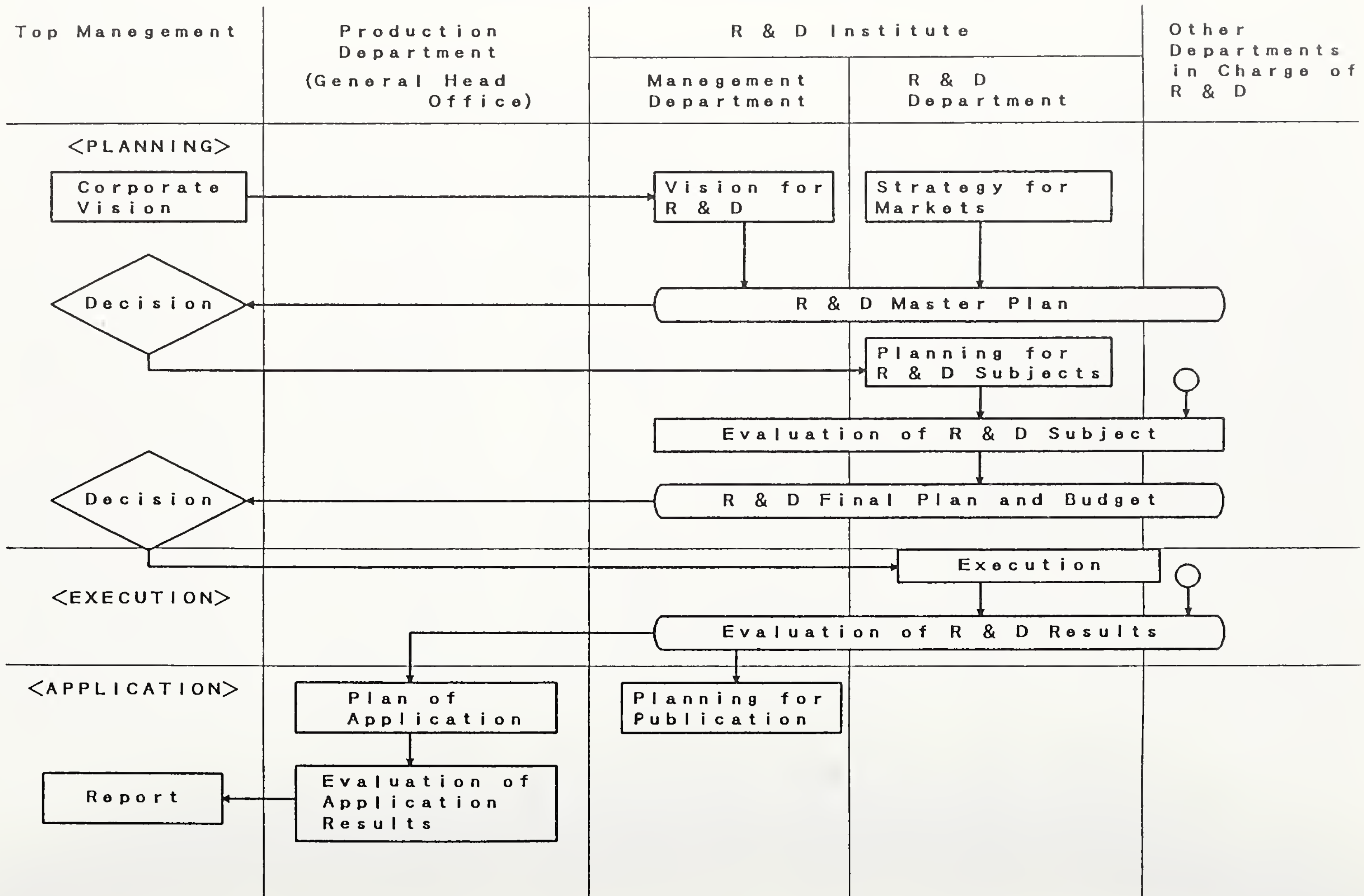
References:

Takenaka: Planners, Architects, Engineers & Contractors, Takanaka corporate brochure.

Takenaka Research and Development Institute, Takenaka corporate brochure.

Takenaka Technical Research Laboratory, Takenaka corporate brochure.

FLOWCHART OF RESEARCH & DEVELOPMENT IN TAKENAKA



Hitachi Construction Machinery Co., Ltd.
Tsuchiura Works

Date and Time: Thursday, June 15, 1995, 14:40-17:00

Participants:

U.S. Team Members: Thomas L. Anderson
Steven J. Bomba
Lloyd A. Duscha
Burton Goldberg
Noel J. Raufaste, Jr.

Japanese Hosts: Kozo Ono, Dr. Eng., Director, General Manager, Technical Research Laboratory
Minoru Shiozaki, Director, Senior General Manager, Tunneling Machine Division
Yasuo Tanaka, Senior Researcher, 10th Group, Technical Research Laboratory

Summary of Technical Visit:

This plant makes excavators, ranging in size from 0.74 tons to 350 tons, as their main product. They make other products as well, *e.g.,* crawler cranes, front loaders, tunnel borers, road crushing. Their products are sold domestically as well as internationally. They build excavators for the John Deere Company.

All of their excavators are under the control of one microcomputer: engine, arm, and end effector. The microcomputer does electrical system fault diagnosis. They have made the excavator sensor-rich to enable a hand-held maintenance and repair terminal to improve the availability of the machine. The machine is designed for fast repair and simple use.

The innovations they talked about have been in existence for several years. They are not new.

The pile driver/auger is a single arm robot built as an excavator with servo control on the arm. It is able to drill an 8 m deep hole and compensate for drill drift. The machine is a straightforward application of robotics to a rough environment machine. The end effector is moved with a single joy-stick control, a great simplification. The comment was made that the machine with electronics commanded a high price and big profit in the market, for they found the value to be high and the cost of electronics to be low. They have no competition for this machine, and they have patents related to its construction and functioning.

The remote-controlled rock removal equipment was made to remove volcanic debris from the foot of a still active volcano. Since that area was too hazardous for humans. they used a radio link to control a dozer and front end loader. Additionally, they established a linked 3D television system that permitted the tele-operator to sense the dimensionality of the work space. The controllability was found to be very satisfactory. The productivity of the machine was about half of what a human operator would obtain normally. The operator reported the operation of the machines to be similar to a TV game; for a person used to running an excavator he found it more comfortable than sitting in the cab and being jostled.

For these projects that require more than mechanical engineering capability it was said that the help on electronics and robotics was a result of the combined efforts of the research laboratory and the design department. The research laboratory was the source of nonconventional talent and ideas.

The shield segment assembly robot was reported with a video of its operation. It is a huge machine that works very well. It decreased assembly time by a factor of three in a dangerous and inhospitable environment. They use feed-forward control to roughly position the segment. Then they use structured laser light and a digital camera to do feed back control for the final positioning of each segment. The image processing was a development of the Hitachi, Ltd. This was another good example of moving technology for benefit within the firm. The demonstrated system integration of various competencies for competitive advantage. a paper will be published in October, 1995 describing this machine and its performance.

They stated that they went from the idea to a production machine in four years. In a year and a half they made a small (3.5 m) machine and then completed the large machine in the following two and a half years.

We then had a tour of a world-class factory. They make 35 excavators in 8 hours followed by 2 hours of maintenance. Ninety percent of all the welds are done with robots. The factory was neat and smoothly operating, albeit at low production. There is no smoking in the factory. Solvent recovery laws are stringent and carefully followed. Electronics was introduced into their machines 10 years ago, first as engine controls and now for hydraulics control.

References:

Annual Report, Hitachi Construction Machinery, Co., Ltd., 1994.

Technical Research Laboratory, Hitachi Construction Machinery Co., Ltd., undated.

Kawasaki Heavy Industries, Ltd.
Noda Works, Chiba Prefecture

Date and time: Thursday, June 15, 1995, 10:00-13:00

Participants:

U.S. Team Members: Thomas L. Anderson
Steven J. Bomba
Richard A. Cemenska
Lloyd A. Duscha
Burton Goldberg
Noel J. Raufaste, Jr.

Japanese Hosts: Sadao Izawa, Associate Director, Senior General Manager, Kanto Technical Institute
Toshio Atsuta, Associate Director, General Manager, Kanto Technical Institute
Kazuo Mizuno, Associate Director and Senior Manager of Noda Plant
Akira Aradate, Mgr. of Fabrication Dept.
Seiya Kato, Manager, Quality Assurance Department
Yasutaka Kuramochi, Manager, R&D Center

Summary of Technical Visit:

Mr. Mizuno reviewed the history and broad scope of Kawasaki Heavy Industries (KHI) activities, with an emphasis on the Noda Works. The Noda Works is one of three plants that make up the steel structures division of KHI. Noda Works started in 1964 and supplies fabricated steel structures to the Tokyo area, the eastern part of Japan and to overseas locations. Their principal products are bridges, building frames, storage tanks and structures/components for aerospace, marine and energy projects. The plant occupies 180,000 m^2, employs 500 persons and has a 6,000 ton/month production capacity.

The plant uses a Just-in-Time (JIT) production system, borrowed from Toyota and now specialized to Kawasaki's needs as the Kawasaki Production System (KPS). They believe their continuous flow production system enables them to have exceptionally high productivity for a steel fabricator. The Noda Works designs, fabricates and erects/installs their products using in-house design, production, and construction departments.

Mr. Aradate briefly reviewed the several brochures provided to the panel which describe the wide variety of products and technologies introduced by KHI over the last century. a special video presented their corporate vision for the 21st century and the technology innovation they believe will be needed to reach sustainable development. It covered areas as diverse as helicopters, outer space, underground structures, recreational equipment and baggage handling. Clearly, they see themselves as a very comprehensive engineering company.

Two construction technology innovations now in use or under development at the Noda Works were presented: KPS, represented by Single Unit Mixed Production and Conveyance System and Computer Aided Assembly System. a video described the KPS which enables a large variety of small quantity runs to be made productively in the shop using a multiple conveyer system integrated with JIT thinking. The mixed flow permits individual orders to be readily handled. The backbone of its success is careful planning and computer use, from fabrication requirements and process schedule to shop drawings and template preparation. Pieces as diverse as flanges, webs, brackets, stubs, ducts, stiffeners and ribs are carried on conveyers to each work station where assembly, fit up, tack welding, turning, automatic welding, inspection and straightening take place. All welding is done in the flat position and most welding is done by moving the work through the welding machine. Workers perform several processes at each station, with parts brought in by secondary conveyers. Assembles up to 35 tons have been accommodated. Ultrasonic inspection of welds is carried out by in-line "inspector" instruments. Defect rates run 2% to 3% (number of defects/number of inspected points).

The second construction technology innovation reviewed was their computer aided measuring and assembly simulation system. In conventional steel bridge construction in Japan it is normal practice to fabricate and then temporarily fully assemble a bridge structure at the fabrication yard for inspection and to ensure proper fit at the job site. This step is seldom taken in the United States. After inspection, the bridge is disassembled, painted and then shipped to the site for assembly. In an effort by the MoC and the Japan Highway Public Corporation to reduce costs, this pre-assembly step is being considered for elimination, to be replaced by a CAD computer simulation of the assembly. This approach is estimated to cut about 10 % from the fabrication cost of a bridge. Such a simulation requires careful measurement of each fabricated member. This potentially time-consuming process would be carried out with a 3D automatic measuring system located in the workshop at the end of the production line. Up to 40 measurement spots per member (bolt holes, flange edge locations, etc.) would be scanned by a laser instrument located 5 m from the member. a measurement accuracy of 0.5 mm (length) and 2 seconds (angle) for targets within 15 m are possible. The system is in the trial stage and they are developing their own assembly simulation computer software. They estimate the system will be ready for full trials in six months and will involve comparisons of simulated assembly with actual assembly. Currently, they have developed and are testing two 2D systems, one for longitudinal simulation and the other for lateral simulation. The secret to success of this system is that discrepancies (representing distortion) must be easily seen in the computer simulation displays. The laser-based measuring device is being designed to automatically select and focus on targets that would be attached to the structural elements. The system is being jointly developed by the steel and bridge groups at the Noda Works and is supported by the Kanto Technical Institute.

A tour of the workshop was conducted. We saw very high quality work, and the KPS system was very evident. Assemblies with many pieces, both thick and thin, were in various stages of production. Structural steel building frame elements seen in production were intended for steel reinforced concrete construction or box sections that would later be filled with concrete after erection and assembly. All connections between assemblies were designed to be made away from high stress column-beam intersections, and typically these were bolted connections. Steel joint connections fabricated under shop quality conditions and inspection are common practice in Japan. [We saw no exceptions during our stay in Japan.] During the shop tour a preassembled 100+ m span steel orthotropic plate girder bridge was seen awaiting inspection before disassembly and painting. Although automatic welding is used for all production line work, defects were seen being repaired by manual grinding and welding on the line.

In response to a question regarding how KHI stays technically advanced, it was stated that KHI believes it is "necessary to adopt all new technical advances in their field, such as welding and inspection, with a positive attitude."

Summary of Significant Findings:

- Use of JIT production system to handle single unit mixed assemblies efficiently

- Developing an automatic piece measuring and computer aided assembly simulation system to replace costly pre assembly of steel bridge structures.

- Impact of Japan's recession seen in some idle production lines

- KHI and Noda Works competes for MITI and other government-sponsored R&D in Japan. Their experiments with the free electron laser for industrial use was cited.

- KHI initiatives in Computer Aided Manufacturing (CAM) have been limited to electronic data exchange in-house between design and the production lines.

- Three and five year R&D plans have been made for each area of CAM.

- Steel erection is generally undertaken by a consortium.

- On shield tunnel projects, KHI delivers their product to a general contractor.

- Although KHI had constructed several large steel bridges over the past few years in the Kobe region, none of them received damage to the superstructure which they supplied. Damage, where it did occur, was limited to footings, caissons, shoes and approach spans due largely to ground failure.

- The Tuned Liquid Column Damper (TLCD) reported in their literature has seen limited use -- in two cases to dampen wind-caused swaying of bridge towers.

References:

Realizing Dreams through Technology, Kawasaki Heavy Industries, Ltd., Cat. No. 1A0062, Mar. 1994.

Noda Works, Kawasaki Heavy Industries, Ltd., Cat. No. 5R0081 Mar. 1993.

Steel Structures, Kawasaki Heavy Industries, Ltd., Cat. No. 3R1799, Mar. 1994.

Bridge, Kawasaki Heavy Industries, Ltd., Cat. No. 3R1278, Nov. 1993.

Computer Aided Assembly System - copies of overhead transparencies used in presentation

Komatsu Research Institute

Date and Time: Thursday, June 15, 1995, 14:00-17:30

Participants:

U.S. Team Members: Richard a. Cemenska
Ezra Ehrenkrantz
Richard G. Gann
Charles I. McGinnis
Boyd C. Paulson, Jr.
Kenneth F. Reinschmidt

Japanese Hosts: Mr. Tadayuki Hanamoto, Chief Research Manager, Tunneling and Boring Machine Group
Mr. Masao Kikuchi, Chief Research Manager, Plastic Products Group
Mr. Kazunori Kuromoto, Chief Research Manager, Group 1
Mr. Koji Ogaki, General Manager, Research Center
Mr. Hideyuki Takehara, Chief Engineering Manager, Construction Robotics Department
Mr. Kazuo Uehara, Chief Research Manager, Advanced Research Laboratory

Summary of Technical Visit:

The purpose of this visit was to gather input on future earthmoving and building construction equipment in Japan from a manufacturer's perspective. The topics discussed included the major thrusts for construction and building machine research at Komatsu, the advanced work being done at this research institute, and the future of construction robots. A shop tour was also included where prototype equipment was demonstrated.

The meeting opened with a video tape describing the worldwide activities of Komatsu including their design capability, parts support, joint ventures, machine tool products (large stamping machines), semiconductor products, electronics design, robotics capability, building material handling robots, mobile crushers, emissions control research, vibration and noise control technology, and simulation capability. Much of the information presented in the video is also available in a booklet "Komatsu Corporate Profile" given to US. Team members.

The scope of Komatsu's R&D for the construction industry was described in terms of how the core technology in four areas (mechanical structures, dynamics and control, sensors and components, materials, and diagnostics and intelligence) were being leveraged into four major product areas: earthmoving machinery, building machinery, tunnel machinery, and construction. Currently their

R&D expenses are approximately 6.6% of sales, which is down from the 7.2% value previously invested.

Countering the high value of the yen was described as a major problem facing Komatsu currently. The development of new technology providing higher value was presented as one strategy being used to combat the adverse exchange rates.

A technique for identifying opportunities for introducing new machines was described. Potential new sales segments were identified on a plot with the vertical axis being "Market Growth" and the horizontal axis being "Rate Of Mechanization." The Rate of Mechanization for a particular task was defined as the ratio of machine expense (used to do a task) divided by the sum of the machine expense plus the cost of those elements of the task that are not yet mechanized. By this method, tasks that are highly labor intensive have a low score for "Rate of Mechanization." Market segments having a high growth rate and a low Rate of Mechanization are identified as candidates for new machines. Industrial cranes and factory robots were identified as two segments for which Komatsu is currently developing new equipment.

