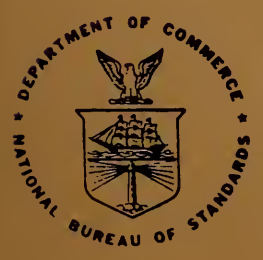
NBSIR 87-3565

Building Technology Project Summaries 1987

Noel J. Raufaste

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Gaithersburg, MD 20899

May 1987



U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NBSIR 87-3565

BUILDING TECHNOLOGY PROJECT SUMMARIES 1987

Noel J. Raufaste

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Gaithersburg, MD 20899

May 1987

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

FOREWORD

The building research program of the National Bureau of Standards, the Nation's central engineering measurement laboratory, is conducted by its Center for Building Technology (CBT). CBT works cooperatively with other organizations, private and public, to improve building practices. It conducts laboratory, field, and analytical research. It develops technologies to predict, measure, and test the performance of building materials, components, systems, and practices. This knowledge is required for responsible and cost-effective decisions in the building process and cannot be obtained through proprietary research and development. CBT provides technologies needed by the building community to achieve the benefits of advanced computation and automation. CBT does not promulgate building standards or regulations, but its technologies are widely used in the building industry and adopted by governmental and private organizations that have standards and codes responsibilities.

Construction is one of the Nation's largest industries. In 1986, new construction put in place amounted to $375 billion, about 8.9 percent of the Gross National Product. Over two-thirds of the Nation's fixed reproducible wealth is invested in constructed facilities that shelter and support most human activities.

CBT research provides knowledge for decision making. This knowledge includes characterization of the environments in which buildings must operate (such as wind loadings), characterization and definition of the performance of buildings, components, and systems (such as the mechanisms for heat loss through a window or wall cladding element), and methods of testing for performance qualities that will apply equitably to a whole family of potentially competitive proprietary materials and components.

The CBT staff of 130 includes 84 professionals, of whom 30 are registered professional engineers and 44 hold doctorates. The principal disciplines are structural, materials, mechanical engineering, physics, and chemistry.

Among the variety of special facilities and equipment at CBT are a large-sale testing facility including a reaction buttress 45 feet high with a lateral force capacity of 1.2 million pounds in conjunction with the universal testing machine of 12-million-pound capacity is capable of testing structural components 60 feet in height; a tri-directional structural testing facility with its associated computer control data acquisition and processing equipment capable of applying forces of displacements in three directions simultaneously to full-scale structural components and systems; seven environmental chambers, including a 30x40x50-ft chamber, for developing thermal performance modeling techniques required to predict human comfort and energy efficiency of buildings; a guarded hot-plate that measures insulation performance of thicknesses up to 15 inches; a calibrated hot-box to provide precise measurements of heat and moisture transfer in full-scale building wall and roof sections; a five-story plumbing research laboratory with high-speed computer data acquisition system to study the performance of water supply and drainage systems; daylighting laboratories; an illumination color laboratory capable of presenting eight light sources independently; an outdoor solar-collector test-method for development area, including a passive solar test house and facilities for experimental solar heating and cooling systems; a network of

outdoor material exposure sites; materials reference laboratories include the Cement and Concrete Reference Laboratory sponsored by the American Society for Testing and Materials and the AASHTO Materials Reference Laboratory sponsored by the American Association of State Highways and Transportation Officials; and a well equiped materials research laboratory with a scanning electron microscope and many other instruments for materials characterization.

This report summarizes CBT's research for 1987, and is arranged according to CBT's research programs. Each summary lists the project title, its activities, point of contact in CBT, and sponsor.

CONTENTS

COMPUTER INTEGRATED CONSTRUCTION

EXPERT SYSTEM FOR DURABLE CONCRETE

James R. Clifton, Building Materials Division, (301) 975-6707

Sponsor: National Bureau of Standards

The projects' objectives are to develop a prototype expert system to select constituents for concrete (subjected to a broad range of service conditions) and to document the development of the expert system which will help develop other expert systems.

Expert systems can assist in decisionmaking for selection of construction materials. They should give recommendations at or near the level of human experts, thus facilitating and improving the selection process. Concrete was selected for developing a prototype expert system because it is the most widely-used man-made construction material and the knowledge for making durable concrete is not easily accessible to all.

This project collaborative with several CBT groups and the professional community. The ACI Guide to Durable Concrete, developed by ACI Committee 201 on Durable Concrete, is the prime source for the factual portion of the knowledge base. An ACI subcommittee reviewed CBT's expert system and recommended improvements to the knowledge base. Other ACI documents have been used to develop the knowledge base, e.g., guidelines on Corrosion of Metals in Concrete and on Cements. The expert system will be submitted to ACI Committee 201 for consideration as a possible supplement to, or replacement for, the Guide to Durable Concrete.

EXPERT SYSTEMS FOR AIR INFILTRATION PREDICTION AND CONTROL IN BUILDINGS

Andrew Persily, Building Environment Division, (301) 975-6418

Sponsor: National Bureau of Standards

This research focuses on developing an expert system for air leakage diagnosis and infiltration characterization in residential buildings.

There are no adequate procedures to characterize building air movement, diagnose air leakage problems, or determine appropriate retrofit procedures and their effects. Predictive models of infiltration have been developed, but the models require detailed descriptions of the building leakage characteristics and other generally unknown information.

During FY87, CBT will further develop the prototype expert system produced in FY86 for characterizing air infiltration and air infiltration related problems in residential buildings. The FY86 prototype has concentrated on the diagnosis of moisture related air leakage problems with additional considerations regarding infiltration prediction and retrofit planning. The final system is intended to use available information on the building and yield its infiltration rates as a function of weather conditions, identify heat loss, condensation, and indoor air quality, and recommend appropriate retrofit procedures and anticipate their effects. The system will employ an existing predictive model of air infiltration and a knowledge base of building construction details, a database of building component leakage characteristics, and a set of heuristic rules.

The FY87 effort will evaluate last years prototype system. The system will be examined from a knowledge engineer's point of view to evaluate the appropriateness of the production rule approach. Based on the results of this evaluation, the prototype will be modified into a more correct and appropriate form.

This effort also will expand the prototype to air leakage problems beyond the current emphasis on moisture issues, including indoor air quality, heat loss/gain, and thermal comfort. As the system is revised and expanded, the process of evaluation by various domain experts will continue.

INFORMATION EXCHANGE TECHNOLOGIES IN THE BUILDING PROCESS

Kent A. Reed, Building Environment Division, (301) 975-5852

Sponsor: National Bureau of Standards

The aim of this project is to develop the technical basis for correct and efficient information exchange standards for the building industry.

The many participants of the building process continue to be plagued with the errors and inefficiencies that occur because information is not available when needed, is incorrectly transferred, or is incorrectly interpreted. Rational techniques are needed for developing and testing information exchange standards if computer integration of the building process is to be achieved.

CBT will continue to serve as cochairman of the Architecture, Engineering and Construction (AEC) Committee of the Initial Graphics Exchange Specifications (IGES) Organization. CBT will work closely with the AEC Committee members to define AEC-subsets of IGES entities and develop requirements for AEC-oriented test cases. CBT will create test cases and organize an IGES-vendor round-robin activity in which the current CAD-data exchange capability in the AEC-industry will be demonstrated quantitatively. The results will be analyzed and evaluation criteria will be proposed for consideration by the IGES Testing Methodology Committee.

The building data protocols research will be extended. This research resulted in the definition of the Modular Semantic-Application Layer Protocol (MS-ALP) in FY86. An intelligent agent that simulates next-generation computer aided design software will be developed using the Automated Reasoning Tool (ART) and linked to the existing test programs that form the experimental test bed for MS-ALP. The prototype semantic model for building information will be extended and the protocol will be exercised and refined. Close coordination will be maintained with the IGES Organization and with the ongoing activity of the Committee on Advanced Technology for Building Design and Engineering formed by the Building Research Board/NRC.

KNOWLEDGE REPRESENTATION AND USE IN THE BUILDING PROCESS

Kent A. Reed, Building Environment Division, (301) 975-5852

Sponsor: National Bureau of Standards

The purpose of the project is to develop principles for correct and efficient representation and use of domain knowledge in computer-aided design, construction and operation of buildings.

Construction projects in the building industry must deal with domain knowledge in many forms. The representation of engineering data is reasonably well understood, but the problems of representing and using other knowledge such as the intents of the participants, accepted practices, and the explicit and implicit constraints imposed by building standards and codes are just now being understood.

CBT, in cooperation with Carnegie-Mellon University (CMU) and the University of Illinois (UI), has developed systematic methods for representing and analyzing construction standards, codes and specifications; for expressing their requirements in computer-usable form; and for interfacing them to computer-aided design programs. This work has culminated in two software systems. The Standards Analysis Synthesis and Expression (SASE) software system provides standards-writers with an integrated set of tools for constructing, testing decision tables, developing information networks, constructing and manipulating classifier trees, and for developing scopelists, indices, and outlines. The Standards Interface for Computer-Aided Design (SICAD) software system is an experimental test bed that demonstrates how elements in a CAD-database can be checked for compliance with the provisions of a standard when it is expressed as an extended SASE-model.

During FY87, CBT will work with the Civil Engineering Department of CMU to explore the use of logic programming techniques to replicate and extend the core representation and analysis functions of SASE. CBT will complete development of a code checker program based on SICAD and the ACI-318 Building Code for Reinforced Concrete Structures. Also working with the Civil Engineering Department of UI, new principles for SICAD will be developed which resolve the currently recognized problems with multiple databases and semantic interpretations.