Two future market needs for earthmoving equipment were identified as excavators capable of operating in tight space constraints and alternatives to "digging." Existing products are also being updated to meet new market needs. Examples cited included new mini-excavators for better versatility, electronic controls added to hydraulic excavators (HEs) to provide easy operation, and autonomous control systems for off-highway trucks used on large mines.

HEs are expected to remain the "workhorse" on many Japanese construction sites for the foreseeable future. Very small units are needed for the basic market with attachments, such as hydraulic "breakers," used to handle a wide variety of tasks. Komatsu is changing the "shape" of the body making it more rounded to allow use in small confines and is developing new linkage configurations (such as used on the PC75UU-2) which allow complete operation in only one lane of the roadway. Many of the small units are in the rental fleet which is expected to continue to be the case in the future.

Larger HEs are using automatic control technology to improve their capabilities. New machines have an array of sensors on board (*i.e.*, hydraulic pressure, pin angle, and cylinder stroke) to allow semi-automatic operation. a number of examples of available work modes were reviewed including: auto-slope, digging depth control, bucket hold, auto-grade, ditch finishing, high/low limit settings. The sensors are also being used to improve operator comfort through dynamic linkage damping and to reduce noise through controlled approaches to hydraulic cylinder limits.

Komatsu has experience with a number of advanced vehicles including an undersea track type tractor (TTT), an unmanned wheel loader (WL), an automatic TTT (requires operator input only for forward/reverse and steering), and a "breaker" with a 3-D video system for tele-operation. They also discussed an unmanned OHT that has a "learn" mode to establish the route and a "replay" mode for vehicle operation. The truck uses a number of safety systems for collision avoidance including lasers, ultrasonics, and mechanical. It does not currently use Global Positioning Systems (GPS) technology but could if required. It is currently for sale only in Japan.

Komatsu is involved in a joint venture on a MITI-sponsored project to demonstrate a system capable of manufacturing pre-cast concrete beams four times faster than conventional (manual labor) techniques. The driver for this project is the anticipated shortage of skilled workers willing to do this type of job. A prototype system is operational that automatically cuts and bends the reinforcing bar and ties them together. A hardener is used to speed the curing time of the concrete. Currently a beam can be removed from the mold after 30 min. and it can be lifted after 3 hours. The prototype system requires only one worker for distributing the concrete into the mold and has demonstrated twice the productivity of manual systems. They expect to meet the four times goal for improvement.

The problem of high construction costs in congested areas was discussed. New low rise residences are expected to use more pre-fabricated panels, modules, and structural elements in the future. A new line of equipment is being developed to meet the new material handling requirements which are expected to be heavier and more "bulky" than conventional construction practices typically require. Examples presented included the LT300 Reach Tower Crane used to lift material from the street, the LC08M-1 (small crane for inside use - has extension boom), the LS300 Material Handler (small unit for inside use - positions pipes for welding, glass sheets, and similar applications), and the CZ50 Material Handler (compact rubber belted unit for lifting and transporting heavy loads, such as pre-cast concrete beams, inside buildings). All of these units are designed to operate effectively in tight quarters. A related product group, mobile crushers, has also been recently introduced for use at demolition/rebuild construction sites to process scrap concrete and other hard materials for disposal or use as fill material. These units utilize a magnetic device to remove metal from the material.

Research is being done on techniques to install underground services without excavation. a pipe jacking system was reviewed that incorporates special cutters to allow use in applications where rock is present.

Komatsu has built a demonstration version of a soft rock bed sharp-curved tunneling machine for use in MITI's Underground Space Development Technology Project. The machine can excavate continuously in sharp curves with a minimum radius of 7 m. Their conventional tunneling machines use electromagnetic sensing radar (500 MHZ) to detect buried objects (pipes, etc.) *ca.* 1 m in from of the cutting head.

They are participating with Mitsubishi Chemical to develop applications for Carbon Fiber Reinforced Plastic (CFRP) Rod as a replacement for conventional reinforcing bar. This material has been used at several demonstration sites in the United States and Canada starting in 1993. The characteristics of the CFRP rod can be tailored to meet a variety of application needs.

After the presentations, Komatsu hosted a tour of their labs with a focus on new vehicles and technology under development. Equipment demonstrated included a portable welding robot capable of measuring joint characteristics and setting welding parameters accordingly, a segment assembly robot for shield tunneling machines, and a small HE equipped with a manipulator arm capable of lifting pipes and other similar components for final positioning.

The general subject of automation in the construction industry was discussed briefly after the tour. Their opinion was that autonomous equipment would not have a major impact on construction sites for the next 10 years. It was suggested, however, that autonomous trucks for mining applications would be in regular commercial use in less than 10 years.

Significant Findings & Impressions:

Komatsu is a diverse company with business interests in construction equipment, components and systems, industrial machinery, software, electronics, plastics, and construction, housing and real estate. Many of these businesses operate from a worldwide base.

Their construction equipment business designs, manufactures, and markets products worldwide.

The projects and discussions that took place during this meeting indicated that at least one segment of their construction equipment research agenda is focused on meeting the needs for building construction equipment in Japan with a major focus on material handling. A second focus is semi-automatic controls for existing products such as hydraulic excavators. These examples are part of their strategy to counter the high value of the Yen and increase margins by introducing technology and machines with high value into new markets.

Autonomous construction equipment is not expected to be in common use in the next 10 years with the exception of large off-highway trucks in mining applications which will be in commercial service sooner.

Their worldwide presence has given them access to the same level of technology available to construction equipment manufacturers in the Japan, Europe and the United States. Product differences between the major equipment suppliers are primarily due to varying business strategies and the need to use existing manufacturing assets.

References:

Komatsu Corporate Profile, corporate brochure, undated.

Several corporate brochures describing the equipment described above, in Japanese.

Nippon Steel Corporation

Date and Time: Wednesday, June 14, 1995, 13:00-17:30

Participants:

U.S. Team Members: Steven J. Bomba
Edward E. DiTomas
Mr. Ezra Ehrenkrantz
Noel J. Raufaste, Jr.
Kenneth F. Reinschmidt

Japanese Hosts: Mr. Komei Fukuda, General Manager, Construction & Architectural Materials Division
Mr. Yoshio Nakazawa, Group Manager, Marketing & Engineering Service Department
Mr. Noriyuki Kawabata, Manager, Construction Materials Development & Engineering Service Division
Mr. Morio Seiryiu, Group Manager, Cable Structure Design & Technology, Development & Engineering Services. Division
Dr. Eng. Yoshifumi Sakumoto, Senior Manager, Architectural Materials Development Department

Summary of Technical Visit:

Nippon Steel was founded in 1934 as the Japan Iron and Steel Company. In 1995, it employed over 44,000 persons. In 1995 they had sales of ¥2.1 trillion ($25 billion) and produced 25.3 million tons of steel. Our meeting was in their Tokyo Headquarters.

Nippon Steel's mission is to: identify and meet customer's needs, develop design methods that achieve Green Technologies; and increase profits. Nippon Steel's strategy is to better exploit Japan's construction market for steel. This decision is based on 1994 statistics that Japan's domestic volume of iron was 64.5 million tons of which 31.5 tons (49%) were used in construction.

Nippon Steel has been developing a fire resistant (FR) steel to promote their product line based on the rationale that the product would appeal to designers because it eliminates the need for fire protection material as required by *Japan's Building Standards Act* and gives designers greater artistic flexibility. The Act requires that building have a three-hour fire rating and that temperatures shall not exceed 350 °C on average. Nippon Steel started work on FR steel in 1988 through a French steel maker, Creusot-Loire Company. Research was conducted to evaluate steel's tensile strength and high temperature yield point by adding molybdenum and niobium. The FR steel resists a load corresponding to the allowable stress under permanent loading at 600 ℃. The FR steel meets The

Ministry of Construction's *Design System for Building Fire Safety (1988)* modification. The FR steel is being incorporated in several Japan buildings. Mo steel has not yet been commercialized. Our Nippon Steel hosts estimated the cost of using this new material will increase structural costs by 25%.

Nippon Steel has developed a proprietary computer simulation of the structural response of a building to a fire. The model demonstrates the value of FR steel. They sell this model to their competitors for about ¥10 million.

To increase profits, Nippon Steel was reorganized to nurture a strong international presence. Factories for sheet steel production were modernized; they are developing new products such as aluminum alloy steel for automotive industry. Their electronics and information business addresses VLSI and semi-conductors; new materials focus on advancing knowledge of silicon wafers, gold bonding, ceramics for use in semiconductor equipment, and soft ferrite cores. Their chemical industry is seeking ways to better use by-products to produce construction materials such as blast furnace slag to produce construction aggregates, work is underway on special flexible circuit boards and they produce carbon fibers.

Nippon Steel discussed the fabrication and installation of their high strength steel cables for the almost 4 km length Akashi-Kaikyo Suspension Bridge which crosses the Akashi Straits between Honshu and Awaji. Construction is expected to be completed in 1999 at an estimated cost of ¥470 billion ($5.7 billion). Their 1.12 m diameter main cables were erected by the prefabricated strand method. Approximately 200,000 tons of steel will be used in the superstructure.

Cable strands, comprised of 127-5.23 mm diameter galvanized wires were factory fabricated in 4,085 meter lengths. High strength wire with 1760 MPa (255,000 psi) tensile strength was used rather than the standard 1560 MPa (225,000 psi) wire. Each strand was transported to the construction site where it was pulled from one anchorage over the saddle of each tower and fastened to the opposite anchorage frame. This procedure was repeated 289 times to fabricate each main cable. Nippon Steel extended U.S.-designed parallel wire strand for cable fabrication and erection. The advantage of using this method is the strands are continuous from anchorage to anchorage and eliminate the in place spinning of cables, thus reducing the probability of accidents occurring. In order to use the parallel wire strand method, a unique cable squeezing machine was designed to form the parallel strands into the final circular shape by vibrating each of the 290, 127-wire strands (36,830 wires) into a round shape with a void ratio of about 18%.

The use of a higher strength wire, 1760 MPa (255,000 psi), reduced the number of strands required, thus saving erection time and cost. Use of the higher strength wire also reduced the number of suspender ropes from four to two needed to connect each stiffening truss panel point to each cable hanger attachment on the main cable. This also reduced erection time and cost.

Another project highlighted was Nippon Steel's use of titanium alloy for corrosion protection. They recently developed a titanium cladding over a 5 m section in the splash zone of bridge piers to protect against corrosion. The procedure involves a thin layer of copper placed between a 1 mm titanium sheet and the steel column facing. Using a hot rolling process to squeezes out molten titanium-copper inter-metallic compound which oxidizes with the residual air forming a bond of 180 MPa or higher. The cladding process was the first ever used in a construction application. This work in corrosion protection was performed at Nippon Steel's Steel Research Laboratory near Tokyo.

During 1993, Nippon Steel staff published over 500 technical papers and reports on various aspects of steel manufacturing, fabrication and use. The reports are available in the open Japanese literature; some are available from the U.S. National Technical Information Service (NTIS).

Summary of Significant Findings:

Nippon Steel is pursuing several approaches to new materials, products, processing hardware, and computer software that will reduce construction time and cost and improve design flexibility.

Follow-up:

It would be useful to verify the performance of the new products and to understand better the roles of the participating parties in their development, especially relative to Nippon Steel's in-house R&D capabilities. It would also be useful to understand the relationship between product and technology suppliers, such as Nippon Steel, and the construction companies.

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FR Steel, Fire-Resistant Steel for Building Structural Use, October 1992.

NKK Corporation

Date and Time: Wednesday, June 14, 1995, 09:30-12:30

Participants:

U.S. Team Members: Steven J. Bomba
Edward E. DiTomas
Ezra Ehrenkrantz
Noel J. Raufaste, Jr.
Kenneth F. Reinschmidt

Japanese Hosts: Dr. Mitsuyuki Hashimoto, Senior Engineer, Bridge Construction and Engineering Department, Steel Structure, Machinery, and Construction Division
Mr. Hisatoshi Shimaoka, Manager, Technology Development, Building and Construction Department, Building and Construction Products Center
Dr. Osamu Yamamoto, General Manager, Planning and Coordination Department, Research and Development Division

Summary of Technical Visit:

The NKK Corporation Research and Development Division consists of the Applied Technology Research Center, the Materials and Processing Research Center, and the Engineering Research Center. The discussions between the Panel and NKK Corporation focussed around specific two technology development case studies presented by NKK: the development of ribbed tubes and the development of design and fabrication software.

Mr. Shimaoka presented the work on development of ribbed tubes. NKK's research arises from a consideration of the social demands required by Japanese society. Among these are: larger and higher structures, increased usable space, environmental conservation, improved working conditions, and shortage of construction workmen. These social demands generate demands on structures, among which are: high strength and high ductility for seismic protection, smaller structural sections, decreased waste, shorter construction periods, and construction manpower reductions.

In response to these, NKK has developed new construction materials, including sheet piles, tubes, H-sections, beam sections, and column sections. The NKK ribbed tube technology was developed starting ten years ago and has been approved by the Ministry of Construction prior to use, as all construction materials and products must be by law. The policies and views of the NKK Corporation are said to be identical with those of the Ministry of Construction.

In construction, steel and concrete have been competitors. Steel has high tensile strength and high ductility, but its high stiffness makes it subject to buckling instability. Concrete has high compressive strength but low tensile strength and high fragility. Composite design resolves this competition by using steel and concrete in ways which exploit their natural strengths. In conventional reinforced concrete columns, low tensile strength concrete is balanced by high tensile strength steel, but in composite columns with concrete-filled steel tubes, buckling of the steel is prevented by the concrete. In ribbed tube composite columns, there is clear composite action, stress transmission between the concrete and the steel, and high bond strength due to the ribs.

In the rolling mill, ribbed plates are formed by rolling steel strip between a flat roll and a grooved culiver roll. The ribs are spaced 40 mm on centers. The ribbed sheets are spiral-welded to create a tube with helical ribs.

NKK Corporation has performed testing to determine the optimal height of the ribs. If the ribs are not high enough, the concrete bond with the steel breaks and there is sliding at the steel-concrete interface; the result is low strength and low rigidity. If the ribs are high with respect to the concrete shear strength, the concrete shears; the result is high strength and high fragility. At the optimal rib height, failure is by local crushing of the concrete between the ribs; the result is high strength and high ductility. The optimal dimensions are:

rib height: 2.0-4.5 mm
spiral angle: 30-75 degrees
rib height to shear strength ratio: 0.05-0.15

Applications of the ribbed tubes include:

- cast-in-place reinforced concrete piles, with inner ribs;
- composite columns, with ribs on the outside of the square tubes; and
- composite soil-cement tubular piles, with outer ribs.

Comparing conventional cast-in-place reinforced concrete piles with piles using ribbed tubes, those made with the ribbed tubes:

- use the same amount of steel,
- reduce pile volume and the volume of soil displaced by 30%,
- reduce concrete volume by 30%,
- reduce the work period by 10% to 20%, and
- absorb twice the energy for antiseismic protection.

In the construction of soil-cement composite piles, a hole is drilled in the ground, the soil is mixed with cement milk, and the ribbed tube is installed into the soil-cement column. Soil-cement composite piles carry loads by both bearing and friction. In the point bearing layer, at the lowest depth, the ribs are both the inner and outer surfaces, whereas in the friction layer up to the surface, ribs are on the outer surface only.

Composite performance depends on the mechanical bond between the soil-cement and the steel pipe. The bond strength between the pipe and the soil-cement inside is sufficient to carry the bearing load. The carrying capacity of composite soil-cement piles is determined by its dimension, not by the dimension of the steel tube; ribbed tubes, which increase the friction factor, therefore result in more efficient use of the steel.

The NKK Corporation is proposing the use of ribbed composite columns for bridge piers on the Second Tomi Expressway in mountainous areas, where the piers are 50 m to 100 m high. In this proposal, clusters of outer-ribbed tubes would be used inside precast concrete shells; cast-in-place concrete would fill the space between the ribbed tubes and the precast shells. Normal strength concrete, 240 Newtons per square millimeter, is used. No increase in the design strength of the concrete is allowed due to the confinement of the concrete by the steel pipe. The cost premium for the ribbed tubes, compared to normal steel pipe, is ¥16,000 per ton, or about 15 %.

Development of this technology began in 1985 and reached the point of manufacture 2 years later, in 1987. Since then, 30,000 tons per year of ribbed tubes have been used for composite concrete piles; the total volume used for composite columns in the 7-year period since 1987 is several thousands of tons. The soil-cement application was approved by the Ministry of Construction four years ago and only a few cases have been built; some construction is in progress.

The ribbed tube is covered by NKK patents, and the Ministry of Construction is reluctant to allow the use of construction technologies that are proprietary to a single company. Deployment of ribbed tube technology might have been faster if it had been developed by a joint venture or consortium of several companies. The Ministry of Construction is now considering a new approval system to open up technology development in the private sector.

Dr. Hashimoto presented the development of the computer software system BRISTLAN, or Bridge Structure Lofting Language. This system was derived from earlier computer systems:

Steel Production Systems: Bridge and Steel Structures Lofting Language (1971)
Integrated I-Girder fabrication System (1985)
Material Takeoff and Cutting Plan System (1985)

Steel Design System: I-Girder Design (1975)

The new BRISTLAN is a completely new code, but the functionality and interfaces are based on the earlier systems to facilitate switch over. The system integrates design, fabrication, and construction, and is based on a three-dimensional database. The Design System provides structural axis single-line definitions, three-dimensional coordinate definitions, and three-dimensional member definitions using wire frames, surfaces, and solids. It supports parent-child inheritance of attributes and a hierarchy of bridge blocks.

The Integrated Fabrication System produces data for numerically controlled tools for cutting, welding, and assembly. It provides definitions of fabrication methods and member development in blocks, pieces, and groups. Parts are nested on plates for efficient cutting. The system determines the optimal path for laser cutting, under the constraint that the laser tool cannot retrace its path; this path determination is difficult and very time-consuming, and often must be done manually. Plasma arc cutting is also used.

The Monitoring System and Output System provide inspection drawings, structural coordinate drawings, and member piece drawings, NC data, manufacturing drawings, member lists, and assembly drawings. Pieces are marked automatically and welded by robots.

The NKK corporate system includes Local Area Networks and Wide Area Networks in the factories.

The client receives the inspection drawings, but no transfer of the electronic information for subsequent use by the owner for maintenance or other purposes has been contemplated. Structural analysis of the bridge could be integrated with the system, but is not at the present time; structural analysis and design are performed separately by the client's consultant and the bridge design data are re-entered manually into BRISTLAN. In one major bridge application, NKK Corporation is fabricating one-half of the bridge and Mitsubishi is fabricating the other; there is no interface between the systems used by the two fabricators.

The Design System took three years to develop and the Fabrication System took three years more. All coding was in the C language. The BRISTLAN system is not based on any commercial Computer-Aided Design (CAD) system, but macros for computer graphics manipulations were purchased from an outside software house. Oracle is used for the database. There is no provision for electronic output, although Dr. Hashimoto suggested that DXF format output might be considered in the future.

According to NKK, the use of these systems since 1971 has reduced costs and improved quality, but the primary justification seems to have been in client presentations, in order to secure more business for NKK Corporation.

Summary of Significant Findings:

It appears that a straightforward evolutionary product improvement, ribbed steel tubes for composite columns, takes as long to introduce in Japan as anywhere else, and that the Ministry of Construction may not have been active in accelerating this deployment because it is proprietary to one company, as opposed to the product of a joint venture or consortium, which would provide a higher confidence level.

The bridge structure lofting system appears to be a competent and successful package meeting the internal needs of NKK, as developed over a period of more than 20 years. It does not, however, push the state-of-the-art of software development. It apparently does not include functions such as material control or erection sequencing. It is not integrated with other functions, such as bridge structural analysis or bridge maintenance, because these functions are performed by others (consultants and customers, respectively), neither does it provide direct electronic input or output to interface with these external functions. The client apparently receives the same output product as before, hard copy inspection drawings. Although NKK says that presentations of this software help it to get work, presumably the desired effect is to display a high degree of competence, quality, and efficiency rather than to provide specific value to the customer. The system has not affected the process of bridge engineering, fabrication, and erection nor was it intended to; it automates certain parts of this process that belong to NKK as steel supplier, fabricator, and erector. Although no information is available to compare this system with any used by others such as Nippon Steel or foreign steel fabricators, it appears to be competent, cost-effective, but not extraordinary.

Deep LNG & LPG Storage Tanks at Ogishima [Shimizu Corp. and Taisei Corp.]

Date and Time: Tuesday, June 13, 1995, 09:00 - 12:00

Participants:

U.S. Team Members: Edward E. DiTomas
Lloyd A. Duscha
Ezra Ehrenkrantz
Richard G. Gann
Boyd C. Paulson, Jr.

Japanese Hosts: Mr. Takashi Nakajima, Gen. Mgr., No. 2 Design Dept., Civil Engr. Div., Shimizu Corp. (Designer of LNG tank)
Mr. Nakashima, Site Manager, Shimizu Corp.
Mr. Sugino, Construction Manager, Shimizu Corp.
Dr. Aketo Suzuki, Mgr., Const. Engr. Dept., Civil Engr. Div., Taisei Corp.
Mr. Yasuo Tsubone, Site Manager, Taisei Corp.

Summary of Technical Visit

This visit served two functions. First, Mr. Nakajima provided an overview of Shimizu and some of their current R&D priorities; Dr. Suzuki provided a similar presentation for Taisei. Second, we learned about and visited the construction sites of Shimizu's deep LNG and Taisei's deep LPG tanks at this site. These were independent adjacent projects for Tokyo Gas, not joint ventures.

Shimizu's general presentation reflected a shift in emphasis away from the high technology, megastructures and long-term thinking that were emphasized in the 1990 visits. Instead, issues like providing more comfortable living environments, historic preservation, and sustainable development have come to the fore.

Taisei's presentation echoed some of these themes, but also had a more technical emphasis, including their development of "Biocrete," a concrete material that is highly workable in placing, needs little or no vibration to cover dense rebar configurations, yet retains the structural integrity and durability of more conventional concrete. They also described some new tunnel boring machines (TBMs) that (a) have mechanisms for making sharp horizontal and vertical turns, and (b) have a smaller TBM nested within a larger one so that the smaller one can excavate alcoves and passages laterally from the main tunnel. If these machines work as designed, they are significant innovations that would be valuable in urban tunneling (*e.g.*, allowing sewers to follow street grids) and in constructing underground nuclear waste disposal facilities (alcoves used for storage, tunnels for access).

Japan's strong seismicity combined with soft sedimentary coastal areas, plus its near total dependence on imported energy supplies, stimulated research in the late 1960's and 1970's to construct large underground storage tanks for LNG and LPG. The basic research included safe proximity of nearby tanks in the case of leaks that froze and expanded soils, cryogenic behavior of concrete, and materials handling systems. They have now been building these tanks for 2 decades. While there was little new to see in these visits to the adjacent Shimizu and Taisei LNG and LPG tanks, they did reflect state-of-the art scale, designs and construction methods. Both used slurry walls 60 m to 66 m deep for their primary containment structures, with secondary concrete liners 1.5 m to 2.2 m thick constructed as excavation proceeded to depths of 40 m to 60 m. The Taisei LPG tank was smaller, at 60,000 m^3, and used a deep 66 m slurry wall (36 m below the bottom of the tank) as an uplift cutoff to allow for a comparably thin (1.5 m) concrete bottom slab. The Shimizu LNG tank holds 200,000 m^3 and uses a heavy (9.8 m thick) bottom slab to resist uplift. Both tanks are to be covered with 5 m to 10 m of soil (taken from the excavations), bringing the height of this part of the artificial Ogishima Island to 14.4 m above sea level.

Summary of Significant Findings:

The general technical capabilities of large companies such as Shimizu and Taisei have been well publicized and thus there was little in the presentations that was not already known. However, both presentations certainly reflected companies with very strong technical and organizational capabilities that can undertake large and complex projects anywhere in the world. They are continuing to innovate, often in cooperation with manufacturing and materials companies, so they should remain competitive in the future.

References:

Civil Engineering, Shimizu corporate brochure, Tokyo, August 1993.

Rotating TBM, Technical Report, Taisei Corporation, Tokyo, 1994.

Taisei Super Workable Concrete, Biocrete 21, Technical Report, undated.

Technical File, a 130-page collection of reports on Taisei technologies, Taisei Corp., Tokyo, undated.

The World's Largest Underground LNG Storage Tank, Shimizu corporate brochure, Tokyo, undated.

Harumi-1-chome District Renovation Project
[Mitsui Construction Co., Ltd.]

Date and Time: Tuesday, June 13, 1995, 13:30-17:00

Participants:

U.S. Team Members: Thomas L. Anderson
Steven J. Bomba
Richard A. Cemenska
Burton Goldberg
Charles I. McGinnis
Noel J. Raufaste, Jr.
Kenneth F. Reinschmidt

Japanese Hosts: Mr. Shun-Ichiro Kamijo, Senior Managing Director
Mr. Tuneo Kikuti, Project Manager, Harumi Redevelopment Project
Mr. Toshihiko Nagusa, General Manager, Technical Development and Planning Department
Mr. Yoshihumi Nakagawa, Civil Business Marketing Division
Mr. Tatunori Sada, Technical Research Institute
Mr. Seinosuke Sawa, Civil Business Marketing Division
Mr. Takashi Sato, General Manager, Design and Planning Division
Mr. Kentarou Tokura, Technical Research Institute
Mr. Shin-Ichiro Yagi, Project Manager, Harumi Redevelopment Project
Mr. Kazuhisa Yahagi, Director General, Technical Research Institute

Summary of Technical Visit:

The purpose of this visit was to gather input on current design and construction practices for high-rise apartments from a construction company's perspective. The topics discussed included construction site management and construction applications of global positioning systems (GPS). A tour of the River City 21 Residential Community managed by Mitsui was also included to provide an example of typical interior layout and designs used in new construction in Tokyo.

The meeting took place at the site of the 50-story apartment building in the Harumi-1-chome District Redevelopment Project (HDRP) in Tokyo. A complete tour of the construction site was planned but had to be cut short due to rain. The visit consisted of a one-hour overview presentation in a conference room at an adjacent building, a guided tour of the site from the 3rd floor walkway at the adjacent building, and an on-ground demonstration of the global positioning system (GPS) being developed by Mitsui Construction. Following that, the team moved to the River City 211 Residential Community to see an example of a typical large urban residential complex in Tokyo.

The HDRP project is a 50-floor complex with 632 residences. Once completed, it will be the tallest residential complex in Japan and will incorporate accelerographs to provide data for future use. The project is owned by the Housing and Urban Development Corporation (HUDC). Mitsui was awarded the contract by open bidding.

The building is supported by end-bearing piles set into bedrock 34 m down using proprietary pile-driving equipment. The basement excavation and finishing and above ground floors are progressing simultaneously to speed construction. The steel structure is being completed at a rate of 6 days per floor with 300 workers on site. (This was said to be about one half the typical number of workers for a site such as this.) Computerization was offered as one technology being used to reduce the number of workers required. Material control was mentioned as one example of innovative computer usage at this site. The ordering, delivery dates, quantities, and material tracking will be controlled by computer.

The complex will be protected with an automatic fire sprinkler system. This is apparently a first for residential construction in Japan.

Mitsui has pursued computerized systems since 1987. They introduced CAD systems and building construction robots to their business in 1987 and in 1989 began to use computer integrated construction systems. At that time, the technology was being used to improve worker productivity, counter the anticipated worker shortage, and to boost the "image" of the construction industry. In 1992 the technology and systems began to be used for different purposes including a strategic information system to win jobs, improved profitability, and a supporting system for projects under unfavorable order conditions.

The current practice at Mitsui for large scale projects is to connect major departments together with LANs to allow convenient sharing of CAD data. For this project, computer simulation was used in planning the excavation and to evaluate construction alternatives. Systems are also in place for computerized monitoring and control of the finishing process including links to the manufacturer (ordering, and delivering) and job site (assembly and transportation). The HDRP project has 13 terminals on site to support the project. These terminals will be entry points for data on material flow as well as documentation of personnel on site through the use of magnetic ID cards. The magnetic cards will also allow the tracking of individual worker locations and will be tied to a safety system that will sound an alarm if an attempt is made to lift an object over his position. The specific sensing technology for individual worker location was not explained in detail.

Additional questions were asked on the subject of job site computerization and the responses are summarized below:

- Pocket terminals are used to enter the locations of major structural members such as beams and columns into the computer system.

- Bar codes are used to identify and track major components such as wall and floor sections, but not for smaller components such as light switches. The overall material tracking system was said to be an adaptation of an existing system.

- Approximately 50 workers will be expected to enter data from bar codes and to document the work of subcontractors.

Questions were asked about two other areas: women in the workforce and safety.

- Women are currently only gradually coming into the workforce and are mostly involved in finishing operations.

- A safety meeting is held every morning at 8:00 a.m., where the day's work is reviewed and any unusual safety related issues discussed.

After discussions on the HDRP building were concluded, a demonstration of proprietary GPS technology was held. The system is described in detail in a Mitsui publication "Navigation-Type Surveying System Using Real-Time Kinematic GPS." The basic technology (Real Time Kinematic GPS - RTK-GPS) is attributed to a U.S. manufacturer. The major benefit of the system developed by Mitsui is the ability to output the results in real time accurate to within 20 mm. It is currently being used in a number of surveying applications on 12 construction projects. It is not being used on the Harumi project because the proximity of tall buildings blocks the view of the GPS satellites.

The visit concluded with a trip to the "River City 21" residential community which was also mentioned in the 1991 JTEC report. The particular apartment visited was a three-bedroom unit of approximately 90 m^2. The rent was estimated at approximately $8100/month. Overall, the styling was similar to units found in the United States although somewhat smaller.

Summary of Significant Findings:

The HDRP project appeared to be well planned both in initial design and in the actual construction. New technology was being introduced to improve material flow and documentation of the "as built" conditions. The strategy to excavate and finish the basement in parallel with the construction of building the structure appeared to save several weeks from conventional methods.

The overall implementation of GPS for site surveying appears to be consistent with practices of other leading contractors in Japan and the United States. The use of GPS technology in construction applications in Japan is expected to continue to grow.

The River City 21 community is well-planned and provides convenient access to many services.

Tokyo International Forum, Glass Hall Project [Obayashi Corp. and Kajima Corp.]

Date and time: Wednesday, June 14, 1995, 13:30-16:30

Participants:

U.S. Team Members: Thomas L. Anderson
Richard A. Cemenska
Lloyd A. Duscha
Burton Goldberg
Charles I. McGinnis
Boyd C. Paulson, Jr.

Japanese Hosts: Kouichi Fujii, Manager, Obayashi Corp.
Hiroaki Kuzuwa, Project Director, Obayashi Corp.
Takekazu Mizumaki, Senior General Manager, Obayashi Corp.
Shin Tawara, Project Planning Manager, Obayashi Corp.
Kaname Tonoda, General Manager, Obayashi Corp.

Summary of Technical Visit:

The Tokyo International Forum is a complex of five buildings under construction on the site of the former Tokyo Metropolitan Office Buildings, located adjacent to the southern end of the Tokyo subway/railway station and immediately east of the JR railway right-of-way. The Glass Hall is designed to be the centerpiece structure of the Forum. The facility is intended to be the center for cultural activities and, in the words of the government, "provide the inspiration for hope for the 21st century." Its scheduled completion is in 1996. Construction of the Forum is a joint venture, with Obayashi and Taisei being the lead entities. Kajima is involved in carrying out the Glass Hall construction.

The entire Tokyo International Forum project is estimated to cost ¥150 billion ($1.8 billion), exclusive of the land which is already owned by the government and valued at about ¥230 billion. The Glass Hall is estimated to cost ¥40 billion, and ¥55 billion is estimated for the other structures. Electrical, mechanical, HVAC and other utilities are being handled by separate joint ventures. Many contractors are involved in order to spread risk, transfer technology and distribute the work in the industry. The site has an area of 30,000 m^2.

The Forum facility will feature a 5000-person capacity main hall for the performing arts, a smaller concert hall, a theater, exhibition rooms, convention hall, large gallery and support facilities, all accessible from the Glass Hall at several levels, served by sky bridges. The Glass Hall has a unique lens-shaped plan and is entirely glass covered. This enclosed atrium measures 208 m long, 32 m wide and is 70 m high. The firm of Rafael Vinoly is the U.S.-based architect for the project.

The roof of the Glass Hall is made of a cable structure resembling the keel and ribs of a long, slender boat. It is supported on two fire-resistant steel columns. The 620 individual rods that connect between ribs and thereby make up the cables were pretensioned by jacking the ribs together at the center of the truss. The tendency for torsional motion of the roof truss is resisted by 38 equally spaced vertical cable trusses extending from the roof truss to the ground floor on the west side and from the roof truss to the top of the conference center on the east side. Cables in the vertical trusses were post tensioned through an assembly located at the base beneath the floor level. The overall effect achieves a graceful, light, open and highly "transparent" structure of immense scale. The structure is fitted with 2.5 m square glass panels made up of two 8 mm thick panes bonded together. The fittings used in the cable truss, and the east side glazing were supplied by U.S. manufacturers.

The design of the Glass Hall featured earthquake, wind and erection load evaluations using a supercomputer and full-size component tests. Analyses for earthquake included four design events including 1.5 times the 1940 El Centro record and an artificial record representing the 1923 Tokyo earthquake. A lateral roof drift of 26 cm was calculated for the maximum seismic condition. Wind tunnel tests of the Forum facility were conducted in Canada and the results used to establish design wind and anchorage loads. Design values were less than code-specified forces that would have been required in the absence of such tests. Verification tests were conducted on a full size cable truss to assess static strength for both axial and bending loads, to aid in erection evaluation and to support the constructability assessment. A full-size mock-up of glazing panels and support mullions (featuring a sliding joint to accommodate frame drift) was tested (static and dynamic) for wind, earthquake, roof loads and water deluge to verify structural integrity and leak tightness. Wind displacements are calculated to be 1.5 times that for a conventional high rise building. Tests confirmed the glazing system could perform properly up to wind velocities of 60 m/s, well above the typhoon wind requirement.