ASSESSMENT OF ROBOTICS FOR IMPROVED BUILDING OPERATION AND MAINTENANCE

James E. Hill, Building Environment Division, (301) 975-5851

Sponsor: General Services Administration

The project's objective is to assess the potential for robotics in daily operation and maintenance of GSA buildings and to develop guidelines and performance criteria for the application of robotic devices to insure safe and reliable operation within a building.

GSA is interested in potential applications of robotics for operation and maintenance functions such as window cleaning, floor cleaning, trash compacting, and miscellaneous materials handling. Some of the robotics devices under development have potential for use in these applications.

CBT will make a comprehensive assessment of the possible application of robotic devices to a variety of building operation and maintenance functions. The assessment will include a state-of-the-art survey of robot technology with potential use in building operation and maintenance. The assessment will include an analysis of operation and maintenance functions in building identifying those that are potentially promising for robotic application. The most promising ones will be where the work must be done in dangerous or hazardous conditions (e.g., window cleaning on the exterior of multi-story buildings), where the environment is very structured and the tasks are repetitive and/or where high quality and high skill levels are required and skilled workers are in short supply.

Potential barriers to the use of robotics within the buildings will be determined. Recommendations will be made for changes in GSA practices so that GSA can take advantage of the robotics age. A procedure for implementing robotic use for selected applications will be developed.

ECONOMIC METHODS FOR BUILDING STANDARDS

Harold E. Marshall, Center for Applied Mathematics, (301) 975-6131

Sponsor: National Bureau of Standards

The building community needs sophisticated, practical methods and guidelines to consistently evaluate alternative building technologies. The need for standardized, improved methods, and guidelines to help the building community achieve affordable buildings that meet performance objectives stems in large part from the rising costs of building materials, the high costs of construction due to safety/environmental regulations, the alleged decline in construction productivity, and the uncertain costs of energy.

Economic methods and supporting analyses will be developed for application to building problems. A special publication on handling risk and uncertainty in the economic evaluation of buildings will be submitted to ASTM for use in the development of a standard. The existing standard economic methods, including the life-cycle cost, net benefits, internal rate of return, and savings-to-investment and benefit-cost ratio methods will be revised. This work provides an integrated ASTM and NBS approach, resulting standards are formatted so consensus can be reached by ASTM.

The building community will benefit from building economics methods developed at NBS and adopted as recommended practices through the ASTM process by achieving target levels of building performance with lower life-cycle building costs.

STRUCTURAL PERFORMANCE

STRUCTURAL ASSESSMENT OF THE U.S. OFFICE BUILDING IN MOSCOW

Nicholas J. Carino, Structures Division, (301) 975-6063

Sponsor: Department of State, Office of Foreign Buildings

This effort focuses on conducting an analysis of the U.S. Office Building in Moscow and providing recommendations and cost estimates for correcting any structural flaws and construction defects.

In 1969, an agreement was signed between the U.S. and the Soviet Union to construct new embassies in their respective countries. Construction of the U.S. embassy in Moscow began in 1979, and built according to Soviet plans. The building design is a mixed structural system of precast concrete and steel members. Originally scheduled for completion in 1982, the project experienced delays and increasing costs. In an effort to address the difficulties in completing the project, Congress passed an amendment to the Continuing Appropriations Act for Fiscal Year 1987. The amendment authorizes NBS to conduct an independent analysis of the office building. The analysis is to include "an assessment of the current structure, recommendations, and cost estimates for correcting any structural flaws or construction defects."

The investigation consists of four phases. The first phase is an assessment of the building as defined by the contract documents. Potential failure mechanisms will be identified, critical loading conditions will be considered for each failure mechanism, and the distribution of forces will be determined. The strength of the Soviet building components and their connections, as described in the contract documents, will be determined according to accepted engineering practice, supplemented with available test data. Structural integrity of the designed structure will be assessed for consistency with accepted U.S. standards and practices.

The second phase will establish the as-built condition of the structure. Site data for the project will be reviewed. NBS will perform a field investigation. Representative samples will be secured to establish in-place material strengths. Key structural components and connections will be examined using available test methods. The non-structural system (roofing, brick facade, glazing) will be investigated.

In the third phase, the structural integrity of the as-built structure will be assessed. Attention will be given to the effects of flaws on the strength of members and connections. Laboratory and analytical studies aimed at assessing the influence of the flaws will be conducted as required. Based on a review of design details, the materials used, and the workmanship, the ability of the building envelope to function as intended will be assessed.

The final phase will involve recommendations for remedial measures that may be required to provide the necessary structural integrity for members or connections, or to ensure performance of the envelope.

NDT METHODS FOR CONCRETE

Nicholas J. Carino, Structures Division, (301) 975-6063

Sponsor: National Bureau of Standards

The objective of this research is to gain a fundamental understanding of the interaction of stress waves with internal discontinuities in concrete structures and to develop test methods and proposed standards that use the impact-echo technique for nondestructive evaluation of internal condition of existing concrete structures.

There is no satisfactory method for locating internal defects in concrete structures. The impact-echo methods has the potential to fill this need. A fundamental understanding of stress wave propagation through a heterogeneous material, such as concrete must be developed.

The feasibility of the impact-echo method has been demonstrated under laboratory conditions using controlled-flaw specimens. Dynamic finite element analyses of plates containing disk-shaped flaws have been completed, and a field test system is under development. The FY87 research will evaluate the performance of the technique for locating two common types of flaws in concrete: honeycombing and delaminations in concrete slabs overlaid with asphalt concrete. Analytical and experimental studies will be performed. In addition, new experiments will be performed to verify preliminary successful results in determining the depth of a simulated surface opening crack and detecting ungrouted tendon ducts. Work on this project includes a cooperative effort with NBS's Automated Production Metrology Division.

STRUCTURAL/MECHANICAL DESIGN CRITERIA FOR LOW IMPACT RESISTANT STRUCTURES (LIRS)

Richard D. Marshall, Structures Division, (301) 975-6071

Sponsor: Federal Aviation Administration

This project will provide the FAA with test data, design criteria, and analytical models to predict the response of low impact resistant structures to aircraft impact.

The potential hazard of an aircraft colliding with approach lighting structures during landing or take off operations has led FAA to investigate the possibility of developing structural systems with low impact resistance. The goal of designing low impact resistance structures (LIRS) is to impart minimum damage to an aircraft in the event of an accidental collision. "Break-away" mechanisms implemented in structural systems have been considered by FAA to fulfill the goal. To ensure the effectiveness of such a system, the investigation of impact characteristics of structural systems, including components such as the electrical conductors and the development of analytical models for simulating impact phenomenon are needed.

The research consists of three separate activities. Activity one is to investigate the behavior of electrical conductors by performing static and dynamic pull tests on conductors of the type used for approach lighting LIRS. Activity two involves the assessment of design loads and the analysis, erection, and testing of an antenna support structure. Activity three will be devoted to development and validation of analytical models for predicting the response of LIRS subjected to aircraft impact.

FLOW-INDUCED VIBRATIONS OF BLUFF BODIES

Richard D. Marshall, Structures Division, (301) 975-6071

Sponsor: National Bureau of Standards

This project will center on obtaining a basic understanding of the mechanisms involved in the aerodynamic excitation of bluff bodies and the response of taut strip models.

The taut strip model is simple and has ability to accommodate multiple modes of vibration. It is an attractive alternative to other complex and expensive models to study wind-induced structural vibrations. Recent wind tunnel studies of taut strip models of rectangular cross-section and width to depth ratios typical of engineering structures have shown that instabilities due to torsional flutter, galloping and vortex shedding are possible. Using carefully conducted experiments on a series of rectangular prisms, the basic mechanisms of excitation can be isolated. These experiments are needed to test existing theories of flow induced vibration and to establish the validity of taut strip models. The aerodynamic instabilities of the type to be studied in this project include cases of instability referred to as "strange attractors". The resulting body motions, although having the appearance of being random, are actually deterministic and are referred to generally as "chaotic" motions.

A series of rigid, spring-mounted, rectangular prisms will be tested in the NBS Calibration Wind Tunnel. Emphasis will be placed on cross-sections having width to height ratios in the range 0.5 to 4. Companion studies using taut strip models covering the same range of width to height ratios will be conducted and observed instability boundaries will be compared with theoretical predictions. The main thrust of the approach addresses excitation mechanisms in smooth flow; the modifying influence of incident turbulence will be explored as time permits.

ASSESSMENT OF THE UNCERTAINTIES AND RISKS ASSOCIATED WITH THE DYNAMIC BEHAVIOR OF COMPLIANT OFFSHORE STRUCTURES

Emil Simiu, Structures Division, (301) 975-6076

Sponsor: Minerals Management Service

The purpose of this project is to study various aspects of the dynamic behavior of compliant structures for identifying and reducing uncertainties and risks associated with such behavior.

Compliant offshore structures are increasingly being used in various applications, particularly in deep waters. Their hydrodynamic, dynamic and structural behavior is complex, and little if any experience is available to draw upon in evaluating their performance from a safety point of view.

This research includes an investigation on the effect of structural amplification of wind-induced dynamic motions on response of compliant offshore structures, and an investigation of the effect of Lighthill's nonlinear potential flow term on estimation of offshore structure hydrodynamic dampling. Consultations are maintained with the American Bureau of Shipping Det Norske Veritas, Department of Navy, and other agencies with an interest in risk assessment applied to compliant offshore structures.