All finishing elements and support structure used for the 5000-seat concert hall are isolated from the primary structure with rubber pads in order to reduce transmission of unwanted structure-borne noise into the chamber. The two decorative, tapered roof support columns are cast of fire resistant steel and are 50 m long with a maximum diameter at mid-height of 4.5 m. They are laterally supported at two locations along their length. These elements use internal stiffening ribs and are concrete filled.

The Obayashi Research Institute also analyzed the structure and confirmed the rigging procedure for construction. Computer analyses were carried out for all stages of erection, especially the cable truss roof structure.

The Glass Hall was constructed with simultaneous foundation excavation and superstructure erection. The superstructure roof system was erected using the jack down method. These techniques have proven to be faster, safer and cheaper than conventional methods. The 30 m deep diaphragm wall foundation was complicated by the need to accommodate a subway tunnel which runs 2 m to 3 m below the original ground surface across one corner of the building footprint. The cable truss roof was first assembled and pretensioned on scaffolding at the roof elevation. It was then jacked down on to the two support columns. Following this operation the vertical cable trusses were connected and tightened, followed by addition of the curtain wall and glass.

Ground was broken for the project in October, 1992. A 1-to-50 scale wood model, at a cost of ¥135 million, was constructed in New York at the request of the client. It has been in use to publicize the project at major trade fairs around the world. It has also proven to be useful to aid in erection and understanding construction sequencing.

Following the site visit the U.S. team members traveled to the Century Tower office of Obayashi Corporation's Building Division in Tokyo to discuss construction technology innovation and receive Obayashi responses to questions assembled by the panel and submitted to all Japanese hosts through PWRI several months prior to the panel visit. The discussion ranged over a wide variety of topics. A summary of significant findings and observations follows.

- Obayashi sees few differences in project management methods in use by contractors in Japan and the United States, nor with SE Asia or Europe for that matter.

- Obayashi currently generates $1.2 million/year in sales per person, excluding construction labor. Their goal is $2 million/year/person.

- They are moving to more management computer use in the future. They see the United States ahead of them in this area.

- Forty percent of projects use field computers; plans are for these to be connected to the home office in the future.

- Obayashi said they are using design models (CAD) at several construction sites, although the panel did not visit these..

- The impact of the economic downturn has narrowed the focus of their investments to two areas: construction technology R&D and project management tools. No new hiring is taking place and they believe they can maintain their current staff size through the recession.

- The government continues to announce federal plans to invest heavily in infrastructure projects over the next ten years. Government projects make up less than half of Obayashi's work volume.

- Obayashi's profits next year are projected to be significantly down from ¥29 billion this year.

- Their R&D spending level will continue (currently at 1% of revenues) and renewed efforts made to work together with several contractors. Obayashi would like to reduce this level of spending; the government wants it increased. The most likely outcome is no change.

- They feel they are not so competitive overseas. At home their competitive advantages are advanced technology knowledge and financial strength, so they tend to bid projects overseas where these elements come into play.

- Seldom do they invest directly in a project ("stay away from risk"), however, they are very active in assisting clients to arrange for credit or other forms of project financing.

- Although they do not currently have enough work to keep all their people busy, they are very concerned with the aging work force and the lack of young people entering the construction industry. They see investment in construction technology R&D as one strategy to meet this long-term problem.

- Obayashi's safety record, *e.g.*, number of injuries, is about one-third of the industry average in Japan. The MOC monitors contractor safety records closely and typically Obayashi conducts monthly safety inspections of all their construction sites. When performing work in foreign, developing countries they usually use the same systems they employ in Japan with some adjustment as needed. For example, they can't bring all of their "facilities" to other countries, so the safety practices may suffer in spite of their best efforts.

- They believe that their construction safety program is "overly safe," viz., it is very difficult to comply with. Although they have a first-rate construction safety program, they also believe that they do more than is necessary.

- They are not ISO 9000 certified, but they are studying it to be ready to seek certification. They believe it will be the standard in Japan in a few years. They are currently seeking certification for their overseas civil engineering company which does work in Australia, Singapore and Indonesia.

- Project cost control in the field uses computers in part. Mostly manual monthly reports are filed from the field to the home office.

- Safety and quality are musts on every project, and cannot be prioritized. Cost is just beginning to enter the picture.

- In their view, U.S. subcontractors are more independent than in Japan. They envy that. They work with about 30 subcontractors on a regular basis. This traditional system is based more on "family harmony" than on competitive position.

- Career pathing for a (lead) engineering designer is 20 years experience, half in the field, half in design in the office.

- Organized labor is generally limited to industry unions made up of contractor employees. Over 90% of laborers employed by subcontractors do not belong to a union.

- Craft worker training is a concern. Recently Obayashi engineers have taught classes to craft workers. It was well received and subcontractors have asked for repeat classes.

- They have had success in international bidding. Recent wins in Australia, Hong Kong and California involve projects with high or advanced technology (airports, toll roads, tunnels) where they feel they are more competitive.

- It is their view that university research should be limited to basic research. Applied research should be undertaken by industry to ensure rapid turn around.

- The annual JSCE conferences are very helpful to transferring ideas from the university to industry.

- Equipment manufacturers and contractors should work together to develop new equipment to meet future construction innovation needs. Such equipment must be capable of proper use by both skilled and unskilled workers.

- The recent Hyogo Ken Nanbu earthquake has resulted in a modest (4%) increase in their business volume. Seismic provisions of the national code are under review as a result of the earthquake with some changes expected in late 1995.

- Seismic retrofit projects have increased noticeably in the Kobe area. Retrofit activity elsewhere in Japan is anticipated in the next several years.

- Obayashi top management regards R&D investment somewhat as an obligation to maintain their image of scientific and engineering support. The newer generation of management sees the investment in economic terms as vital to compete in the market.

- Goal-oriented research, with its sense of urgency and results focus, has proven to result in a poor environment for creating good ideas. Researchers are reported to be very discouraged and uncomfortable with this new strategy.

Summary of Significant Findings:

- Unprecedented use of cable trusses

- Application of fire-resistant steel
- Top down construction method
- Simultaneous foundation excavation and superstructure erection
- Extensive full scale tests of structure and glazing elements to conform performance under design conditions

General Impressions:

The panel was unanimous in its praise for the impressiveness and scope of the Glass Hall. It is destined to become the identifying structure icon for the Tokyo skyline in the future. It is a pioneering structure that is judged to remain on the leading edge of architectural design and structural innovation for years to come. Project descriptive brochures in English were not available at the time of the visit, but will be available in the near future. Japanese versions are attached.

Reference:

Glass Hall, Tokyo International Forum, two Obayashi Corporation brochures (in Japanese).

Tokyo Rinkai Hukutoshin Project

Date and Time: Tuesday, June 13, 1995, 16:00-18:30

Participants:

U.S. Team Members: Edward E. DiTomas
Lloyd A. Duscha
Ezra Ehrenkrantz
Richard G. Gann
Boyd C. Paulson, Jr.

Japanese Hosts: Takashi Nakajima, General Manager, Design Department, Civil Engineering Division, Shimizu Corp.
Dr. Aketo Suzuki, Manager, Construction Engineering Department, Civil Engineering Division, Taisei Corp.

Summary of Technical Visit:

This 29-story hotel building was well along in its construction, with the structure almost completed, and most of the rooms enclosed. The building, of conventional design, will have 884 rooms and parking for 512 cars. A 24-story tower sits on a 5-story base, which provides all service and back-of-the-house functions, except for a large ballroom facility built adjacent next to the tower.

The project was staffed with about 60 professionals, about triple the U.S. complement for a project of similar size and complexity. A foreman was assigned to each pair of floors.

The hotel is being built using the "Perfect Layered Construction Method for Steel Structures," a method devised to improve the safety of the working environment. The steps in the sequence are:

- erection of 4-story columns,
- addition of girders,
- alignment,
- fixing and welding,
- installation of horizontal nets,
- installation of decking,
- installation of pre-cast floor slabs,
- erection of pre-cast concrete curtain walls, and
- erection of aluminum curtain walls.

The pre-cast concrete floor panels have no vertical concrete counterparts, and the partitions between rooms use four layers of 21 mm sheet rock for acoustic separation. In the United States, building would be more likely to use crosswall panels to assist in taking lateral loads than in providing for very heavy floor construction without crosswalls, which requires the steel structure to take these loads only at the columns. Cores and stairs were not designed to contribute to taking earthquake forces.

The structural system is heavier and the beams deeper than would be typical of U.S. construction. In order to save floor-to-floor height, the beams are perforated with reinforced openings for services. These openings are precise and the various services fit through them snugly. The tolerance control is excellent not only for products of a single subsystem but also for the integration of components of various building subsystems with one another. It would improve the future flexibility of the building had the designer selected castillated beams with many openings. The team was told that the intended use for the hotel as part of a convention center had already been canceled.

The time to complete a floor is 6½ days from start to completion of an enclosure. Everything is coordinated so that the materials to complete a floor are lifted into place with the pre-cast floor slabs.

The job site was extremely clean throughout. Safety systems were built into the construction process, and the manager stated that there had been no injuries to date.

Tokyo Terminal Renovation

Date & Time: Wednesday, June 14, 1995, 09:30-12:00

Participants:

U.S. Team Members: Thomas L. Anderson
Richard A. Cemenska
Lloyd A. Duscha
Charles I. McGinnis
Boyd C. Paulson, Jr.

Japanese Hosts: M. Kitauchi, Field Engineer, Obayashi Corp.
H. Sakamota, Project Manager, Obayashi Corp.
K. Tonoda, General Manager, Planning Department, Obayashi Corp.

Summary of Technical Visit:

This project consists of providing a new platform at the Tokyo railroad terminal to accommodate the Hokuriku S.E. line, which is being converted to a high speed (bullet train) line connecting with Nagano for the 1998 Winter Olympics. It is owned by the East Japan Railway Company.

The Tokyo terminal handles an immense amount of traffic: 1,800,000 passengers and 3,600 trains daily. The available platforms are insufficient to handle the added traffic and also do not match the needs of the train. Essentially, the project amounts to shoe-horning another platform into an already congested area without enlarging the real estate footprint and while maintaining traffic. To accomplish the shoe-horning, it is necessary to shift and improve four other platforms with accompanying track, plus shifting one platform to a higher elevation.

While the anticipated fare revenue is expected to repay the investment, the primary driver for the project is to provide rapid, first-class transportation between the Olympics site and Tokyo.

Although no new technology is demonstrated at this project, it is a vivid demonstration of the complexities encountered in renovation projects accomplished within limited confines. This is a situation which will be faced increasingly in the United States. At this project, deep foundation shafts and heavy support framework are being placed underneath existing platform structures with very limited headroom. This dictates considerable handwork as well as special configuring of the structural steel to accommodate handling. Above all, it requires detailed planning of the execution. In this case, five years were devoted to planning.

The soil is soft clay requiring that the supports be founded on Tokyo-gravel-strata 16 m to 18 m down. Shaft diameters vary from 2.2 m to 2.6 m and are being dug by hand with ring beams and sheeting being placed as the digging progresses. Overhead space limits mechanical assistance. Steel support columns must be threaded between tracks, which is allowed only between 0100 to 0400 hours so as not to impede movement of trains and people. Underpinning the existing structure is being accomplished using a trench method with 8 m to 9 m long pilings divided into 3 sections and bolted together to accommodate driving.

To further complicate the process, the project is essentially split in half and is being performed by two contractors. It was claimed that this has not caused an inordinate amount of problems as both contractors were dedicated to timely completion. The owner does employ a construction manager for coordination.

Contractors and workers are able to cope with working in tight quarters as the working space in Japan is naturally limited, even on "greenfield" projects. Rehabilitation and renovation will also become more prevalent in the United States with time, which will dictate that more effort be devoted to advance planning of the construction sequence.

Summary of Significant Findings:

Successful renovation work can be accomplished in a timely manner, but must have detailed advance planning and constant management attention.

General Impressions:

The team was most impressed with the work being accomplished in tight quarters. Management was dedicated to quality, timeliness and safety. This was the first visit to the site by an outside party.

References:

Tokyo Terminal Renovation Project, brochure, undated.

Trans-Tokyo Bay Highway

Date & Time: Tuesday, June 13, 1995, 14:00-15:30

Participants:

U.S. Team Members: Edward E. DiTomas
Lloyd A. Duscha
Ezra Ehrenkrantz
Richard G. Gann
Boyd C. Paulson, Jr.

Japanese Hosts: Takashi Nakajima, General Manager, Design Department, Civil Engineering Division, Shimizu Corp.
Dr. Aketo Suzuki, Manager, Construction Engineering Department, Civil Engineering Division, Taisei Corp.
Mr. Osamu Takagi, Project Manager, Underwater Tunnels, Taisei Corp.

Summary of Technical Visit:

This project is to construct a 15 km toll highway traversing the central part of Tokyo Bay from east to west and connecting Kawasaki and Kisarazu. Its purpose is to accommodate the yearly increasing traffic load in the greater Tokyo area, to redistribute urban functions, and to permit development of multiple centers in areas still offering room. Major features of the project include: creation of two artificial islands, dual two-lane 14.1 m diameter underwater tunnels and a 4-lane connecting bridge.

The cost of the project is estimated at ¥1.5 trillion ($18 billion). Its economics derive from reduced driving distance and time. For instance, the driving distance between Kawasaki and Kisarazu will be reduced from 110 km to 30 km and cut the required driving time by 75%. Similarly, the distance between Tokyo and Kisarazu will be reduced by 45 km. Although using a bridge rather than a tunnel in the deep water section would have been less costly by several fold, the more expensive option was selected because of the potential impact on navigation and to reduce the environmental impact. Nevertheless, the projected repayment period is 30 years based on a ¥5,000 yen ($60) crossing toll. First year traffic volume is expected to be 33,000 vehicles per day, increasing to 64,000 after 20 years.

Two 10 km long underwater tunnels will be used where surface marine traffic is heavy and a 4.5 km long bridge where such traffic is lighter. Two man-made islands are needed: one located 4.6 km from the Kawasaki shore serves as a midpoint ventilation shaft and as another access point for tunneling operations; the other is located 4.5 km from the Kisarazu shore and serves as the junction between the seaside terminus of the bridge and the beginning of the tunnel. These structures are constructed in soft ground, under deep water, and in a highly seismic-prone area.

The center artificial island, actually a structure, is located in 28 m of water with 30 m of soft soil beneath. To stabilize the foundation in the work area, sand compaction and deep mixing were used. The first element of construction was an annular structural steel trestle, 198 m outside diameter and 48 m wide, extending to the sea floor. This serves as a work platform, retaining wall and ultimate protection for the ventilation shaft. This portion was assembled on shore in 14 sections, barged to the site and secured to steel piles. From that platform, a 98 m diameter slurry wall, 2.8 m thick, extending to hard ground (114 m below sea level) was constructed and the material within excavated to 70 m below the water surface. The bottom slab of the ventilation tower is 6 m thick and the wall is 4 m thick. The shaft diameter selected was based on including provisions to accommodate a third tunnel in the future. After tunnel excavation is complete, the interior will be divided into floors to accommodate tunnel ventilation equipment, fire fighting equipment and tunnel crossovers.

The island serving as an interface between the bridge and the tunnel is 650 m long by 100 m wide and consists of sand and gravel placed atop the sea floor. The ramp between the tunnel and the bridge traverses the fill material. The island has a protective system consisting of circular steel pile structures filled with sand and capped with concrete.

The bridge leading from Kisarazu to the island is 4.4 km long and sits on 42 Y-shaped steel piers of which 12 are in deep water. These piers were preassembled on land, barged to the site and set on a concrete pile cap. The 12 deep-water piers have special cladding in a 5 m splash zone to protect against corrosion. A 1 mm titanium sheet is placed over a thin coating of copper on the pier surface. A hot rolling process forces out a molten titanium-copper compound which oxidizes and forms a strong bond. This is the first time such a cladding process was used in a construction application. High damping rubber bearings support the bridge members on the piers.

Tunneling will be accomplished using eight slurry shield boring machines working from the end access points and the center island. Boring machines are furnished by several of the equipment manufacturers visited during this trip. Tunnels are spaced 28 m apart and approximately 50 m below the water surface. Pre-cast segmented ring blocks are placed automatically after each 1.5 m advance. Flexible segments are provided at the end and center structures and at slope changes to compensate for seismic effects. To facilitate the tunneling operations from the center island, two temporary pile-founded steel frame structures are provided to support the slurry operations and other equipment requirements.

The project construction is divided into several contracts. Construction was started in 1988 and is slated for completion in 1997.

Sponsorship and financing of the project is a joint undertaking. The Trans-Tokyo Bay Highway Corporation (TTB) concluded a contract with the Japan Highway Public Corporation (JH) of the Ministry of Construction to raise the necessary capital from JH, interested local governments and the private sector, and to manage the project. Of the 85% portion to be funded by TTB, 47.7% is from government guaranteed bonds, 30.6% from official loans, 14.3% from private loans and the Japanese Development Bank, and 7.4% from its own capital.

Summary of Significant Findings:

This is a mammoth undertaking requiring extensive preconstruction planning which appears to have been well carried out. The construction contractors involved are well organized to carry out this project. Their dedication is to timely completion; however, quality and safety are not being sacrificed. The contractors are provided advance funds equivalent to 40% of the work scheduled for the contract year. The titanium cladding process for steel at the waterline is a new technology. This is a very large public works undertaking for a quasi-private organization. Environmental, aesthetic and social qualities received more than cursory consideration.

Follow-Up:

By virtue of the work completed to date and the detailed planning accomplished, it appears the work will proceed smoothly to completion unless unforseen problems are encountered in tunneling. As for follow-up, a glamorous project such as this always has a certain amount of attraction.

Reference:

Trans-Tokyo Bay Highway, Trans-Tokyo Bay Highway Corporation, Tokyo, 1994.

Housing Institute of Complete Project Management Subsidiary of ABC Development Corporation

Date and Time: Saturday, June 17, 1995, 09:00-11:00

Participants:

U.S. Team Member: Burton Goldberg

Japanese Hosts: Hideyo Totani, Executive Director
Senda Kenji, Secretary General

Summary of Technical Visit:

The Housing Institute of Complete Project Management (HICPM) is a non-profit subsidiary of the ABC Development Corporation that does a significant amount of housing development in Japan. ABC stands for Assia Broadcast Corporation. The mission of HICPM is to provide "technologically advanced housing construction systems to the people and organizations in the housing industry in Japan by importing advanced housing systems, as well as materials and services from overseas." It was officially established on June 1, 1995. Among the projects are:

- research and information about domestic and overseas housing industry,
- publication of a monthly magazine, *Builder*, and other housing-related books,
- conduct of seminars and professional training, and
- exchange of know-how with other organizations.

In carrying out these tasks it has sought to establish a close relationship with the National Association of Home Builders (NAHB) in the United States.

The fundamental premise of the organization is that the Japanese housing industry must catch up with the United States. The housing industry consists of three parts:

- the big housing producers or prefabricators such as Misawa and Mitsui,
- the building material wholesaler who controls many small builders, and
- individual small builders.

According to Mr. Totani, ever since the Korean war there has been a shortage of good building materials in Japan. Consequently, aside from lumber, the Japanese industry uses light gauge (1.6 mm) steel, concrete block, and wood chips with adhesive. The small builder wants good material, so he affiliates with a materials wholesaler who, as a result, often controls the builder. To alleviate a small builder's potential cash flow difficulties, these wholesalers allow them 210 days to pay the remainder of the bill. Some of the huge trading companies such as Mitsubishi control many of the material wholesalers. They issue bills that are government guaranteed. Sogashosha is an example of a super-trading company. Mitsui, Mitsubishi, and Kadatsu are other examples of such companies, but are smaller.

There has been a migration from rural to urban areas. The share of Japan's population in urban areas has increased from 35% to 80%. The small home builders have a long history in the rural areas. According to Mr. Totani, the rural home builders are good and reliable and have excellent relations with their neighbors, but in urban areas the small builders have been defeated by the big housing material wholesalers and are not very stable.

Mr. Totani stated that housing prices in Japan are more than five times people's annual income. Typically, over 40% of a family's annual income is required to pay for a house. More than 70% of the housing has been re-built, *i.e.*, demolished and built anew. In order to be really affordable, housing prices must be only three times annual income. When the current recession began, the government was eager to stimulate the housing industry. Under the economic stimulation policy they offered low interest loans of 3.7% (now 3.8%). Capital payments plus interest were initially low and were gradually raised in a step-up system on the belief that incomes would rise. For example, the home buyer would pay ¥100,000 ($1200) per month in the first year. At five years, the payment would increase to ¥200,000 a month and by 10 years would rise to ¥400,000 a month. The recession came, however, incomes did not rise, and people had trouble in meeting payments. Consequently, the government offered a tax reduction and reduced the payments every year of the first five years by ¥300,000. Also, prospective buyers were allowed to pay money as rental on the house. New house construction has averaged 1.5 million units per year. Even though Japan will continue with its subsidies, demand will not increase, in Mr. Totani's view. People will not buy because they cannot pay unless the housing price goes down.

If the government were to promote import of U.S. housing at a price of $200,000, 30% or $60,000 would be for building materials which could be imported from the United States. This is two-thirds of the price that the Japanese pay, but 1.5 times the price of the U.S. export. The actual price of materials would be $40,000. Including the cost of transportation and wholesaling, the total cost would amount to $60,000.

A $100,000 house in the United States could cost twice as much in Japan. If a $100,000 house were to be imported from the United States to Japan it would cost $150,000. In actuality it would cost $180,000 because Japanese design is expensive and accounts from 12-15% of the total house cost in Japan, equivalent to 25% to 30% of the U.S. cost. The Japanese would design and send the drawing to the United States. By law, every building must have a certified designer, even if a U.S. design is adopted.

It is Mr. Totani's objective to promote U.S. housing in Japan. He has used some NAHB literature to teach the critical path method. The home building distribution chain is very complicated. The customer first goes to a dealer. After the design is fixed, it goes to the factory which makes the house and ships it to the builder. The builder delegates to a "sub-sub" the task of allocating the work among the subcontracting foremen who deal with the workers.

Summary of Significant Findings:

Mr. Totani sees the mission of his organization as changing the Japanese housing industry. In this regard, he is translating many of the NAHB publications for Japanese home builders. The Japanese market is big: 1.5 million housing units at a materials cost for each at $40,000 amounts to $700 billion. He is interested in learning more about the Research Center and I promised to send him some information and publications.

General Impressions and Need for Follow-Up:

Housing construction represents a case where the United States might contribute to Japanese technological know-how and reduce institutional and technical barriers. This will require extensive work by NAHB and others. Mr. Totani desired more information on the Research Center and its publications.

Misawa Homes Co., Ltd.

Date and Time: Monday, June 12, 1995, 09:30-12:00

Participants:

U.S. Team Members: Ezra Ehrenkrantz
Richard G. Gann
Burton Goldberg

Japanese Host: Mr. Nobuyuki Abe, Assistant Manager of Sales Section of Tokyo Misawa Homes Co., Ltd. at its Setagaya Division.
Various unnamed members of his staff assisted in the computer presentation and narration.

Summary of Technical Visit:

The visit took place in the Tokyo offices of the company. Misawa is one of the largest residential builders in Japan. Their average home is about 100 square meters in floor space.

A computer-aided-design (CAD) system was demonstrated on video, giving two- and three-dimensional perspectives on a systematic walk-through of various rooms of a house. The viewer or potential customer could thus obtain, from a variety of angles, a realistic sense of the interior of the house as well as exterior views through windows. Interior design elements such as furniture, carpets, etc. were also placed in various rooms. The presentation could also simulate changes in light. Through an electronic catalog the customer and manufacturer can enter the system to see how much material is required, but the system apparently is not yet capable of translating the design into drawings useful in construction or into precise estimates of construction cost. The system is said to work efficiently with custom design. A scanner reads different types of materials for all kinds of houses. The system is useful in designing the house and allowing the customer to preview the design and get the feel and look of the rooms. From the manufacturer's point of view, however, designs produced in this manner will not be as economical to produce. Customized housing is 15 to 20 percent more expensive than standardized housing.

The following information was obtained during an ensuing question and answer session:

- *Are all houses prefabricated?* All components are of two types: those assembled in the factory as modules and then shipped to the site and others assembled at the site. The largest box-type unit that can be shipped measures 1.8 m x 2.7 m x 4 m in height and is limited by road traffic law.

- *What is new in their houses?* The use of ceramic frames, more reinforced concrete in the box, and steel frame clad with ceramic. The definition of "ceramic" was vague, with different manufacturers using different definitions.

- *Are roofs the same as 5 years ago?* There were no new roofing system designs, but the process of manufacturing is different. A panel method of production has been adopted consisting of different types for the ceiling, floor, and wall. For example, they use a stressed-skin panel with glass wool. They have two types of roof: steel frame and wood panel. Cementitious asbestos has been used for roof covering, but asbestos is hazardous. A new material, mineral fiber reinforced concrete, is now used as a substitute.

- *Is there a cost difference between steel frame versus panel construction?* It was hard to tell. A lot depends on design, but he thought that steel framing was less expensive.

  They first build the roof on the ground, jack up the roof to the second story, and then build the first story. This was said to compare with the British jack-built system. This is an effective construction system in Japan where the land area is limited and is considered a low-cost housing method of production.

- *How many stories do you build to make it economical?* Consumers demand three-story houses, but 2-stories are more economical for the jacking system. Regulations are factor in how many stories you can build. For the Misawa-8 single-family house, all 3 stories have typically been wood, but regulations now allow wood for 3-story terrace houses. Wood is still not allowed for apartment houses.

- *How much wood versus steel is used in housing in general?* Eighty percent of ordinary houses are wood, but not apartment houses. In new construction 70% of units are wood and 30% are steel. As a result of the "bubble" recession, wooden houses are now increasing and are more economical than steel frame housing.

- *How many houses do you produce annually?* They produce 20,000 to 30,000 housing units annually. Note that a recent article in *Automated Builder* cites this number as 45,000.

- *What is the base for your expenditure in industrialized housing?* Manufacturers of prefab housing in the United States are subject to the vagaries and extremes of the economic cycles which militate against an economically viable system of production. Misawa is reasonably assured that housing production will not go below 20,000. The system is still viable under extreme fluctuations, but such conditions are not economically favorable. They keep a close eye on the stock of prefabricated housing. When 90% of the production is still in stock, they worry that units will become obsolete and will be hard to sell.

Environmental control is focused inside the house. A new air conditioning system, TES, produced by Tokyo Gas, has a high initial cost, but its operating cost is low. Heating systems run by gas are warm and are combined with efficient ventilation systems. A solar photovoltaic system (PV) is expensive. They are investing ¥6 million for PV solar energy on an experimental basis and under a government subsidy of ¥4 million. Tokyo weather is not ideal for such a system. Batteries can store energy which can be sold back to the utility. If the total cost of PV homes is ¥30 million of which 24 million is the house, then with a PV subsidy they are raising the price of a house by 6%.

They have adopted a new floor heating system which emits infrared radiation. Wires laminated on 7 mm thick polyvinyl chloride sheet are laid beneath the carpet. The system can be mass produced and is very cost-effective. Energy conservation is as important in Japan as it is in the United States. Utility fees are high and they are very conscious of energy conservation, but there are no regulations.

There has not been much demand for renovation or remodeling, but such activities are increasing.

Follow-Up:

This meeting was with a mid-level executive of the marketing division of Misawa, and was thus less technical than other visits. Some follow-up on material technologies and the technology of construction would be useful.

Reference:

Development of Technology of Misawa Homes, Wooden House, 25 Years of History, Misawa Homes Institute of Research and Development," Technical Report, Volume 50.

OM Solar Association

Date and Time: Wednesday, June 14, 1995, 09:00-14:00

Participants:

U.S. Team Members: Richard G. Gann
Burton Goldberg

Japanese Hosts: Kazutada Kobayashi, Assistant Manager, Canon Inc. Ecology R&D Center
Ichizo Koike, Managing Director, OM Solar Association

Summary of Technical Visit:

The visit began with a tour of the OM Solar House and a Mitsui house conducted in the morning by Mr. Kobayashi at a model home park in Yokohama. Further discussion took place at the Canon building in Shinjuku.

The name "OM" is derived from the family name of Professor Oku Maru, an architecture professor. OM Solar is an association of about 300 local house builders. The association through its membership has built and sold 7,000 homes, all within Japan, that incorporate some form of solar energy technology. The association's annual sales growth rate is 1.5%. The construction technology it promotes, incorporating a combination of passive solar techniques and phototvoltaics (PV), is said to be complicated compared to conventional methods. Canon is in joint partnership with OM Solar because of Canon's interest in mass marketing photovoltaic (PV) cells which they manufacture.

The association employs about 80 people at their headquarters in Hamamatsu City in the Shizuoka prefecture of Japan. Nine are first class contractors qualified by and meeting the standards of the Ministry of Construction in the Japanese government. These nine work for the 300 local home builder firms that comprise the OM Solar membership. Each member has about 30 employees, so the association serves approximately 900 employees.

Mr. Koike sees the advantage of OM Solar in two areas: sharing technology and in business advertising.

Energy is very expensive in Japan. Global warming is also an issue of concern, and the Ministry of Construction (MoC) is fostering cohabitation with the environment. Stimulating the use of solar energy is part of this. MITI's Sunshine Program, design to promote photovoltaics, subsidizes about one half of the cost of a residential solar energy installation.

The length of Japan is equivalent to the north-south distance across Europe and therefore has a variety of weather zones. OM Solar tracks weather conditions by location, using data from the weather forecasting bureau of Japan. It has a computer program that analyzes this data for 839 measuring points throughout the country. It also analyzes materials of construction such as wood and metal and distributes the results to its members. OM Solar normally has a plan for the house, allowing computation of the thermal efficiency and heating requirements before the house is built.

The OM Solar system reduces energy consumption with a combination of generic passive solar heating technology and complementary air handling. Photovoltaics for direct conversion of sunlight to electricity are being added. Seventy percent of the system deals with heating and boiling of water, while PV generation deals with the remaining 30%, chiefly appliances and lighting. Mr. Koike stated that the crucial point is the utilization of outside fresh air. In some seasons, they use the cool night air to reduce interior temperatures. [In Japan's hot, humid nights this does not reduce the temperature but does bring down the humidity, thereby increasing the comfort level.] Mr. Koike feels it is more effective to use PV-generated electricity to run an air conditioner.

The system also interacts with the utility provider, selling electricity to the utility during the daytime and buying from the utility in the night time. The net balance is almost zero. The unique aspect of the OM system is that it uses air rather than liquid for transferring solar energy.

OM Solar has a patent on their technology in the United States and Canada. It took them one year to obtain their patent in the United States which they received in 1990. It took three years to get the Japanese patent. Sometimes it can take 4 or 5 years to get a patent in Japan. It was noted that software is not subject to patent.

About 700,000 single-family housing units are built each year in Japan, about half of the total residential units. Seventy percent are produced by local home builders while 30% are manufactured by the prefabricators. Mr. Koike stated that prefabricated housing manufacturers have garnered an increasing share of total houses due to rising costs. Local home builders compete, but on an "unequal" basis. Local builders, however, know their areas better than the manufacturers. They want to utilize the resources of OM to achieve some uniqueness in their local areas.

As the demand for this type of construction increases, there is a need to transfer it exactly to home builders. The OM system is not intended to be installed separately, but rather to be integrated with the structure of the house. The builders have to rely on OM for the method of design and installation of the new technology. Therefore, a major function of the association is to develop technical education for the home builders. The headquarters staff absorb and generalize the experience gained from localities. They then invite local home builders to their headquarters. It takes about 30 days to master the technology, but the builders cannot afford the time to do it at once, so it takes 1 to 2 years to complete this program. A minimum of 2 people from a firm must be trained to become a member of the association, one person each for design and installation. Other people want to join the association, but rather than increasing membership they would prefer to focus on quality.

In the area of technology and research and development (R&D), they are working with Cannon. Mr. Kioke feels that PV technology combined with the OM solar system is an ideal combination. house, allowing OM to give the specification of the heating power before the house is built. Mr. Kioke stated that this represents the best combination of low technology with high technology, backed up with computer technology.

Each member of the association is small, but together they can be effective. For instance, they share the cost of the expensive advertisements in the two nationwide newspapers, each with about ten million readers a day. OM Solar with its host computer can communicate in terms of technology as well as business, and is encouraging members to purchase personal computers. They are thinking of connecting to Internet. They are also organizing print media leaflets and catalogs. Among their international activities, they held a conference in Hungary where energy is scarce. In China, they participated in a local government joint venture with a few associations where they covered technology and knowledge rather than shipping hardware.

Summary of Significant Findings:

Many of the passive solar features of the OM solar house are already well known in the United States and have been adopted in the few passive solar homes that have been built in the United States. What may be unique in the OM Solar system is the particular configuration of the passive solar components, especially the controller or damper near the top of the roof used to control the inflow and outflow of air. The combination of PV and passive solar with PV has also been attempted in the United States, but is not widespread.

Follow-Up:

It would be useful to see how they plan to integrate PV technology with the controller or other elements of the system. Probably the most interesting aspect of OM Solar is its system for transferring technologies to small builders to help them compete with the large firms. Capturing this knowledge would be useful in a similar program now under consideration by the NAHB Research Center and NIST's Manufacturing Extension Partnership.

Reference:

OM Solar Association and OM Institute, corporate brochure, undated.