This work will be used by MMS to establish research needs about the reliability of compliant offshore structures and to verify reliability approaches implicit in the design of such structures. The research will assist MMS in ensuring acceptable risks to the public as far as the safe operation of compliant offshore structures is concerned.

PUNCHING SHEAR STUDY OF REINFORCED SHELL

H. S. Lew, Structures Division, (301) 975-6061

Sponsors: Minerals Management Service, Department of the Interior and the Oil Industry

The objective of the project is to develop a rational criteria for the design of thick and heavily reinforced concrete shells, particularly of lightweight concrete subjected to high intensity concentrated loads in the range of 100 tons/sq. ft. (10 MPa).

The performance of concrete shell elements subjected to high local forces will be studied. The behavior of shell and plate elements will be evaluated using small scale physical models. Tests will be made on 1/6-scale and 1/3-scale models to study the size effects. The experimental program will be supplemented with analytical studies to predict the expected performance of the test specimens. The analytical models will be simulate the multi-axial stress states within thick members and will incorporate nonlinear material behavior.

The results of this study will be used to develop safety standards for the Mineral Management Service and will serve as guidelines for design of thick concrete shells.

DYNAMIC CHARACTERIZATION OF STRUCTURAL NETWORKS

Emil Simiu, Structures Division, (301) 975-6076

Sponsor: National Bureau of Standards

Structural systems are continually being developed which the dynamic response must be determined with high accuracy up to frequency components of thousands of Hertz. Such systems, which include orbiting space structures, typically consist of networks with relatively simple topologies and with elements that are relatively long compared with typical wavelengths of traveling disturbances. Recently, mathematics suggested that it is advantageous to characterize such systems dynamically by Greens function (the responses of the various coordinates to unit impulse excitations). In practice, it is necessary to evaluate Green's function experimentally for the actual structure, rather than analytically for an idealized model. Work is aimed at developing computational and experimental capabilities allowing highly accurate identification of dynamic response characteristics of structures of the type described above.

These capabilities will be based on recent mathematical research resulting in the development of pulses of the inverse Gaussian type and generalizations which allow the systematic and accurate solution of the inverse problem described above. Numerical experiments will be conducted to assess the accuracy with which it is possible to recover the exact Green's functions by deconvolution of responses contaminated by noise. The research will be conducted over a period of two to three years in collaboration with the Center for Applied Mathematics.

A parallel effort will aim at the development of a testing capability consisting of computer-driven rapid-acceleration actuators which reproduce the requisite pulses to within the accuracy needed, and of devices for the synchronized measurement of the corresponding dynamic response.

The research will provide a useful application to structural engineering technologies of mathematics, structural dynamics, and measurement sciences. It will contribute to improved reliability of structural systems developed for defense, communications, and industrial purposes.

STRENGTHENING METHODOLOGIES FOR STRUCTURAL MEMBERS

H. S. Lew, Structures Division, (301) 975-6061

Sponsor: National Bureau of Standards

This research will develop efficient methods to strengthen existing structural members for vertical and lateral loads.

Recently, an increasing number of old structures have been strengthened to the levels of performance required by current codes and standards. There are no standard methods for strengthening structural members. This research will evaluate the effectiveness of strengthening methodologies based on analytical and experimental studies.

This multi-year effort will evaluate the effectiveness of various strengthening methods for beams, columns, connections, and shear walls. The first year effort includes establishing the research agenda and conducting exploratory laboratory tests.

During FY87, an experimental study of the behavior of several strengthening methods for compression members will be performed. The selection of specific strengthening methods for experimental study will be guided by the results of computer simulations.

SPREAD FOOTINGS FOR HIGHWAY BRIDGES

Felix Y. Yokel, Structures Division, (301) 975-6065

Sponsor: Federal Highway Administration

The objective of this project is to develop a comprehensive design procedure and a draft standard for shallow foundations.

Two design limit states govern the geotechnical aspects of the design of shallow foundations: (1) shear failure in the supporting soil leading to rotation, sliding, or plunging of the footing; (2) excessive displacements leading to failure or distress in the supported structure, pavement failures, or alignment and drainage problems.

Data on settlement and structural tolerance to settlements, collected by FHWA, and other available data will be carefully evaluated to determine the accuracy and degree of reliability with which foundation displacements and displacement tolerances of the superstructure can be quantified. As appropriate, stochastic models will be developed from the data to facilitate the determination of the reliability of predictions that can be made on the basis of available data.

Analytical methods of settlement prediction on the basis of data from in-situ and laboratory measurements will be calibrated against the available data. This information will be used to develop appropriate design procedures for incorporation in a proposed design manual and draft standard.

The design manuals will be based on the principle of limit state design and will contain quantitative criteria for allowable displacements for the characteristics of the superstructure and analytical approaches to settlement prediction, tied to present methods of in-situ and laboratory soil exploration.

RELIABILITY OF WOOD STRUCTURES

Erik Henrickson, Structures Division, (301) 975-6067

Sponsor: National Bureau of Standards

The project will develop resistance criteria for probability-based limit states design of engineered wood structures taking into account the statistical variation in wood strength, the stochastic nature of loads, and the creep rupture behavior in wood.

Structural codes governing the design of engineered wood structures do not include probability-based limit states design. Probabilistic approaches to wood design are complicated because wood is a natural material with large variabilities in its mechanical properties and because wood strength is strongly dependent on load rate and load duration effects.

The research is directed toward developing probabilistic design criteria for engineered glulam and heavy timber structural elements. Statistical descriptions of the strength of wood will be determined using data from the in-grade testing program and from other published sources. Load process models for wind and earthquakes will be constructed using statistical data. Reliability analysis methods developed at NBS that account for the effect of load duration on wood members will be used to estimated limit state failure probabilities for members subjected to wind and earthquake loads. This effort will be coordinated with the ASCE Task Committee for LRFD for wood to prepare recommendations for probability-based design for wood structures.

PULSE PROBING AND DECONVOLUTION IN THE DYNAMIC CHARACTERIZATION OF STRUCTURAL NETWORKS

Emil Simiu, Structures Division, (301) 975-6076

Sponsor: Air Force Office of Scientific Research

This project will develop computational and experimental capabilities to identify dynamic response characteristics of structures.

CBT will develop computational and experimental capabilities based on recent mathematical research resulting in development of pulses of the inverse Gaussian type which allow the systematic and accurate solution of the inverse problem. Numerical experiments will be conducted to assess the accuracy which it is possible to recover the exact Green's functions by deconvolution of responses contaminated by noise.

The research will result in application to structural engineering technology of new results of mathematics, structural dynamics, and measurement science research, contributing to improved reliability of structural systems developed for defense, communications, and industrial purposes. Potential spinoffs include development of nondestructive testing methods for such members, as the tethers of deep water compliant offshore platforms, and for active control and damping of dynamic structural vibrations induced by as docking loads on orbiting structures and seismic loads on buildings.

EARTHQUAKE ENGINEERING

TECHNICAL ASSISTANCE AND ENGINEERING EXPERTISE FOR SEISMIC CONSTRUCTION ACTIVITIES

Charles G. Culver, Structures Division, (301) 975-6048

Sponsor: Federal Emergency Management Agency

This research will provide technical assistance to FEMA in connection with the NEHRP activities related to new and existing buildings.

The Federal government serves as an example for others to emulate for using effective hazards mitigation measures in facilities. In recognition of these needs, the Congress passed the Earthquake Hazards Reduction Act of 1977 (P.L. 95-124), and the President established the National Earthquake Hazards Reduction Program (NEHRP) the following year. The NEHRP established the Interagency Committee on Seismic Safety in Construction (ICSSC). The program also assigned the National Bureau of Standards responsibilities to work in the Federal and private sector to improve seismic design.

NBS provides the Technical Secretariat to the Interagency Committee on Seismic Safety in Construction (ICSSC). The Committee assists the Federal departments and agencies involved in their ongoing programs.

NBS works with the Building Seismic Safety Council, an organization of professional organizations, trade associations, and code groups. With NBS technical assistance, the BSSC issued a set of seismic design provisions for new buildings (NEHRP Provisions). BSSC is updating these provisions to incorporate the results of recent research and is working in the area of existing buildings.

Results of this effort includes preparation of "code" provisions for seismic design. These will be available for consideration by BSSC and others. Examples of NBS work include technical assistance for developing typical costs for seismic rehabilitation, technical assistance for handbook on rapid visual screening of hazardous buildings, technical assistance for updating the NEHRP, provisions, technical assistance for handbook on seismic evaluation of hazardous buildings, and management of the ICSSC.

INELASTIC PERFORMANCE OF STEEL BRACED FRAME CONNECTIONS

John Gross, Structures Division, (301) 975-6068

Sponsor: National Bureau of Standards

This project will assess the behavior of gusset plates and the connection of braced elements with columns and beams in steel frames.

AISC has identified the design of the bracing connection in steel frames as an area of primary concern. The force distribution within the gusset plate used in the connection is not well understood. Analytical studies have been financed by AISC at the University of Arizona to study this problem, no experimental tests have been conducted to validate the results.

The NBS investigation will involve experiments on planar braced steel frames. The selection of specific variables and specimen design will be coordinated with analytical studies in progress at the University of Arizona. The experiments will provide information that is not presently available and will serve as the basis for validating new mathematical models.