Japan Federation of Construction Contractors, Inc.
and
Advanced Construction Technology Center

Date and Time: Monday, June 12, 1995, 9:30-11:50

Participants:

U.S. Team Members: Thomas L. Anderson
Steven J. Bomba
Richard A. Cemenska
Edward E. DiTomas
Lloyd A. Duscha
Charles I. McGinnis
Boyd C. Paulson, Jr.
Kenneth F. Reinschmidt
Noel J. Raufaste, Jr.

Japanese Hosts: Dr. Kouichi Yokoyama, PWRI Manager
Mr. Akira Fujioka, ACTEC Planning Department
Mr. Satoshi Maeda, ACTEC Research Department Manager
Mr. Kazuo Hashimoto, ACTEC Utilization Promotion Dept.Manager
Mr. Elgo Hanaiti, Japan Federation of Construction Contractors
Mr. Takashi Sakai, ACTEC Senior Managing Director
Mr. Shin Kirikoshi, ACTEC Research Department Manager

Summary of Technical Visit:

The Japan Federation of Construction Contractors (JFCC) was founded on November 1, 1967 as a representative body of the construction industry in Japan. The JFCC mission is to:

- develop consensus of opinion for vital worldwide construction issues;
- promote close cooperation among industry and economic organizations to contribute to social, economic, and cultural development;
- collect and analyze information to understand economic changes in the construction environment accurately;
- facilitate better understanding of the construction industry by fostering the industry's awareness of the wide scope of social needs and by informing the public of construction industry conditions; and

- strengthen international understanding and cooperation by encouraging exchanges of people and information with the overseas construction industry.

Membership is open to Japanese associations of general construction contractors (*e.g.*, the Japan Civil Engineering Contractors' Association, Inc.), Japanese construction contractors themselves, and foreign corporations engaged in general construction in Japan. The current membership includes 60 large Japanese contractors, 16 special (foreign) members, and 10 association members.

The Advanced Construction Technology Center (ACTEC) is a consortium of 14 construction companies formed to exchange views. It is funded by the construction companies and the equipment manufacturers. Its focus is to identify common problems faced by the industry and is currently reviewing technologies in the following major areas: rationalization and automation, underground space development, new materials applications, and creation and preservation of the environment.

Mr. Hanaiti presented a profile of the present Japanese construction industry as summarized in the booklet he provided, titled, *Construction in Japan 1995*. The booklet gives statistical data, both current and historical, for key measures and indicators such as total construction volume, by year; construction as a proportion of GDP; comparisons with other developed countries; market share vs. company size; and employment statistics. He addressed the status of quality initiatives in the industry, showed the extent of foreign builder certification for work in Japan, and displayed the Federation's membership.

Mr. Hanaiti acknowledged the effect of recent difficult economic circumstances in Japan, and he expressed hope that the exchange rate will improve (weaker yen) soon. Membership in the Federation is declining. International competition is not a significant factor in the industry as yet. Only about 50 Japanese companies are members of the Overseas Contractor's Association.

Regarding R&D investment, it was reported that funding is provided exclusively by companies from their profits. Recently the rate of funding is declining.

The contractors responded to the Hyogo Ken Nanbu earthquake, providing engineers with local experience to assist in reconstruction and damage assessment and donating both materials and funds.

Regarding labor, there are shortages in specific skills. By policy, construction serves to provide work when necessary. Unemployment elsewhere has resulted in a construction industry employment increase, even though the work volume is declining.

Client interest in project cost has risen to equal his level of interest in schedule and quality. This is hindering the introduction of new technologies into the construction process.

The Japanese hosts asked about U.S. progress toward metrication and ISO 9000 certification. No Japanese contractors are certified in Japan; however, overseas branches of Japanese contractors, such as those located in Asian Pacific Rim countries, are certified.

Summary of Significant Findings:

Chronic national recession and recent exchange rate pressure are affecting the Japanese construction industry quite significantly. Recent natural disasters have exacerbated the problems, as have increased construction employment combined with reduced work. R&D investment is suffering from depressed earnings. Clients are becoming increasingly cost conscious.

Follow-Up:

The Federation maintains an office in Washington, DC at 1825 K Street, NW, Suite 1203; phone: (202) 466-3585; fax: (202) 466-3586

Handout:

Construction in Japan 1995, Japan Federation of Construction Contractors, November 1994.

The Japan Society of Civil Engineers

Date and Time: Tuesday, June 13, 1995, 09:30-12:40

Participants:

U.S. Team Members: Thomas L. Anderson
Steven J. Bomba
Richard A. Cemenska
Burton Goldberg
Charles I. McGinnis
Noel J. Raufaste, Jr.
Kenneth F. Reinschmidt

Japanese Hosts: Tetsuro Kato, Chairman, Construction Technology Research Committee, Japan Society of Civil Engineers
Hiroshi Kono, Executive Director, Japan Society of Civil Engineers
Tadahiko Okamura, Shimizu Corporation

Summary of Technical Visit:

A large delegation of Japan Society of Civil Engineers (JSCE) leaders and members of the Construction Technology Research Committee were assembled to present prepared responses to the team's advance questions. (A set of our questions and JSCE answers appears as Appendix B.) After introductions and a brief orientation regarding JSCE, the following key points were made:

- The Japanese construction industry continues to suffer from recession at home and a strong yen which reduces international competitive advantage.

- Asia remains the most attractive region for Japanese international market growth. Interest is active in Europe and the United States as well.

- Construction R&D is often unrelated to near term profit. While 0.8% to 1.0% of construction company revenue goes to R&D, the purpose appears to be one of gaining competitive advantage - in all ways, not quick profit. R&D expenditures are being curtailed under current economic circumstances.

- In addition to normal services of lifeline utility restoration, damage assessment, and removal of damaged structures, construction companies provided vehicles, equipment, volunteer labor, supplies, and even cash donations to assist in recovery from the Hyogo Ken Nanbu earthquake. It was determined that tougher standards are needed, functional redundancy in transportation systems and facilities is required, and more damage resistant facilities are required to support urban activities and prompt recovery.

- Additional study of earthquake forces is required to modernize standards. An official report will be published within two years on damage assessment and restoration. A JSCE presentation on the Hyogo Ken Nanbu earthquake will be made to a plenary session at the ASCE Convention in October, 1995.

- Changes in the public sector procurement process promulgated in 1993 were described. The current recession, combined with these changes, is forcing increased competition. The market has been flat for the past 5 years; the proportion of total work from the public sector has increased; and the market share enjoyed by the top 50 contractors has declined during the past 5 years.

- Offshore competitors are obtaining some work in the Japanese domestic market, but slowly. Foreign awards are mostly for design and CM.

- In 1990, Japan's construction labor productivity was only 75.5% of that in the United States. (The exchange rate change since then will aggravate the situation for Japan.)

- Internationally, Japanese firms are viewed as offering better technology, but at higher prices.

- Structures built after 1985 suffered little or no damage during the Hyogo Ken Nanbu earthquake.

- The ratio of electrical and mechanical engineers committed to construction R&D is increasing due to a trend toward "intelligent" buildings and increasing construction automation.

- Lead time from development to full implementation (standardization) of new ideas and processes averages 8 years.

- Data are not available on 5-year old composite structure performance.

- The problems and options for developing a comprehensive construction database in Japan were discussed.

- The emphasis on safety and techniques used to advance it were discussed.

Summary of Significant Findings:

The Japanese economic recession and the more recent dramatic increase in currency value have increased competition domestically, curtailed company sponsored R&D investment, and limited the international market potential for Japanese contractors.

Contractors are struggling to adjust to public sector procurement rule changes.

Much is expected to come from study of the Hyogo Ken Nanbu earthquake event. Findings are being shared worldwide.

Follow-Up:

JSCE made a very significant effort to respond to team questions, both those provided in advance and those arising during the meeting. Their hospitality was outstanding, and the atmosphere for discussion was completely candid and fully professional. Virtually the entire session was conducted in English.

References:

Overview of the Japanese Construction Industry, June 13, 1995.

Japan Society of Civil Engineering, descriptive brochure, undated.

INCEDE Newsletter, Special Issue, Institute of Industrial Science, The University of Tokyo, International Center for Disaster-Mitigation Engineering, (reports the first 55 hours after the Hyogo Ken Nanbu earthquake of January 17, 1995), January, 1995.

APPENDIX B:

OVERVIEW OF THE JAPANESE CONSTRUCTION INDUSTRY

Construction Technology
Research Working Group of the
JAPAN SOCIETY OF CIVIL ENGINEERS

June 13, 1995

CONTENTS

1. INTERNATIONAL MARKET

a. *How do Japanese contractors view the international market today?* According to the statistics of the MOC's "Construction White Paper of 1992," the total sum of contracts awarded to the Japanese construction industry for overseas construction projects in 1992 was ¥853 billion (U.S. $10 billion, 20% decrease from the previous year) and the total number of contracts received was 1,520 (3% increase from the previous year). In terms of regions, Asia and the Oceania increased and advanced markets such as North America and Europe decreased.

Major markets for civil engineering works exist in construction and rehabilitation of infrastructure, which are closely linked to national policy of the local government. Participation in this market from overseas is primarily limited to the initial development of such infrastructure and accordingly, as local contractors enhance their technical capabilities, this market is likely to diminish for foreign contractors. In this sense, it is very hard for foreign contractors to participate in the conventional civil market. What is left for foreign contractors are projects demanding high engineering expertise or huge financing, which are scarce in the recipient countries.

Under the current situation where the Japanese construction industry also suffers from drastic appreciation of the yen, it is extremely difficult to participate in the market by importing materials or human resources from Japan. To cope with this, the Japanese contractors are either establishing local subsidiaries or joint venture companies with local contractors.

Accordingly as the economies in South East and South West Asia continue to develop, the construction demand in these regions is expected to increase. However, it is envisioned that harsh competition among contractors from all over the world as well as local contractors will inevitably result in marginal profitability in these construction markets.

b. *Where are the opportunities?* In terms of the construction investment volume, the European Union (14 countries) ranks number one, followed by Japan and the U.S.A. However, those countries in the EU and the U.S.A. have high-level construction technologies and few financial problems, as their infrastructure is already well developed. Therefore, it is very difficult for Japanese contractors to penetrate into those civil engineering markets.

It is generally believed by Japanese contractors that the Asian markets are most hopeful because of remarkably rapid economic development, political stability, potential need for infrastructure development to support the production base, and huge populations which would induce inflow of a substantial volume of foreign investments.

On the other hand, some say that more attention should be paid to Latin American countries and Central European countries as future potential markets.

c. *What is the impact of recent currency exchange rate changes?* The current sharp yen appreciation has made overseas projects less profitable and the potential for loss even greater. It has become very difficult for Japanese contractors to win a contract in the very harshly competitive world market, where the low-bid contractors turn out to be contractors from Korea or Italy, etc. From now on, further globalization in the fields of human resources and procurement is needed much more by Japanese contractors.

d. *What is the plan for increasing Japanese market share?* Listed below are the efforts made or to be made by Japanese contractors in order to increase their market share in the overseas construction market:

(a) Advance localization
- Reinforce local subsidiaries
- Fully utilize local staff

(b) Enhance sales abilities
- Increase orders from Japanese clients expanding their overseas business to cope with the strong yen
- Diversify activities by undertaking BOT or CM contracts
- Develop unique technology superior to others
- Enhance ability to present attractive alternative in price and technology

(c) Reinforce work forces
- Collaborate with local contractors
- Collaborate with foreign contractors

(d) Tighten money control
- Restrain yen expenditure
- Globalize procurement
- Increase financing ability

(e) Tighten risk control
- Reinforce ability to collect, analyze and assess data
- Reinforce ability to establish strategy

(f) Cultivate talent
- Exchange techniques and technologies through receiving students and trainees
- Further refine the Japanese way of construction management and propagate it

2. RESEARCH AND DEVELOPMENT

a. *How are research and development efforts in construction technology justified economically?* and *What is the required payback period for new developments?* It should be noted that the payback is not the primary focus of the R&D effort. R&D efforts are to enhance their technological capability and increase the chances of winning contracts, and to secure a competitive edge over other contractors. Thus, R&D effort is not managed with reference to the payback.

b. *Who bears the risk in the introduction of new construction technology?* In order to avoid such risks, construction firms in Japan concentrate their R&D efforts primarily in basic experiments, trial works, pilot works, etc.

c. *Are very large construction firms more likely to innovate new construction technology than smaller firms?* Yes, that is the general tendency, but specialty contractors also innovate new construction technology.

d. *Are construction firms that introduce new construction technology more profitable than others?* This question relates to the answers given in the first two answers in this section. There is no relationship between profit and the introduction of new technology.

e. *What are the roles of the MOC and MITI in encouraging or providing incentives for the development of new construction technologies?* The MOC is making its own effort to research and develop new technologies. On top of its own effort, the Ministry is also implementing measures to promote private sector R&D activities such as public-private joint research activity, a system of screening and certifying of technologies, pilot projects using new technologies, etc.

f. *What impact, if any, has the poor construction market had on Japanese R&D programs - funding, responsibilities, types of studies?* R&D money has been reduced. R&D efforts have shifted from basic theoretical studies to practical studies, and the latter tends to account for a larger ratio in the R&D programs.

g. *How is R&D financed?* Construction firms spend their own money. R&D expenditures account for 0.8 to 1.0% of annual turnover.

h. *What are their contributions?* Construction firms aim at securing a strategic technical advantage over competitors as well as contributing to the general public in the fields of prevention of global environmental destruction, providing economical infrastructure, enhancement of safety, etc.

3. IMPACT FROM HYOGO KEN NANBU EARTHQUAKE

a. *What role did the construction industry play in recovery from the Hyogo Ken Nanbu earthquake disaster?*

(1) Immediately after the disaster we tried to save lives and secure vehicles for the transportation and distribution of the necessities of life. We also sent workers on a voluntary basis.

(2) We engaged in the dismantling and removal of the destroyed railway, highway, and harbor facilities as well as temporary restoration of indispensable facilities.

(3) We contributed to the quick restoration of lifelines, such as water and sewage works, gas pipes, power cables and telephone lines.

(4) We helped with the procurement, transportation, and supply of materials needed for reconstruction work.

(5) We conducted diagnostic tests of the structures that hadn't collapsed but needed to have their safety assessed.

b. *What lessons were learned from this experience?*

(1) In view of the enormous damage to structures that this powerful earthquake caused, it is necessary to introduce structural standards for toughness that prevent buildings collapsing or toppling even if partial destruction happens to occur.*

(2) To better cope with such unprecedented disasters as this one, it is of vital importance to ensure greater functional redundancy in urban systems; to secure alternative road routes and other transportation facilities to take the place of damaged sections.*

(3) It is important to make sure that certain selected facilities are built with greater earthquake resistance---an example might be an earthquake-proof berth in Kobe port---so as to secure minimum functionality in a time of emergency, thus reducing limitations on relief and restoration efforts and avoiding complete breakdown of urban activities.

c. *What changes for the future will result, if any?*

(1) There is an urgent need to look closely at the type of earthquake forces assumed in our design standards and review the criteria for earthquake resistant design presently in use. (Comment of Prof. Hideo Nakamura, J.S.C.E. President (1994).)

(2) At the J.S.C.E. initial proposals in written form on how to determine the quake-resistance of structures were made to the Ministry of Construction and the Ministry of Transportation.

(3) The J.S.C.E. is also planning to publish a report on the damage and economic and social effects of the disaster as well as methods of reconstruction within two years.

4. CONTRACTING STRATEGIES

a. *What changes, if any, have occurred in contracting strategies and practices during the past five years?* Contract strategies have seen great changes over the past five years, with 1993 being the pivotal year. Prior to 1993, the most notable change to contract strategy came about with enforcement of the major project arrangements (MPA) based on a cooperative U.S.-Japan construction agreement. The MPA was introduced seven years ago, in 1988, and was reviewed five years ago, in 1990. New categories of projects were added four years ago in 1991. Contract strategy necessarily changed for projects covered by the MPA, while there was no change in the case of other projects. The critical change to contract strategy in Japanese construction work occurred at the end of 1993. At that time, the Central Council on Construction Contracting Business - one of the consultative bodies related to the Ministry of Construction - announced proposals for new contracting systems. Among these programs, improvements to contracting systems for public construction work were specifically listed.

b. *What trends are visible?* Although the future of the MPA is ultimately in the hands of the U.S.-Japan construction conference, which is likely to meet in the future, if things should continue unchanged and all current projects are completed, it is still within the bounds of possibility that it will die out over the course of time. So change should be driven by the new proposals for construction contracts announced by the Central Council on Construction Contracting Business. Future changes in contract systems for Japanese public construction work will tend to reflect these proposals.

These proposals aim to promote improvements to the general transparency, objectivity, and competitiveness of the procurement system as a whole. In accordance with this direction being taken by the council's proposals, the Ministry of Construction and others involved in public construction work are being asked to pursue reform of the system.