LARGE-SCALE BRIDGE COLUMNS SUBJECTED TO REVERSED CYCLING LOADING

William C. Stone, Structures Division, (301) 975-6075

Sponsor: National Bureau of Standards

The project will determine the influence of size (scale factor) on the seismic performance of bridge columns and provide benchmark full-scale seismic behavior data for bridge columns detailed in accordance with current design criteria.

A national workshop on earthquake resistance of highway bridges held in January 1979, identified research needs and established priorities in the area of seismic aspects of highway bridge design. One of the highest priority research needs was to determine the effects of scale factor on bridge column design to determine whether the behavior of small sections can be extrapolated to large cross-sections and to examine the performance of selected full-scale details. Little information is available on the performance of large cross-section bridge columns.

Research involves:

- designing and constructing a Large-Scale Structural Testing Facility capable of applying the vertical and lateral loads required to achieve ultimate failure in a full-scale bridge column test specimen.

- performing full-scale bridge column tests involving one "flexural" specimen, designed to develop high moments at the base of the column with relatively low axial load and shear components, and two "shear" specimens with high lateral load/moment ratio and varying axial loads. Construction details will be those in actual use in order to obtain realistic performance data.

- conducting a parallel experimental program to obtain seismic performance data for 1/6-scale replicas of the full-scale specimens, and

- developing similitude models to predict the performance of full-scale bridge columns subjected to seismic loads from scale model specimens.

The research will provide a technical base that is currently unavailable to determine if there is scale effect for very large cross-section columns.

CYCLIC LOADING OF MASONRY BUILDING COMPONENTS

Charles F. Scribner, Structures Division, (301) 975-6069

Sponsor: National Bureau of Standards

This research will develop a rational procedure for determining the ultimate shear strength characteristics of reinforced masonry shear walls for use in structural design.

The process of developing tentative seismic design provisions for both unreinforced and reinforced masonry building components reveals a scarcity of information on ultimate strength characteristics. Since seismic resistance is presently based primarily on ultimate strength considerations, the lack of such information for masonry is detrimental to rational design in buildings subjected to seismic loadings.

The investigation will involve experimental testing of failure modes to identify their characteristics and the significant parameters affecting the different failure modes. Analytical expressions for predicting failure as a function of key parameters will be developed.

SECRETARIAT FOR U.S. SIDE UJNR PANEL ON WIND AND SEISMIC EFFECTS

Noel J. Raufaste, Structures Division, (301) 975-9505

Sponsor: National Bureau of Standards and some member agencies

This effort provides for the U.S. Secretariat of the United States - Japan Panel on Wind and Seismic Effects.

The U.S. Panel on Wind and Seismic Effects was created in 1969. Annual meetings alternate between Japan and the U.S. The Panel is composed of 15 Federal agencies participating in 10 task committees. The task committees focus on specific national issues, e.g., earthquake hazards reduction, buried pipelines, and telecommunication systems. The results of task committee workshops and conferences are shared at the annual joint meeting and published as proceedings.

The Panel's objectives are:

1) to exchange wind and seismic technology (including data, information, measurement and test facilities and equipment, and researchers) between appropriate U.S. and Japanese organizations;

2) to develop strong technical links between scientific and engineering researchers of the government, industrial and academic organizations from the two countries, and encourage exchanges of guest researchers;

3) to conduct joint research in areas of strong winds, earthquakes, storm surge and tsunamis, publish findings from joint research efforts, and distribute proceedings of annual joint meetings;

4) to conduct cooperative programs to improve engineering design and construction practices and other wind and earthquake hazards mitigation practices.

The 19th joint panel meeting will be held in Japan during May 1987, along with two workshops. Other workshops will be conducted during 1987.

HEAT TRANSFER

DEVELOPMENT OF A HIGH-TEMPERATURE STANDARD REFERENCE MATERIAL

Robert R. Zarr, Building Environment Division, (301) 975-6436

Sponsor: Department of Energy/Oak Ridge National Laboratory

The objective of this work is to establish a thermal Standard Reference Material (SRM) with low thermal conductivity applicable for use over an extended temperature range.

As better insulating materials are developed the need was identified for a new Standard Reference Material with low thermal conductivity. Materials having high thermal resistance values require special measurement considerations for accurate determination of thermal properties. A low thermal conductivity SRM is needed to calibrate instruments and as a base to compare thermal property measurements.

CBT will purchase 45 specimens, all from one lot of material manufactured by Wacker-Chemie GmbH of West Germany. The specimens are 610 x 610 x 25 mm (24 x 24 x 1 in). From the 45 specimens, a smaller sample (10 to 20 specimens, depending on the lot variability) will be selected. The thermal conductivity of each specimen will be measured at 24 °C (75 °C) using the NBS 1-m Guarded Hot Plate. Specimens will be tested as received with no high-temperature heat treatment and at atomspheric pressure. Since the thermal conductivity of fumed-silica depends on the barometric pressure, an attempt will be made to modify the guarded-hot-plate (GHP) to control the barometric pressure under test conditions to ±2 mbar (±0.06 in Hg). Instrumentation will be installed to automatically measure barometric pressure and control the new equipment.

If the pressure control modifications to the existing equipment are successful, three specimens from the sample set will be tested at controlled atmospheric pressure over the temperature range of the apparatus (approximately 0 °C to 60 °C). At each temperature point the pressure will be changed allowing thermal conductivity measurements at different pressure levels. This procedure provides accurate data to calculate the thermal conductivity as a function of mean temperature and barometric pressure for the lot of material.

Two other specimens, from the sample set, will be selected to study the effects of high humidity on the specimens. The two specimens will be heated at 100 °C until their respective weights obtain a steady value and then remeasured in the NBS GHP. One of the specimens will be placed in an environment at 20 °C, 50% relative humidity (rh); the other in an environment at 20 °C, 75% rh. The specimens will be remeasured in the NBS GHP when moisture equilibrium is achieved. Data from this study will establish the humidity levels which are acceptable for storage of the SRM specimens.

EXPERIMENTAL EVALUATION OF DYNAMIC TEST PROCEDURES

Douglas M. Burch, Building Environment Division, (301) 975-6433

Sponsor: Department of Energy/Oak Ridge National Laboratory

This work will develop an experimental procedure using a calibrated hot box to characterize the dynamic thermal performance of building walls.

For many building types, the transient heat-transfer rate through the building envelope comprises a significant portion of the total space heating and cooling loads. Computer programs are widely used to perform hourly building energy simulations which predict the building envelope heat-transfer rate. Building designers, architects, and owners use these computer programs to size HVAC equipment, to predict peak demands and to predict annual energy costs. Moreover, such programs are used to minimize annual energy costs by investigating trade offs in the envelope design, selecting HVAC systems and equipment, and analyzing various methods of building operation.

Many of these computer programs predict the transient heat-transfer rate through the components of a building using conduction transfer-function equations. Conduction transfer-function coefficients for selected building walls are summarized in Table 29 of the 1985 ASHRAE Handbook of Fundamentals. The mathematical algorithms that generate transfer-function coefficients contain simplifying approximations such as an assumption of one-dimensional heat transfer and constant heat-transfer properties. Moreover, these models do not account for the heat transfer through thermal bridges such as metal ties in masonry walls, and framing in wood walls, and other thermal anomalies. Very little research has been conducted to verify the accuracy of these mathetmatical models.

There is need to develop an experimental procedure using a calibrated hot box to provide a "general" characterization of the dynamic thermal performance of walls. The procedure permits the measured thermal response under one set of boundary conditions to be readily extended to different boundary conditions. This provides a common basis for different laboratories to compare their dynamic test results. This study permits those existing computer programs to be used with greater confidence.

CBT will use the Stephenson Ramp Test on the masonry wall having known heat-transfer properties. The National Research Council of Canada has developed a ramp test procedure with considerable promise and potential for determining empirical transfer-function coefficients (TFC's) that are unique and closely approach those predicted using an analytical model. A ramp temperature waveform will be generated in CBT's climatic chamber. The metering chamber, maintained at a typical indoor condition, will be used as calorimeter. The specimen heat-transfer rate will be determined from an energy balance of the metering chamber at hourly time intervals. From the measured transient specimen heat-transfer rate, CBT will determine the poles and residues for a Laplace transform analytical solution. These mathematical parameters subsequently will be used to determine the TFC's. The TFC's derived from the Stephenson Ramp Test will be compared with predicted TFC's determined from an analytical model. Also, CBT will conduct a different ramp test with the climatic chamber temperature ramped in an upwards direction instead of a downwards direction to verify whether the thermal storage in the metering chamber is being accounted for correctly.

A candidate masonry wall will be selected through a consensus process with industry and government representative and installed in Calibrated Hot Box. This masonry wall be exposed to excitation functions such as a ramp, a sol-air diurnal waveform, and a four-harmonic diurnal waveform TFC's for this masonry wall will be determined using both the CBT curve fitting procedure and the Stephenson Ramp Test procedure and compared to predicted TFC's using an analytical model. Each set of TFC's will be used to predict the transient specimen heat-transfer rate for the other dynamic tests. Recommendations will be made about a preferred dynamic test procedure for using a calibrated hot box to measure the dynamic thermal characteristics of walls.

THERMAL AND ENVIRONMENTAL EVALUATION OF ADVANCED TECHNOLOGY OFFICE BUILDINGS-PHASE II

Andrew Persily, Building Environment Division, (301) 975-6418

Sponsor: General Services Administration

The projects objective is a measurement program that evaluates thermal and environmental performance of advanced-technology office buildings. This program will validate diagnostic techniques for evaluating building performance.

The design and construction of modern, advanced-technology buildings places more stringent requirements on the buildings thermal and environmental performance. A better understanding of the thermal, environmental and operational characteristics of advanced-technology buildings is essential to avoid design, construction and operation errors that may result in a building unsuited to its tenants. The inability to meet thermal comfort criteria and air quality standards in buildings is due to 1) improper selection of building materials, 2) poor building design, 3) poor construction quality, and 4) improper operation of the building systems.

Previous studies have shown the value of diagnostic evaluations in assessing building performance, and have revealed the importance of building envelope air leakage in determining space conditioning loads. Many air leakage and insulation problems can be avoided by using diagnostic tests early in the construction stage and repairing the defects that are located. It is more economical to correct these defects at this stage when the building is complete and occupied.

There is an opportunity to establish and employ diagnostic centers in new buildings to monitor critical parameters that determine the performance of the building and the adequacy of its interior environment. Along with other on-site evaluations, these tests assure knowledge base relating building features to performance and enable corrective actions if necessary. Of particular concern are transient conditions associated with early occupancy.

CBT has developed design specifications for installing a diagnostic center, and developed performance criteria and programming for installing diagnostic centers. Diagnostic centers are expected to be installed in three federal buildings: Portland, OR; Overland, MO; and Long Beach, CA. The evaluations include thermographic inspection of building envelope; thermal resistance measurements; pressurization tests of envelope airtightness; tracer gas analysis of air exchange; and monitoring indoor levels of contaminants.

CBT performed a design review of the new Portland East Federal Building in Oregon and installation of its diagnostic center. CBT also inspected the building during construction to evaluate the contractor's installation of the sensors and equipment to be used in the evaluations.

In this phase, CBT will study cause and effect relationships between activities in the buildings (e.g., cleaning, initial move-in, remodelling, pesticide use, loading dock activity) and resulting indoor air quality conditions within the building. Work also will include design review for installing diagnostic centers in the Overland and Long Beach buildings. CBT will develop guidelines

for building operating procedures and servicing during building commissioning and move-in.

HEAT LOSS CALCULATION PROCEDURES FOR SHALLOW TRENCH HEAT DISTRIBUTION SYSTEMS

Jin B. Fang, Building Environment Division, (301) 975-6417

Sponsor: Tri-Services Committee of DoD

The objective of this work is to develop a calculation procedure that predicts heat losses from shallow trench heat distribution systems, and to estimate the minimum life-cycle heat losses and the corresponding economic insulation thicknesses.

CBT provided assistance in developing a standard test method for underground pipe insulation and heat loss calculation procedures for direct buried conduit systems which are included in Guide Specification for Military Construction FCGS-15705. A procedure based on life-cycle cost analysis was developed at CBT for calculating the maximum allowable heat loss for direct buried conduit type underground systems. CBT also takes part in the Interagency Committee on Underground Heat Distribution Systems to review and approve product test protocols and engineering brochures for use on federal construction projects. The military installations currently maintain approximately 6,000 miles of heat distribution systems. Some of these systems require repair or replacement due to excessive heat loss resulting from deteriorated thermal insulation and corroding pipes and conduits. An in-situ heat loss measurement technique such as the thermal probe method being developed at CBT is needed to locate the defective segments of a direct buried piping system. Field evaluation of a thermal probe method and comparison of its performance with a calorimetric measurement are underway.

During FY86, a procedure was developed to calculate the rates of heat loss from two insulated pipes installed in a shallow concrete trench using a finite element computer program to solve a two-dimensional steady-state conduction problem. Methods to determine the minimum life-cycle cost heat loss and the economic insulation thickness were developed and sample calculations were performed for a range of trench dimensions and pipe temperatures. The heat loss calculation procedures for shallow trench systems will complement the procedure already developed for direct buried conduit system. There is a lack of field data to be used for validation of the predictive methods.

CBT will modify the existing finite element computer program for calculating the rates of heat loss from two underground pipes installed in a shallow concrete trench, to account for the temperature dependency of the insulation and soil thermal conductivities. The calculated results will be compared with the available experimental data. Work will be performed to develop estimates of material and installation costs for constructing various distribution systems of different trench dimensions and insulated pipe sizes. A set of tables will be developed listing the pipe heat losses associated with the minimum life-cycle cost and the corresponding economic insulation thickness based on a range of pipe sizes, fluid temperatures, energy costs, soil thermal conductivities, and the undisturbed earth temperatures. Also, CBT will continue providing technical assistance to the Federal Agency Committee on Underground Heat Distribution Systems, in reviewing product test protocols and test reports submitted for acceptance on various heat distribution systems, and participating in specific assignments as the scope of the tasks are refined.

MATHEMATICAL MODEL FOR PREDICTING COMBINED FLOW OF HEAT AND MOISTURE

Douglas M. Burch, Building Environment Division, (301) 975-6433

Sponsor: National Bureau of Standards

This research will develop a mathematical model to predict the combined flow of heat and moisture through multi-layered retrofitted walls. This model will consider the effect of moisture accumulation on the overall thermal resistance. During FY86, CBT completed a mathematical model and computer program modeling the effect of vapor resistance offered by paint layers, capillary transport of moisture within a layer, and temperature-dependent and moisture-dependent properties.

During FY87, CBT will conduct:

1) Laboratory experiments to condition two walls specimens. Measured profiles of moisture content within the wood siding of the two wall specimens will be compared to corresponding values predicted using a mathematical model.

2) Complete the measurements of diffusion coefficients for specimen materials. Thermal conductivity measurements will be conducted to investigate the effect of moisture on the thermal conductivity of the insulation materials.

3) Analyze moisture transfer found in a typical wall exposed to several outdoor climatic conditions. A magnetic tape weather data processor will be added to the mathematical model of moisture transfer (computer program). A variation of parameters will be performed to determine the relative importance of various building construction and operating parameters on the amount of moisture that accumulates in the typical wall.

INDOOR AIR QUALITY

MEASURING AND PREDICTING INDOOR AIR QUALITY IN AN OFFICE BUILDING

Andrew Persily, Building Environment Division, (301) 975-6418

Sponsor: U.S. Geological Survey

This project will demonstrate and refine test methods to determine the relationship between the performance of the building ventilation systems, the interzonal movement of air and the effectiveness of various contaminant removal and containment methods and the ability of NBS developed models and measurement methods using the U.S. Geological Survey Complex as a test site.

CBT has developed measurement methods and analytical models to determine and predict air movement and contaminant levels in multi-zone complex buildings. To date little verification between the predictions of these models and the actual level of indoor contaminants in complex buildings has been done. This project will permit the study of a specific building complex which is well characterized to evaluate how well the NBS developed measurement methods and analytical models predict air movement and distribution. This technology when validated also will provide information to assist USGS officials to determine how ventilation systems should be designed and operated to ensure a good indoor air quality.

CBT will perform an evaluation of the indoor air quality and ventilation system of the U.S. Geological Survey complex in Reston, VA, to determine the appropriateness of the NBS measurement and modeling procedures in this building type and to assist USGS in investigating the type of ventilation problems in this particular building complex. The tasks NBS will carry out are:

1) measure the ventilation rate and air leakage rate of the complex,

2) determine the ventilation effectiveness in several offices,

3) measure the entrainment of contaminants by the outside air,

4) measure the levels of indoor air pollutants including CO, CO_2, radon, particulates, hydrocarbons, NO_x and volatile organic compounds,

5) measure the interzonal air flow between various zones in the complex and in particular from the laboratory and industry/printing areas,

6) determine operational and environmental conditions which could cause adverse indoor air quality,

7) compare the data collected above and the multi-zone indoor air contaminant model to the pollutant concentration obtained by the NBS multi-zone model.

INFILTRATION/VENTILATION IN LARGE BUILDINGS

Richard A. Grot, Building Environment Division, (301) 975-6431

Sponsor: Department of Energy

This research will develop test methods for evaluating the movement of air into and within large commercial buildings and determine the efficiency of the ventilation systems of commercial buildings by providing a mechanism to remove contaminants at minimum energy cost.

Insufficient data exist on the air leakage and air movement in large commercial structures. Previous DoE/NBS research demonstrated that large buildings experience under- and over-ventilated periods during their annual operation. The design of the air distribution system and the placement of internal partitions may result in uneven distribution of an otherwise adequate amount of ventilation air.

CBT test methods for measuring ventilation efficiency will be applied to the Columbia Plaza building and two other office buildings. Measurements of the distribution of contaminants in these office buildings will be made.

With NIOSH, CBT will analyze the relationship between the level of contaminants and the operation and design of the ventilation system in the Columbia Plaza building. NIOSH will measure the levels of micro-organisms and allergens in the building. These data will be analyzed by CBT and NIOSH to determine relationship between the performance of the ventilation system and the levels of indoor contaminants. Two other office buildings to be studied. One of the buildings selected will have no indoor air quality problems. These buildings will be instrumented and data collection started during FY87.

INDOOR AIR POLLUTION CONCENTRATION MODEL

Richard A. Grot, Building Environment Division, (301) 975-6431

Sponsors: Department of Energy and
Environmental Protection Agency

The purpose of this report is to develop a comprehensive validated computer model that simulates dynamic pollutant movement and concentration variations in buildings.