Given the above, the various government organizations contracting out public construction work should try to choose the most suitable bid and contract system for their purposes, choosing systems which make best use of the present situation while giving fair opportunity to a range of contractors.

c. *What response has there been to public sector procurement policy challenges?* We have to define what a procurement system for a construction project is. We treat it as the bid and contract system.

The procurement system for the public construction work has seen concrete changes since the new proposals were made by the Central Council on Construction Contracting Business. These changes have come about as a result of an action plan for improvements to the contract procedure for public construction work, which began at the beginning of 1994.

Measures taken according to this action plan included adoption of the bid-by-advertising and public offering proposal system as well as improvement of the invited-bid system. Further, a bid surveillance committee and a new performance guarantee system also came into operation.

Enforcing these new systems using this series of measures has reformed the system for the first time in 90 years, and both employers and contractors are now making every effort to learn the new methods.

General speaking, great differences have arisen between the reforms to the procurement system recommended by the government and the actual methods adopted by local organizations. The present situation appears to be that the construction industry is showing a lack of orientation and is trying hard to accommodate the new system.

d. *What are the latest and most efficient project delivery systems being used?* The traditional project delivery system in Japan has developed through the process listed below.

1. Direct Contract or Force Account
2. Direct Contract or Force Account by Labor Supply system
3. Labor contract system by materials supply
4. Construction work including material and labor supply systems
5. Design/construction system
6. Turn-key system

The project delivery system for public construction work has so far reached 4 above, while non-official work has proceeded to 6.

The American construction management (7) (CM) system has not reached Japan, so the only project delivery system for public construction work adopted in Japan is 4, meaning that construction work includes the supply of labor and materials (but design is separated from construction work).

There is other systems which can be compared in terms of efficiency.

Presently, public construction work in Japan is moving toward greater efficiency by developing systems based on 4 above, and public corporations, agencies, and other special corporations are being established response.

e. *Is the concept of Design/Build a factor?* At present, the Design/Build System is not adopted for public construction work in Japan. It was a common understanding in Japan that the Design/Build System was not used for public construction work in other countries. Our public organizations continue to be perplexed by the recent realization that the Design/Build System is indeed in use for public construction overseas. On the other hand, this system is being used for non-official construction work. The ability to execute a project using the Design/Build System is as a barometer for the ability of general construction companies.

5. COMPETITIVE MARKETS

a. *What changes, if any, have occurred in the competitive status of the largest Japanese contractors over the past five years?* The overall construction market in Japan has experienced a reduction in its size due to the stagnation, or the chilling of economy so to speak, in the past five years. This is one of the major causes of intensified competition among general contractors. In addition to this, the employment of the open bidding system on a full scale has brought about the increased competition mainly in the technological and constructional capability of the contractors. Pre-qualification requirement for the participation in the open bidding has become severer than before, and contractors find it difficult to cope with such problems as the selection of an appropriate construction project that most fits their capacity and specialty, non-experience in similar projects, or deployment of experienced site engineers and so forth.

b. *Is the Japanese domestic market relative to foreign, including U.S. contractors, competition?* We can find some U.S. companies that are making effort to display their salient features after accommodating Japanese business practices. In the long run, it seems U.S. contractors can gradually penetrate into the Japanese construction market with success. Some foreign contractors already have bid as sponsor of a joint venture, or have been awarded contracts, in the so called MPA (Major Project Arrangement) projects. They are accumulating experience and competitive strength in the Japanese domestic market. At present, many of the foreign companies seem to take more interest in the design or CM business rather than in construction business.

c. *How do design and supervision professionals as intermediary between the client and the general contractors measure the production efficiency of the general contractor?* We cannot find a proper answer to the question in view of the fact that the client carries out design works in Japan. The situation is such that the general contractor usually offers a proposal for the improvement of design or construction efficiency in terms of a VE proposal or a design change proposal on the design prepared by the client.

6. DESIGN/CONSTRUCTION

a. *How do construction firms measure on-site craft productivity?* and *Are work sampling or time-and-motion studies in use?* To evaluate on-site craft productivity supervisor or manager sum up the workers every work items and every trades from working daily report. He calculates the total on-site craft productivity and on-site craft productivity per work item's unit. Then he evaluates the condition of the project by comparing productivity measured and productivity planned at the beginning of the project.

The result of on-site craft productivity would be fed back in order to reform the construction method and revise the plan, after the construction those data would be preserved providing against future projects. Sometimes in order to get the precise data of craft productivity, work sampling or time-and-motion studies are used.

b. *Is site productivity considered to be high or low?* Site productivity has improved in these five years for using precast method and automated construction machines so-called robots.

c. *What are the major factors affecting site productivity?* The major factors affecting site productivity fundamentally considered those items followed.

- Natural conditions (geometry, geology, weather, ocean weather, etc.)
- Environment near site (countermeasure for life conditions, near structure, land price, etc.)
- Social conditions (procurement of workers and materials, etc.)
- Size of the project (price, volume, succession of same works, etc.)
- Construction technology (reduce workers and work items, using new developed machines, new developed materials, and new methods, etc.)
- Design (standardization, simplification, CAD, etc.)

d. *How do Japanese* engineering/construction *firms define "competitive advantage?"* Japanese engineering/construction firms in general seem to consider abilities below as "competitive advantages". Ability to prepare plan and design fully in accordance with Client's needs and demands together with the profound consideration as to ease of maintenance after completion and also ability to serve quality of construction by means of utilizing their experience and results.

e. *How do they achieve it?* By means of continuous systematic training of its employees conducted by the company and integrated management system to provide and feed back necessary information at any stage of a project, namely planning, design, construction and maintenance.

f. *What do they consider to be their core competencies?* The ability of Continuous Technical R&D and the Systematic follow up competence to answer any needs from clients at any stage (planning, design, construction and maintenance) of a project are considered as their core competence. Besides the ability of safety control and the consideration for the environment condition are considered important.

g. *Who do they consider to be their competitors?* In domestic market, other Japanese firms are considered as competitors, on the other hand in the developing country's market, American and European firms seem to be competitors especially F/S and CM fields, East Asian firms considered as competitors especially construction work fields.

h. *What benchmarks do they use in comparing themselves to their competitors?* Competitive power in price is believed to be an apparent benchmark; however, the technologies such as acquired patents, able engineers and historical data are also considered as a benchmarks.

i. *Do they consider themselves as ahead of or behind their competition in these metrics?* In domestic market, there is little difference in competitive power among construction firms. In international market, especially in developing countries, Japanese construction firms are ahead of Technical capability, however, are behind in terms of competitiveness in price due in particular to sudden rise of management/engineering cost caused by exchange rate.

j. *What do the Japanese clients (industrial owner/operators) think of Japanese engineering/construction companies and of construction technology?* Japanese engineering/construction firms believe that Japanese clients (industrial owner/operators) evaluate their ability and technologies to supply the high quality structures within the fixed construction time and contract price.

k. *What improvements would the clients make, it they could, to the construction delivery system?* The clarity, objectivity, competitiveness of the bidding system have to be more restrict, and the endeavor in order to decrease the construction cost is seemed necessary. Also, in view of the progress of internationalization, it is necessary to reconsider the bidding system will be a easy understanding one for foreign firms.

APPENDIX C:

PANEL BIOGRAPHIES

THOMAS L. ANDERSON

Education:

University of Idaho, B.S., Civil Engineering, 1958
University of Idaho, M.S., Civil Engineering, 1961
University of Colorado, Ph.D., Structural Dynamics, 1967

Position:

East Coast Regional Manager
Fluor Daniel Technologies

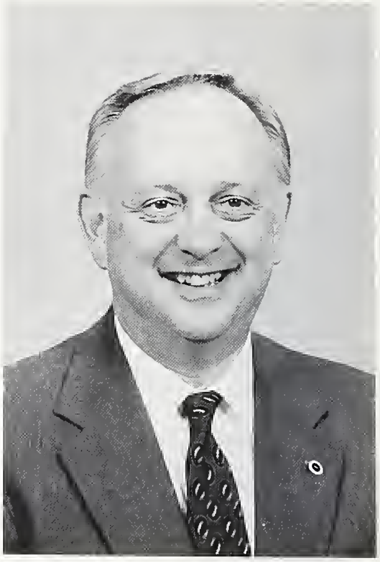
Tom Anderson worked as a research engineer for Boeing Airplane Company from 1961-1962 and served on the University of Idaho Civil Engineering faculty from 1962-1970. He then joined Battelle Memorial Institute Pacific Northwest Laboratories where he served initially as senior research engineer and later as manager of the structures and mechanics section (1970-1973). He then joined Fluor Daniel, Inc. as supervising structural engineer (1973-1982) and continued to assignments as technical manager (1982-1984), senior technical manager (1984-1988), senior director and manager of Civil/Structural Engineering (1988-1989) and general manager of Engineering Services for the 3,000 person Irvine Operations Center (1989-1993). In 1993, he was appointed as a two-year postdoctoral fellow at RAND's Critical Technologies Institute, where he provided policy analysis support to the Executive Office of the President of the United States in assisting in carrying out the mission of the President's National Science and Technology Council.

Dr. Anderson has authored over 50 published technical papers and reports and he is an active member of the Earthquake Engineering Research Institute where he serves on the Board of Directors and the Editorial Board; Structural Engineers Association of California, Seismology Committee; the American Society of Civil Engineers, Technical Council on Lifeline Earthquake Engineering and working group on high-level waste repositories; and Seismological Society of America. In addition, Dr. Anderson serves on the Oversight Committee of the National Center for Earthquake Engineering Research, SUNY, and is past chairman of the University of California, Irvine, Science Education Advisory Board. Dr. Anderson is a frequently invited speaker on the subject of the selection and implementation strategies for seismic isolation technologies and frequently serves on NSF proposal review groups, national conference steering committees, and is active in business-education partnership activities.

Current interest and recent responsible project assignments include the coordination and direction of seismic design of the base isolation system for the 911 emergency response center for Los Angeles County Fire Department, conceptual design to isolate motion sensitivity SDI ground base laser facilities, and seismic design considerations for underground nuclear waste repositories, as well as chairing and serving on peer review panels for similar projects.

In his current assignment, Dr. Anderson is responsible for facilitatiang the process of strategically investing Fluor Daniel's capaital and resources into technologies, businesses and industries to create new business opportinities for Fluor Daniel, its clients and its business partners.

STEVEN J. BOMBA



Education:

University of Wisconsin-Madison, B.S., Physics, 1959
University of Wisconsin-Madison, M.S., Physics, 1961
University of Wisconsin-Madison, Ph.D., Physics, 1968

Position:

Vice President, Technology
Johnson Controls, Inc.

Steve Bomba has been Vice President of Technology at Johnson Controls, Inc. since October of 1990. Dr. Bomba has held several professional, managerial and executive positions at Rockwell International, Allen-Bradley, Texas Instruments, Mobil Oil Co., and U.S. Army Signal Corp.

In addition to his experience in the private sector, Dr. Bomba also includes a distinguished academic background, holding three degrees in physics from the University of Wisconsin-Madison. He has also attended executive schools for managers of innovation and technology at Harvard, MIT and Northwestern.

RICHARD A. CEMENSKA

Education:

Bradley University, B.S., Mechanical Engineering, 1974
Stanford University, M.S., Mechanical Engineering, 1975
Bradley University, M.S., Electrical Engineering, 1991

Position:

General Manager
Advanced Fuels
A subsidiary of Caterpillar Inc.

Rich Cemenska began his career with Caterpillar as an hourly summer hire in the summer of 1969 and entered the Caterpillar Engineering College Co-op program in 1970. Graduating from Bradley in 1974 with a Bachelor of Science Degree in Mechanical Engineering, Rich began a career path with the Technical Services Division that would span more than two decades and two additional Master of Science degrees.

Rich's career has included assignments in engine research, electronic control systems, and research and systems integration. As a Technology Manager for the Technical Services Division, he recently completed an assignment where he was responsible for monitoring worldwide developments in electro-hydraulics, transmissions and engines with a specific focus on Japan. He was most recently promoted to General Manager of Advanced Fuels, a technically-driven subsidiary of Caterpillar Inc.

EDWARD E. DiTOMAS

Education:

Pennsylvania State University, B.S., Civil Engineering, 1962

Position:

Chief Engineer
The Turner Corporation

Ed DiTomas joined Turner Construction Company in 1963, and during the next 27 years held a number of operational positions covering a wide range of responsibilities, with emphasis on the engineering and management of building projects. These projects included office buildings, corporate headquarters, research facilities, hotels, hospitals, data processing centers, government buildings, educational facilities, condominiums and parking garages, as well as renovation and fire damage restoration work. His construction experience covered diverse geographical areas including the northeastern, southeastern and midwestern United States.

In 1990 Mr. DiTomas assumed the position of Chief Engineer for The Turner Corporation. As Chief Engineer he provides technical support to all business units and projects throughout the company; and establishes and monitors the implementation of administrative and procedural controls for project management. He is also a member of Turner's Committee on Sustainable Development, manager of Turner's green building activities, Turner's representative on the U. S. Green Buildings Council, participates in Turner's support of construction industry R & D efforts and a company trainer of management and technical subjects.

In addition to his responsibilities in Turner, Mr. DiTomas is an active member of ASCE and serves on the Society's Committee on Quality in the Civil Engineering Profession. He is also a member of the Construction Industry Institute's committee on Modeling Lessons Learned and a member of The Associated General Contractors of America's committee on Building Codes & Permits. Other activities include membership in CSI, ACI and ASTM; active participation in numerous industry related symposia; partnering with key players in construction industry manufacturing and speaking to various organizations and universities on construction related issues.

Mr. DiTomas served in the United States Navy from 1956 to 1958, in the Public Works Division, U. S. Naval Air Station, Port Lyautey, Morocco.

LLOYD A. DUSCHA

Education:

University of Minnesota, B.C.E., Civil Engineering, 1945

Position:

Independent Consulting Engineer
(Retired Deputy Director of Engineering & Construction, U.S. Army Corps of Engineers)

Lloyd Duscha joined the U.S. Army Corps of Engineers in 1946 as a structural engineer involved in the design and construction of earth dams, hydraulic structures, and hydropower plants in North Dakota and Montana. From 1959-1966, he served as Chief, Engineering Branch during the construction of the Atlas D and F, and Minuteman I and II intercontinental ballistic missile sites in Nebraska and North Dakota. Subsequently, served as Chief, Engineering Division of the Philadelphia District responsible for planning and design of dams and other water control projects in the Delaware River Basin and shore protection along the New Jersey and Delaware coasts. In 1971, he was assigned as Chief, Engineering Division of the Missouri River Division with responsibility for overseeing the engineering aspects of water resource and military construction projects in a 14-state area. In 1979, he became Chief, Engineering Division of the Civil Works Directorate in the Office, Chief of Engineers and in 1983 became Deputy Director of Engineering and Construction responsible for setting policy and directing the execution of the Corps of Engineers mission in civil works, military construction and support for other agencies.

As a consultant since 1990, he has been involved in a wide range of activities pertinent to the engineering-construction industry on the national and international scene, to include such aspects as business development, organizational management, dispute resolution, serving on Consultant Boards for large dams, advising on dam safety programs, and performing various water resource assignments for the World Bank.

Mr. Duscha is a registered engineer and member of the National Academy of Engineers, Tau Beta Pi and Chi Epsilon. He received the Board of Regents Outstanding Achievement award from the University of Minnesota, the President's Medal from the American Society of Civil Engineers and the Public Servant of the Year award from the American Consulting Engineers Council. His professional activities include having served as President of the U.S. Committee on Large Dams, Chair of the Dam Safety Committee of the International Commission on Large Dams, and on the Board of Directors of the American Consulting Engineers Council Research and Management Foundation. He is actively involved in activities of the National Research Council, having served on the Committees on New Technology & Innovation in Building, Tunnel Contracting Practices for the Superconducting Super Collider, and the U.S. National Committee on Tunneling Technology. He now serves on the Board on Infrastructure and the Constructed Environment.

EZRA D. EHRENKRANTZ

Education:

Massachusetts Institute of Technology, Bachelors of Architecture, 1954
University of Liverpool, Masters of Architecture, 1956
Fulbright Fellowships, Building Research
Station, Great Britain, 1954 - 1956

Position:

Sponsored Chair
Architecture and Building Science
New Jersey Institute of Technology

Ezra Ehrenkrantz has initiated and directed extensive architectural research concerning human needs in the built environment. The ability to understand and resolve problems and issues related to a systems approach to design--based on the balance between needs and resources--has been a foundation of Mr. Ehrenkrantz's work. Corporate, foundation and government sponsors have funded his research with more than $10 million of awards.

In addition to his position at NJIT, Mr. Ehrenkrantz is a founder and principal of Ehrenkrantz & Eckstut, a New York City based architecture and planning firm. During his years of architectural practice, Mr. Ehrenkrantz has established a reputation as a specialist in design, building technology, management systems and housing -- meeting a wide variety of user requirements for many different building types.

Mr. Ehrenkrantz's work has received a number of awards. In addition to over two dozen major design awards for specific buildings and planning projects in housing, education, health and other areas, Mr. Ehrenkrantz received the Medal of Honor 1993 from the New York Chapter of the AIA and was named Construction's Man of the Year by Engineering News-Record (1969). He has also received the Building Research Advisory Board's Quarter Century Award (1977) as well as the Governor's Design Award, State of California, for the Systems School Design (1965).

Mr. Ehrenkrantz has served on the White House Task Force on the City, the National Commission on Urban Problems, the Commerce Technology Advisory Board, the NIST Building Research Division Advisory Board, National Academy of Science Building Research Board (Committee for and Infrastructure Research Agenda; Chairman, Building Diagnostics Committee; Chairman, U.S. Embassy Component Design Committee), the AIA Long Span Structural Failures Committee, Judiciary Advisory committee on Americans with Disabilities Act Compliance, and the Citizens Commission on Planning for Enrollment Growth NYC Board of Education. He has served as a Board Member and Treasurer, Lighting Research Institute and as a Board Member of Housing New Jersey. He is the author of several articles and books.

RICHARD G. GANN

Education:

Trinity College, B.S., Chemistry, 1965
Massachusetts Institute of Technology,
Ph.D., Physical Chemistry, 1970

Position:

Chief, Fire Science Division
Building and Fire Research Laboratory
National Institute of Standards and Technology

Dick Gann joined the National Bureau of Standards in 1976 as a Research Chemist. During the next six years, he successively became Head of Fire Chemistry Research, Head of Exploratory Fire Research, and an NBS Program Analyst before assuming his current position in 1982. Dr. Gann leads the Fire Science Division in developing the scientific and engineering understanding and metrology for fire research. The current foci are on the formation/evolution of smoke components in flames, ignition, innovative fire sensing, fire resistant polymers, and fire extinguishment.

Dr. Gann had spent two years as a Postdoctoral Research Associate at the Space Research Coordination Center and the Department of Chemistry at the University of Pittsburgh and four years as a Research Chemist in the Combustion and Fuels Branch of the Naval Research Laboratory. He also worked briefly for the American Cyanamid Co. and the Standard Structural Steel Co. In 1984, he was a Senior Executive Fellow at the John F. Kennedy School of Government, Harvard University.

Dr. Gann's broad research interests include flame inhibition chemistry, atmospheric and combustion chemical kinetics, smoldering combustion, fire detection and suppression, confined space fires, smoke generation and toxicity, fluid flammability, and fire model validation. He has over 40 personal publications, 250 supervised publications and 300 presentations to university, professional, industrial, and government audiences.

Dr. Gann is an active member of the Combustion Institute, having been Program Chairman of the 23rd International Symposium on Combustion, Vice Chairman of the Publications Committee; he is currently Chairman of the Eastern States Section. He also belongs to the American Chemical Society, the ASTM Committee on Fire Standards, and the National Fire Protection Association. He is U.S. Coordinator for the U.S.-Japan Panel on Fire Research and Safety and was U.S. Chairman of the U.S.-Japan-Canada Working Group on the Toxicity of Smoke from Building Materials. He chaired the Technical Groups under the Cigarette Safety Acts of 1984 and 1990 and the Technical Committee of the Halon Alternatives Research Consortium. He is a member of Phi Beta Kappa, Sigma Pi Sigma, and Sigma Xi; and is currently on the Editorial Boards of *Combustion and Flame* and *Fire and Materials*.

BURTON GOLDBERG

Education:

Tufts University, B.S., Biology, 1953
Boston University, studies in the Graduate School of
Public Administration from 1958
Massachusetts Institute of Technology, Masters in City Planning, 1960

Position:

Senior Analyst
Economics and Policy Analysis
NAHB Research Center, Inc.

Burt Goldberg has over 20 years of experience in technology-related policy and commercialization issues in the development and planning of housing, physical facilities, and infrastructure. He has managed the NAHB Research Center's and the U.S. Department of Energy's (DoE) Advanced Housing Technology Program (AHTP) for the past six years. Previously he worked for the U.S. Congress, Office of Technology Assessment (OTA) and the consulting firms of Arthur D. Little, ICF, and Real Estate Research Corporation.

In his work under AHTP, Mr. Goldberg investigated product innovation in the U.S. home building industry and developed a methodology for evaluating the potential impacts of emerging technologies, devising a plan for speeding housing innovation. He also supervised technology assessments of selected innovative products, such as insulated pre-cast foundations, foam insulation, and plastic composites. Under the auspices of the Civil Engineering Research Foundation, he participated in a White House-Construction Industry Workshop on National Goals, and authored a white paper presenting the housing industry's perspective on seven goals related to innovation in the construction industry. Mr. Goldberg wrote background and policy position papers for the Department of Housing and Urban Development's (HUD) National Home Ownership Strategy relating to reduction of production costs in housing. He conducted an assessment of the conditions and market for the production of autoclaved cellular concrete in New England, evaluating the impact of competing and advanced technologies on its use as a substitute material in residential building. For HUD, he drafted a report to Congress on the status of research to determine the U.S. competitiveness in residential technology. For DoE, he led a project investigating the factors affecting the commercialization of a plastic insulating concrete foundation and wall forming system and is now investigating the obstacles to widespread commercialization and integration of photovoltaic systems in residential buildings. Before joining the Research Center, Mr. Goldberg developed for OTA alternative energy scenarios and policy options for residential housing in center cities based on an analysis of federal policies in a report entitled "Energy for More Efficient City Buildings." He was responsible for a study for the National Institute of building Sciences and HUD investigating the need, feasibility, and problems in requiring that all residential single-family housing meet applicable energy efficiency standards. For HUD, Mr. Goldberg evaluated the impact of Operation Breakthrough's industrialized housing experiments on financial institutions, housing system procedures, labor unions, consumer, and state and local governments.

CHARLES I. McGINNIS

Education:

Texas A&M University, B.S., Civil Engineering, 1949
Texas A&M University, M. Engr., Civil Engineering, 1950

Position:

Associate Director
Construction Industry Institute
University of Texas at Austin

Chuck McGinnis entered the U.S. Army Corps of Engineers as a commissioned officer in 1949. Over a 30-year career he served in construction related assignments in Europe, Africa, Asia, Central America, and the United States. He held responsibility for managing large public works planning, design, and construction projects as well as for operation and maintenance of extensive U.S. Government facilities. He was Director of Engineering and Construction for the Panama canal in 1971. He was Vice President of the Panama Canal Company and Lieutenant Governor of the Canal Zone Government from 1972 until 1974. He was responsible for water resources management in the United States at a local, regional, and as his final military assignment, at the national level. He retired from the U.S. Army as a Major General.

Upon conclusion of his military career in 1979, Mr. McGinnis became Vice President of a mid-sized design and construction company specializing in industrial construction. He served this corporation as its Executive Vice President and Chief Operating Officer. Concurrently, he was President and Chief Executive Officer of the corporation's design subsidiary company.

In 1987, Mr. McGinnis joined the staff of the Construction Industry Institute at the University of Texas at Austin. For the next five years, he managed the Institute's research program. He is a Senior Lecturer on the Civil Engineering Faculty of the University of Texas. He is a frequent speaker to academic, professional, industrial and government audiences. He is an advisor to the Texas State Preservation Board staff, and he is active in alternative construction dispute resolution advancement.

Mr. McGinnis is a Fellow and Life Member of the American Society of Civil Engineers. He is a Fellow of the Society of American Military Engineers, and a member of the National and Texas Societies of Professional Engineers. He is a registered professional engineer in the states of Texas and Missouri. He is a member of Tau Beta Pi and Chapter Honor member of Chi Epsilon.

BOYD C. PAULSON, JR.

Education:

Stanford University, B.S., Civil Engineering, 1967
Stanford University, M.S., Civil Engineering, 1969
Stanford University, Ph.D., Civil Engineering, 1971

Position:

Charles H. Leavell Professor of Engineering
Department of Civil Engineering
Stanford University

Dr. Paulson teaches in Stanford University's Graduate Program in Construction Engineering and Management and is presently director of that program. He served on the Civil Engineering faculty at the University of Illinois in 1972 and 1973. He was also a Visiting Professor at the University of Tokyo in 1978, the Technical University of Munich in 1983, and the University of Strathclyde in Glasgow, Scotland in 1990-91. He is the author or co-author of 2 books and over 90 papers.
Dr. Paulson's research and teaching interests are primarily in computer applications in construction, including automated data acquisition, operations simulation, and automated process control. He has had numerous research projects in these and other areas sponsored by the National Science Foundation, the U.S. Department of Transportation, and others.

Dr. Paulson's professional activities include past Chairman of ASCE's Committee on Professional Construction Management and the ASCE Task Committee on Computer Applications in Construction, past Vice Chairman of ASCE's Construction Research Council, and past Chairman of the ASCE Construction Division Executive Committee. He was twice elected as secretary of the Project Management Institute. He is a member of Tau Beta Pi, Sigma Xi, ACM, ASCE, ASEE and the IEEE Computer Society.

His honors and awards include ASCE's 1980 Walter L. Huber Civil Engineering Research Prize, West Germany's Alexander von Humboldt Foundation Research Fellowship in 1983, ASCE's 1984 Construction Management Award, selection in 1984 as a Distinguished Scholar by the U.S. National Academy of Sciences Committee on Scholarly Communication with the People's Republic of China, the 1986 Henry M. Shaw Lecturer at the North Carolina State University, the Project Management Institute's 1986 Distinguished Contributions Award, 1990-91 faculty research and teaching scholarships from The Fulbright Foundation and The British Council, the 1992 Kudroff Memorial Lecturer at Pennsylvania State University, and the 1993 ASCE Peurifoy Construction Research Award.

NOEL J. RAUFASTE, JR.

Education:

Iowa State University, B. Sc., Industrial Engineering, 1967
Iowa State University, B. Sc., Architecture, 1967
George Washington University, graduate studies
in Engineering Administration

Position:

Manager, Cooperative Research Programs
Building and Fire Research Laboratory
National Institute of Standards and Technology

During 1967 to 1972, Noel Raufaste, employed by a private consulting firm, directed studies on cost/economic and systems analysis of Federal, military, private sector programs and directed market research studies. He joined NIST in 1972 to coordinate BFRL's Federal agency building technology projects. He is now responsible for BFRL's Cooperative Research Programs: he creates research programs with Federal and state agencies not traditionally funding BFRL/NIST; initiates research efforts with industry; serves as the U.S.-Side Secretary General to the U.S.-Japan Panel on Wind and Seismic Effects, and strengthens international cooperative research activities. He facilitates and intensifies NIST's industrial technology commercialization efforts, develop CRADAs, and improve the exchange of NIST's S&T to the U.S. private sector (work performed at NIST's Office of Research and Technology Applications). He is directing the planning for the Civil Engineering Research Foundation's February 1996 International Research Symposium on Engineering and Construction for Sustainable Development in the 21st Century. Mr. Raufaste is leading BFRL's efforts to disseminate its information through the electronic media. He has coordinated, for many years, BFRL's research program planning activities, communicated the Laboratory's research results to the building community, broadened the base for other agency funding, managed cooperative research programs, and managed the building technology computing facility. During 1983-89, he was consultant to the National Academies of Sciences and Engineering Board on Infrastructure and Constructed Environment (formerly the Building Research Board). He worked with international government and private building organizations in developed countries, where he managed and initiated joint research and attracted guest researchers to NIST, and in developing countries to improve their ability to standardize and industrialize.

Mr. Raufaste has written or jointly authored over 65 reports; is active in the National Institute of Building Sciences (NIBS), where he is Chairman of NIBS' Consultative Council; the American Society of Civil Engineers; the International Council for Building Research Studies and Documentation (CIB), and member of three CIB Working Commissions; the Washington International Trade Association; and Past Executive Secretary of the National Academies International Technology Council; a recipient of various Federal awards including the Department of Commerce Bronze Medal, and international commendations from the Philippine Institute of Civil Engineers, the Indonesian Institute of Architects, the Republic of China Association of Standards; is a member of the NIST Editorial Review Board; served as technical advisor to the Agency for International Development; and is an elected officer in several civic, educational, and church activities.

KENNETH F. REINSCHMIDT

Education:

Massachusetts Institute of Technology, S.B., Civil Engineering, 1960
Massachusetts Institute of Technology, S.M., Civil Engineering, 1962
Massachusetts Institute of Technology, Ph.D., Civil Engineering, 1965

Position:

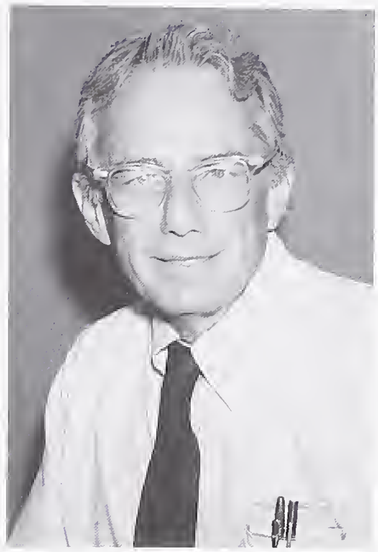
Senior Vice President
Stone & Webster, Incorporated
President and Chief Executive Officer
Stone & Webster Advanced Systems Development Services, Inc.

Ken Reinschmidt joined Stone & Webster Engineering Corporation in 1975 as a Consulting Engineer. During the next 20 years he successively became a Senior Consulting Engineer, Vice President and Chief Consulting Engineer, member of the Board of Directors, and Senior Vice President and Manager of the Consulting Group before assuming his present position with SWASDS in 1992. In 1993 was elected to the additional position of Senior Vice President of Stone & Webster, Incorporated. Prior to joining Stone & Webster, Dr. Reinschmidt was an Assistant Professor of Civil Engineering, Associate Professor of Civil Engineering, and Senior Research Associate at the Massachusetts Institute of Technology. He also served as a lieutenant and captain in the U.S. Army Transportation Corps from 1965 to 1966, and received the Legion of Merit.

Dr. Reinschmidt's consulting interests include automated engineering design, design optimization, computer-aided design, construction simulation, system dynamics, computer-aided project management, knowledge-based systems, neural networks, genetic programming, risk analysis, and project scheduling. He has over 100 publications in these areas.

Dr. Reinschmidt is a member of the U.S. National Academy of Engineering, a Fellow of the American Association for the Advancement of Science, a member of the Society of the Sigma Xi, Tau Beta Pi, Chi Epsilon, the Institute of Management Sciences, the Operations Research Society of America, and the American Society of Civil Engineers (ASCE). He is a life member of the Society of Architectural Historians and the Archaeological Institute of America. He was awarded the Thomas Fitch Rowland Prize of the ASCE. He is a member of the Corporate Advisory Board of the Civil Engineering Research Foundation (CERF) and the Co-chairman of the Thrust Group on Construction and Equipment for "Engineering and Construction for Sustainable Development in the 21st Century: An International Research Symposium and Technology Showcase" to be held in 1996. He has served as a member of the Executive Board of the National Initiative for Product Data Exchange (NIPDE), directed by the Undersecretary of Commerce for Technology, the Advisory Board for the Deputy Director for Engineering of the NSF, several NSF review panels, the Building Research Board of the NRC of the NAS/NAE, the Committee on Foam Plastic Structures, and the Committee on Advanced Technology for Building Design and Construction. He chaired the Committee on Integrated Database Development, the Panel for Building Technology of the Board on Assessment of the NIST Programs, and the Committee on Education of Design and Construction Professionals of the NRC of the NAS.

ARTHUR H. ROSENFELD



Education:

University of Chicago, Ph.D., Physics, 1954

Positions:

Senior Advisor, Energy Efficiency, U.S. Department of Energy
Co-Chair, Subcommittee on Construction and Building,
National Science and Technology Council

Art Rosenfeld was Enrico Fermi's last graduate student, in experimental particle physics, at the University of Chicago's Institute for Nuclear Studies. He worked in the Nobel Prize-winning hydrogen bubble chamber group of Professor Luis Alvarez from 1955 to 1973, and served as Chairman of the group from 1971 through 1973. He also founded, in 1964, the International Particle Data Group, which still publishes the well-known Particle Data Tables. From 1955-94, he was a Professor of Physics at the University of California at Berkeley.

The OPEC oil embargo in 1973 turned Dr. Rosenfeld's attention to efficient use of energy, and in 1975 he founded the program at Lawrence Berkeley Laboratory which later became the Center for Building Science, CBS, which he chaired until 1994. CBS developed many successful technologies to improve the efficiency of buildings: electronic ballasts for fluorescent lamps (which led to compact fluorescent lamps), "low-emissivity" windows, and the computer program DoE-2, for the energy-efficient design of buildings and the calculation of building standards. These technologies will save owners of U.S. homes and buildings about $20 billion annually.

Professor Rosenfeld was also active in designing energy policy, particularly in California, where he was active in the California Collaborative. This collaborative effort changed the profit rules for utilities, making it more profitable for them to sell efficient energy services than to sell electricity or gas.

His current research interest is the demonstration of Cool Communities (cool roofs, pavements, and trees to shade buildings). This strategy can save 20% of U.S. air conditioning and reduce smog by 10% to 20%, at a net annual savings in air conditioning of $10 billion to $20 billion.

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