Most previous work reported for indoor air pollution modeling is based on a simplistic one-room dilution model which ignores the thermal effects and mixing dynamics. A comprehensive analysis of pollution migration in buildings requires accurate simulation of all processes affecting pollutant concentration. These processes are infiltration, generation, dilution, reaction, removal, and exfiltration. CBT has recently developed a comprehensive dynamic building simulation model called TARP. In addition to detailed thermal conduction and radiation calculations, TARP computes infiltration and interroom airflows by considering the flows through all openings (doors, cracks, etc.) and requires a mass balance in each room. The flows are a function of wind, stack effect, and forced ventilation. The TARP model automatically handles the infiltration, exfiltration, and interroom dilution aspects of the contamination equation which are the most computationally complex parts of the problem. It can also serve as a framework for adding other components of the contaminant equation.

During FY87, work will be performed to enhance TARP. Work will be concerned with local air velocities, ventilation effectiveness, and removal of contaminants which have localized sources. A more detailed model of the movement of contaminants through HVAC systems will be developed that will include situations where individual rooms are not well mixed and such concepts as ventilation efficiency. The model will be formulated so it will be compatible with development of modern computer energy simulation techniques.

MICRO-MODELING OF CONTAMINANT CONCENTRATION IN A SPACE

Richard A. Grot, Building Environment Division, (301) 975-6431

Sponsor: National Bureau of Standards

CBT is developing models to predict the distribution of contaminants within building spaces.

Many pollutants are released into a space from point sources and the distribution of such pollutants within a space is not uniform. Some pollutants may affect health when relatively high concentrations are inhaled for only a short time. Therefore, there is a need to predict areas where high concentrations will exist. Most modeling to date assumes complete mixing in a space or employs a two-compartment assumption with uniformity within each compartment. There is a need for validated models for the short-term exposures to pollutants which can result from such activities.

This research will predict the distribution of contaminants in a space. This information will be used as a basis for developing simplified micro-models.

METHODS FOR MEASURING THE EFFICIENCY OF DEVICES FOR REMOVING GASEOUS CONTAMINANTS FROM AIR STREAMS

Bal M. Mahajan, Building Environment Division, (301) 975-5857

Sponsor: National Bureau of Standards

This project is developing measurement methods for filter efficiency to remove gaseous contaminants from air stream.

Attempts were made to evaluate gaseous removal devices, however, no general procedures are available for evaluating these devices. Methods are needed to evaluate these devices so effective and economical control methods can be promoted for improved indoor air quality.

CBT's is developing methods to evaluate the effectiveness of devices to remove gaseous pollutants from air. These methods will employ a test duct system in which a sample filter/device is challenged with several gaseous pollutants introduced into the intake air. The gaseous pollutants will be selected according to their possible adverse health effects, and their possible presence in the indoor air. Methods will be developed to safely introduce metered amounts of pollutants into the intake air of the test duct system. Methods will be developed, utilizing mass spectroscopy, gas chromatography or other feasible means, to measure the concentration of the gaseous pollutants in the intake and outlet air of the test duct system. The gaseous pollutant removal efficiency of the device can then be calculated from the measured data.

Also, methods will be developed to measure the capacity of such filters. It will be possible to combine the removal efficiency of a device with its contaminant load to provide information for comparison between filters and to estimate system effectiveness and economic analysis of various alternatives.

CBT maintains close cooperation with ASHRAE technical committees on gaseous contaminants and removal equipment to assist in providing a basis for promulgating a consensus standard.

CHARACTERIZATION OF VOLATILE ORGANIC CHEMICAL EMISSIONS FROM PRODUCTS USED IN BUILDINGS

Samuel Silberstein, Building Environment Division, (301) 975-6420

Sponsor: National Bureau of Standards

CBT is developing procedures to identify and determine the amounts of volatile organic chemical (VOC) emissions from products used in buildings. Such products includes: plastics, underlayment, paneling, medium-density fiberboard, carpeting, wood, chemicals used in the treatment of these products, pesticides, cleaners, glues, and combustion products from cooking and heating. There have been increasing numbers of incidents of "sick building syndrome" resulting from off-gassing of VOC from building materials as listed above. It is often difficult to predict if building materials will emit gases and vapors under normal or abnormal operating conditions. CBT will place products in measuring chambers located in an environmental chamber where temperature and relative humidity (RH) are carefully controlled. Pressed-wood products will be tested. It will be determined whether VOC concentrations can be made high enough, by minimizing air exchange rates in the measuring chambers, to permit VOC to be analyzed directly without concentration.

Qualitative and quantitative analyses of VOC's will be made using analytical instrumentation. Test protocols will be developed from the data for use in characterizing VOC from building materials.

MECHANICAL SYSTEMS AND CONTROLS

BUILDING OPERATIONS AND CONTROLS LABORATORY AND INTEGRATED BUILDING SERVICES

George E. Kelly, Building Environment Division, (301) 975-5870

Sponsor: National Bureau of Standards

The objective of this project is to perform fundamental and applied research on building controls, building system dynamics, whole building performance, system optimization, and integrated building services for evaluating the performance of building systems and controls.

About 25% of U.S. energy consumption is expended in heating, ventilating and air conditioning residential, commercial, and institutional buildings. Annually, a considerable amount of manpower and money goes into maintaining the equipment and systems which service these buildings. Fire prevention and alarm systems are usually completely separate and rarely make use of the advanced technologies currently under development for energy control systems. Smoke control in small buildings is usually nonexistent. Limiting electrical power demand systems, transportation, and security systems are usually completely separate and independent of all other services. Computer-based energy management systems are so complex that most building designers are afraid of them. This list of problem areas indicates the desperate need of the building community for information on how to design, control, and integrate the various services provided in today's buildings. Guidelines and specifications are needed to fill these information gaps and to provide how-to-do-it manuals for building designers, owners, and operators. Such information would greatly improve the reliability of building systems and controls, reduce maintenance requirements, and provide better services at lower first costs.

FY87 research focuses on performance of whole buildings using HVACSIM^{+}, whole building simulation program, and the NBS Administration building, evaluating building control strategies that involve dynamic interactions between the building shell, the HVAC system and controls, and investigating the use of real time building system models for optimizing whole building performance. A joint research effort with the Center for Fire Research focuses on developing procedures for commissioning HVAC systems and computerized building management systems in fire control and smoke removal applications.

BUILDING/HVAC/CONTROLS DYNAMIC MODELING

George E. Kelly, Building Environment Division, (301) 975-5870

Sponsor: Department of Energy

The project's objective is to develop and verify building system models and a simulation program to evaluate the dynamic interactions among the building shell, the HVAC system and controls.

None of the currently used building simulation programs (e.g., BLAST 2, DOE 2) account for HVAC/control dynamics. As a result, there is little reliable data on the amount of energy waste in buildings due to control dynamics and no information how to design and operate building control systems to optimize dynamic performance.

CBT's recently developed building/HVAC/control system program HVACSIM$^+$ will be used to model NBS's 11-story Administration building. Data on the performance of this building will be collected using the energy management and control system (EMCS) installed in this building as a part of CBT's Building Management and Controls Laboratory project. This data will be used to verify and refine the building shell portion of HVACSIM$^+$ and the verified program employed to study the dynamic importance of whole building systems. The results of this work will be published to provide building researchers with essential information on the performance of building/HVAC/control system dynamics.

THERMAL MODELING OF BUILDINGS

George N. Walton, Building Environment Division, (301) 975-6421

Sponsor: National Bureau of Standards

This research develops modern modeling techniques for predicting the dynamic performance of whole buildings.

Large buildings have complex interactions between the building mass, the air and furnishings within zones, and the distribution/HVAC system. It is necessary to understand and to simulate these complex interactions and the heat storage and transfer mechanisms to assess their effect on thermal performance. Building energy performance models used by designers are usually single zone, one dimensional heat transfer models that neglect these interactions. Little theoretical work has been performed to identify the most desirable structure for these simulation programs that will facilitate modification and future updating.

CBT developed the Thermal Analysis Research Program (TARP) which predicts the interzone heat transfer and interzone movement of air. During FY86, CBT developed accurate and efficient models to predict radiative energy exchange around a building and inside a building and incorporated modern adaptive computer methods into building energy models. The algorithm development for radiative energy exchange included methods for calculating view factors, shadows, and solar transmission.

FY87, research focuses on developing a theoretical basis in the modular structure of thermal analysis simulation so modern computer methods as adaptive computer language can be applied to the major general elements of thermal simulation. These elements include formation of component response, description of the environmenal driving forces, assembly of the model equations, solution methods for solving the equations and evaluation of the system dependent quantities. This approach will examine the theoretical basis of the analytical approach, the characteristics of the computational algorithms, the nature of the data structures, and the necessity of developing and implementing new methods. As a first step, the computer program ESP, developed by the University of Strathclyde, will be obtained and adapted for an NBS minicomputer or an engineering work station. Component models of building zones and HVAC systems will be developed for use with the ESP program and the SPANK energy kernel system being developed by the Lawrence Berkeley Laboratory.

This investigation is the beginning of a theoretical basis to develop a new structure for building thermal simulation that can be easily modified to accomodate future needs.

INSPECTION AND TESTING PROCEDURES FOR COMMISSIONING HVAC EQUIPMENT AND SYSTEMS

James Y. Kao, Building Environment Division, (301) 975-3844

Sponsor: General Services Administration

The objective of this project is to develop comprehensive inspection and testing procedures for commissioning HVAC equipment and systems in federal buildings.

The acceptance inspections of new buildings vary. The performance of the building sub-systems and their energy consumption are contingent on the sub-systems being installed, adjusted, and operated according to the intention of the designers. Recent research has revealed the poor performance of many HVAC control systems, even when the systems were newly installed.

The testing and balancing standards existing today for HVAC systems are inadequate for the monitoring necessary to guide long-term efficient operations. The responsibility of correcting deficiencies in operating performance is not easily resolved. A considerable amount of attention has recently been focused by ASHRAE, GSA, NBS, and others on developing commissioning procedures for HVAC equipment and systems.

CBT is developing recommended inspection procedures for a variety of typical HVAC equipment, systems, and controls, including refrigeration plant equipment, heating plant equipment, air handling equipment and air handling basic systems, building automation system fire safety system, and unitary heating and cooling equipment. These comprehensive procedures will be used as the initial step in evaluation of HVAC/control system. The purpose of these procedures is to ascertain systematically that the equipment and systems are installed as specified and are meeting generally recognized good practices, so that known and potential problems may be eliminated.

CBT is also developing measurement methods and performance test procedures for the typical systems described above. The procedures will take into account the system operating mode changes and the building load and environment conditions at commissioning time.

The inspection procedures, measurement methods and test procedures will be developed concurrently and the results compiled in a Manual on HVAC/Control Commissioning Procedures having a format similar to the GSA "Quality Standards for Design and Construction." Relevant industry standards of installing and testing of these equipment will be reviewed and synopses included in the manual to provide GSA commissioning personnel with relevant background information. Fundamental measurement techniques and calculation equations will also be included. Standard forms and sample worksheets will be developed and included in the Manual to facilitate usage by commissioning personnel in the field.

THERMAL ANALYSIS FOR RADIANT PANEL SYSTEMS IN NEW/RENOVATED VA FACILITIES

George N. Walton, Building Environment Division, (301) 975-6421

Sponsor: Veterans Administration

The objective of this research is to evaluate the thermal performance of radiant panels relative to two conventional heating and cooling systems in typical VA facilities.

CBT research will modify CERL's BLAST computer program for thermal analysis of buildings and building systems to incorporate system operating parameters and control algorithms for predicting the performance and energy usage of radiant panels.

After modifying BLAST, the new program will evaluate the thermal performance and energy use of radiant panels to conventional heating and cooling systems in single building spacces as in typical VA facilities. Sensitivity analyses will be performed for climate, occupant comfort, and building operating strategies.

This research will increase VA's ability of public domain energy simulation models to include the performance of radiant heating systems.

ADVANCED BUILDING SYSTEM SIMULATION

George N. Walton, Building Environment Division, (301) 975-6421

Sponsor: Department of Energy

The objective of this research is to develop dynamic HVAC system component models as prototypes for a future Energy Kernel System (EKS) proposed by the Lawrence Berleley Laboratory (LBL).

LBL proposed an EKG based on a prototype software system called SPANK (Simulation Problem Analysis Kernel). SPANK uses concepts from network analysis and object-oriented programming to describe and solve whole building simulation problems. The capabilities of SPANK have been successfully demonstrated for solving HVAC problems involving sets of steady-state, algebraic equations. Research is required to determine if the SPANK approach can be effectively applied to real world simulation problems involving dynamic, nonlinear building systems.

CBT will develop dynamic component models for several different Variable Air Volume (VAV) system designs and control options. These models, which will include the "second-by-second" dynamic response of these systems to control actions and changes in zone load, will be developed in formats suitable for use with SPANK, HVACSIM+ (a simulation program developed at NBS), and ESP (a simulation program developed by the University of Strathclyde). Simulation studies will be performed using these three programs to evaluate the strength and weaknesses of each approach. A technical paper summarizing the results of this work and containing recommendations on how the proposed Energy Kernel System should be developed for simulating nonlinear, dynamic building systems will be published. Close communication will be maintained with LBL to facilitate the exchange of information on the Energy Kernel System.

REFRIGERANT MIXTURES

MEASUREMENTS OF MODIFIED HP CYCLES USING NONAZEOTROPIC MIXTURES

David A. Didion, Building Environment Division, (301) 975-5881

Sponsor: Department of Energy/Oak Ridge National Laboratory

The objective of this research is to experimentally evaluate the thermodynamic and operational behavior of modified heat pump cycles and systems hardware using nonazeotropic refrigerant mixtures.

Interest in using nonazeotropic binary mixtures as a working fluid for refrigeration systems has increased. It does not appear that new single component refrigerants can be developed because of the limited number of elements available for combination to produce volatile, nonflammable, non-poisonous, chemically stable compounds. Consequently, improvement in refrigerant performance is expected to result from the application of mixtures of known refrigerants.

The theoretical potential for increased energy performance has caused the initiation of studies dealing with the utilization of nonazeotropic mixtures in heat pumps and refrigerators that require a wide variety of design changes in both the refrigeration cycle as well as components. The intent of this work is to experimentally evaluate in the laboratory the thermodynamic and operational behavior of modified heat pump cycles and components using nonazeotropic refrigerant mixture working fluids. Also it is intended to consider different mixtures whose attributes may vary (e.g., increased efficiency or increased capacity) and to determine their potential for different applications.

CBT developed a heat pump model for nonazeotropic mixtures, under EPRI sponsorship, which uses a new hard-sphere equation-of-state. The new model will be verified through comparisons with data obtained from hardware tests, and also used to supplement the experimental data and help to design the test program.

A criteria has been developed which establishes a method of rating a refrigerant mixture on the basis of a constant heat flux in the heat exchangers and fixes the heat exchange fluid temperatures at the condenser and evaporator inlets and outlets. Tests will be conducted for each mixture on this same basis to consistently compare their respective merits for particular, representative applications. In addition to the empirical characterization and verification of the thermodynamic characteristics of the mixture above, CBT will determine the heat exchanger characteristics that will best exploit the mixture.

The above empirical work will be used in gathering simultaneously the capacity and efficiency of a traditional vapor compression cycle that is operating with a mixture in counterflow heat exchangers. This focus is on the possibilities of modifying the vapor compression cycle to take fuller advantage of the performance benefits available when a mixture is employed. Another effort will explore the advantages of incorporating a liquid pump to transmit refrigerant from the evaporator to the condenser (around the compressor) to obtain independent control of the gliding temperature and gliding composition profiles.

NON-AZEOTROPIC MIXTURE REFRIGERANTS FOR HEAT PUMPS

David A. Didion, Building Environment Division, (301) 975-5881

Sponsor: Electric Power Research Institute

The objectives of this study are to develop a simulation model of a vapor compression cycle operating with binary non-azeotropic refrigerant mixtures and to perform a parametric evaluation of the energy performance advantages of these mixtures for heat pumps.

Conventional vapor compression heat pumps employ single component refrigerants or azeotropic mixtures (those which have a single boiling-condensing temperature-composition phase diagram) as their working fluid. The use of non-azeotropic mixtures as the working fluid appears to offer potential energy performance advantages without major changes in the manufacturing process of existing heat pumps.

The development of the thermodynamic model (equation of state) will be done in conjunction with NBS's Thermophysics Division. Selected mixtures will be measured and a generalized equation of state will be fitted to the data, the heat transfer modelling will be applicable theories of mixtures. The model will be used to study the advantages of non-azeotropic mixtures as applied to heat pumps. CBT will corporate a simulation of the ideal vapor compression cycle with the generalized equation-of-state model and evaluating the attributes of different mixtures as they might be applied to the ideal cycle. Of particular interest is the potential for capacity at low evaporator temperatures, efficiency, compressor pressure ratio, and discharge temperature and pressure. With the University of Maryland modifications to the heat pump cycle will incorporate unique performance attributes offered by non-azeotropic mixtures. A workshop of worldwide leaders in this field will explore the best path for future research. This workshop will be held following the June 1987 ASHRAE meeting.

This study will quantify the thermodynamic performance of non-azeotropic mixtures in today's heat pumps; and some new designs. Also this work will establish the property data of selected mixtures which may be used in other machinery systems.

TWO PHASE FLOW OF REFRIGERANT MIXTURES

David A. Didion, Building Environment Division, (301) 975-5881

Sponsor: Electric Power Research Institute

The objectives of this study are to determine if the degradation of the flow boiling/evaporative heat transfer coefficient of mixture is caused by heat driven nonequilibrium effects or flow quality and 2) to determine if a heated glass tube test section can be developed to provide qualitative information as to the flow and boiling patterns.

The use of binary mixtures as a working media for power and refrigeration cycles is being researched to improve the thermodynamic performance of current systems. The nonazeotropic behavior of the two components allows for a system design that will have a significant increase in capacity or efficiency or alteration to pressure ratio. The evaporator is an essential component affecting the performance of the power and refrigeration cycles. Quantification of working fluid properties are essential for the design and operation of the evaporator. The properties can result in oversizing the evaporator at the design stage; while going too far in the other direction can result in flooded conditions which can lead to liquid impingement on the turbine or compressor during operation.

CBT will perform a series of calorimetric tests on a refrigerant mixture using a two phase flow heat transfer loop (already constructed). This series will consist of tests which are capable of determining the local boiling/evaporative heat transfer coefficient in annular two phase flow in four circumferential positions at each of eight axial stations. This work will establish the fundamental connections of mixtures.

CBT's test rig will be modified so a heated glass test section can be installed to visualize the annular flow in general and the ultrathin liquid layer in particular. This effort will contribute to the two phase flow field in the form of a new empirical technique. The refrigerants and mixtures evaluated in this rig will be selected after the series of calorimetric tests have been completed. The criteria for selection will address the nature of the fluid to have its nucleate boiling suppressed (fluids which require the least and most heat flux to establish the onset of nucleation will be of particular interest to observe).

The refrigeration industry will use these findings to quantify the advantages of binary mixtures in their future refrigeration systems design.

NONAZEOTROPIC REFRIGERANT MIXTURE PROPERTY EVALUATION

David A. Didion, Building Environment Division, (301) 975-5881

Sponsor: National Bureau of Standards

The objective of this project is to determine the values of the thermodynamic and transport properties of nonazeotropic refrigerant mixtures necessary to evaluate the impact these mixtures may have on the performance of refrigeration cycles and determine the expected cycle performance of different refrigerants and mixtures.

The future of nonazeotropic mixtures in the refrigeration industry depends on creating using new types of refrigeration cycles.

CBT is analyzing interactive coefficients already obtained from data and the molecular structure of the components to determine if a pattern can be established. A new equation-of-state, one that models the components as two separate substances, will be developed. It will be predictive in nature with no requirements for experimental data. CBT's work on refrigerant mixtures will be completed which will include recommended methods to predict mixtures. Also, CBT will continue studying the degradation of two phase boiling heat transfer coefficient for mixtures.

TEST PROCEDURES FOR MAJOR ENERGY APPLIANCES

FURNACES, BOILERS AND HOUSEHOLD HEATER TEST PROCEDURES

George E. Kelly, Building Environment Division, (301) 975-5870

Sponsor: Department of Energy

The project's objectives are to develop, testing and rating procedures for determining the seasonal energy performance of central residential furnaces, boilers, and household heating equipment; and to assist DoE by conducting laboratory studies of furnaces, boilers, and household heaters and their associated equipment.

CBT will use its HVACSIM+ program as the basis for modeling the performance of furnaces, boilers, and household heaters, new space heating and domestic hot water heating equipment on the market and new integrated appliances. This simulation program, whose name stands for HVAC SIMulation PLUS other systems, was recently developed by NBS as a research tool for whole building system studies. It consists of a main simulation program, a library of HVAC component models, a building shell model, and an interactive front end program. CBT will develop HVACSIM+ compatible component models for furnaces, boilers, and boilers equipped with tankless coils for domestic hot water heating. These models will be dynamic models to fully account for the dynamic interactions that are important to integrated appliances. Experimental studies will be conducted to verify these models and ensure the results are compatible with existing DoE appliance test procedures.

After the component models are developed and verified, the HVACSIM+ program will be used to study:

- The integration of space heating and domestic hot water heating using appliances covered under ASHRAE's SPC-124P proposed standard.
- The effect of water draw schedule on boiler water heaters using tankless coils.
- Regional heating and non-heating season fractions for determining weighted annual efficiency of combination space/water heating appliances.
- The effect of rapid duty cycling on furnace and boiler performance.

Using the HVACSIM+ program and the component models developed CBT will study the effect of furnace/boiler location treatment on system performance. If the propose law specifying minimum national efficiency standards is passed, NBS will provide DoE with the necessary technical assistance necessary to meet its obligations under this law for future modifications of the furnace/boiler test procedures.

WATER HEATER TEST PROCEDURES

A. Hunter Fanney, Building Environment Division, (301) 975-5864

Sponsor: Department of Energy

The project's objective is to update, expand, and improve test procedures applicable to conventional water heaters.

DOE must establish test procedures which allow the accurate and repeatable determination of energy efficiency for hot water heaters. CBT is providing technical support to develop, maintain, and improve test procedures applicable to water heaters. During FY 87 a state-of-the-art water heater laboratory will be constructed at the National Bureau of Standards. The facility will permit the testing of electric, gas, heat pump, oil, and instantaneous water heaters. CBT will conduct tests in accordance with the current and proposed test procedure on an oil, gas, and electric water heater to provide an opportunity for the principal investigator to become familiar with both test procedures; analyze comments received in response to articles on water heaters published in the Federal Register and provide DOE with response recommendations; provide technical support to DOE on Requests for Waivers and other matters that may require technical analysis; and participate in the ASHRAE Standards Committee 118.1 which will develop an ASHRAE Standard for water heaters.

HEAT PUMP AND AIR CONDITIONER TEST PROCEDURES

David A. Didion, Building Environment Division, (301) 975-5881

Sponsor: Department of Energy

This research will provide industry, through DoE, with an equitable testing and rating procedure for determining the seasonal energy performance of central residential air conditioners and heat pumps.

DoE has been interested in verifying NBS's draft test and rating procedures for air conditioners and heat pumps (1977 and 1978) and extending its scope to include new designs coming on the market. CBT has developed a procedure by which these mixed systems can be rated without testing complete systems. Required input to this procedure includes a DoE has directed NBS to develop simplified methodologies by which the ratio of capacities of the mixed (new) and matched (original) coil and ratio of refrigerant mass flow rate through the respective expansion devices could be evaluated.

CBT will develop simplified techniques to determine the ratio of capacities of mixed and matched coils, and the ratio of refrigerant mass flow rate through respective expansion devices.

A computer model will be developed of the evaporator coil. It will be offered to the industry to supplant or as an alternative to the catalog data. CBT will develop a simple surrogate fluid test which could replace a more difficult and expensive test with refrigerant for determining a refrigerant mass flow ratio.

The second part of this effort is to develop a rating procedure for variable speed heat pumps that considers equitable test conditions for an intermediate compressor speed test. Laboratory tests are planned to conclude in August; a draft evaluation procedure will be available in FY 88.

REFRIGERATORS, REFRIGERATOR-FREEZERS AND FREEZERS

Bal M. Mahajan, Building Environment Division, (301) 975-5856

Sponsor: Department of Energy

The project's objective is to provide DoE with technical assistance in analyzing test procedures for refrigerators, refrigerator-freezers, and freezers. CBT will:

- Participate and collaborate with the ASHRAE Technical Committee 7.1 in the "Phase II A" of the research effort.

- Analyze the DoE test procedures to determine their ability to measure the relative benefits of efficiency improvement features, particularly solid state defrost control (i.e., ADC), that are incorporated in many of the new products available in the market. Perform tests as appropriate.

- Provide DoE with the evaluation of proposed test procedure changes offered to DoE and evaluate manufacturers waiver requests to advise DoE of the technical validity and to recommend an appropriate action.

LIGHTING RESEARCH

LIGHTING/HVAC INTERACTION COMPUTER MODELING

Stephen J. Treado, Building Environment Division, (301) 975-6444

Sponsor: Electrical Power Research Institute

The purpose of the research is to develop and validate a computer model that simulates the interaction between lighting and HVAC systems.

A detailed computer model will be developed for simulating lighting and HVAC interactions. The model will be based on fundamental principles and validated empirical relationships. The initial model will be used to perform a sensitivity analysis to enable identification of the most significant parameters to be varied during the measurement portion of the research program. Once the measurement results are available, the computer model will be validated using the measurement results, and any changes or modifications in the computer model will be implemented as appropriate. Once validation has been achieved, the model will be used to develop suitable algorithms for building energy analysis programs.

The lighting/HVAC model will be used by energy researchers and building designers to evaluate lighting and HVAC design trade offs, to optimize performance through accurate analysis of lighting and HVAC performance.

LIGHTING ENVIRONMENT ASSESSMENT

Arthur I. Rubin, Building Environment Division, (301) 975-6445

Sponsor: U.S. Army Intelligence and Security Command

The objective of the research is an evaluation of environmental conditions in Army intelligence and security facilities (physical conditions in selected facilities and staff reaction to these facilities) and to develop standards and criteria for improving new and existing facilities.

Many military and civilian employees work in environments characterized by windowless spaces, highly automated equipment, and work tasks requiring concentration. These conditions may lead to lowered performance and employee health problems from lighting, air quality, thermal conditions and lack of view to the outside. Integrated research is needed to identify existing problems and to develop guidelines for environmental changes.

The project is performed in two phases. The first is a literature search, interviews with experts and planning and conducting a pilot study at some field sites. The purpose of this phase is to gain a better understanding of existing environmental conditions and problems, and to develop, test, and refine data collection methods and plan for phase 2 study.

The second phase is a comprehensive field investigation at additional sites. The field studies include physical measures of lighting e.g., luminance, illuminance, contrast, contrast rendering factor, glare. Other measures include temperature, noise levels, indoor air quality, and user reaction.

This integrated research effort will result in improved understanding of environmental conditions and will improve work place conditions in USA-INSCOM facilities.

INTERACTION BETWEEN LIGHTING AND HVAC SYSTEMS

Stephen J. Treado, Building Environment Division, (301) 975-6444

Sponsor: Department of Energy

The project's objective is to obtain the heat distribution characteristics of various lighting systems in typical room thermal environments, to develop a database for detailed lighting heat transfer calculations, to analyze the components of lighting heat transfer, and to evaluate the influence of wall and floor construction and HVAC design on lighting and cooling/heating loads.

ASHRAE studies indicate that electric energy consumption in commercial buildings constitutes as much as 50% of total building energy use. Since the early 1970's efforts have been made to reduce the lighting energy consumption without reducing its illumination performance, such as the development of high efficiency ballasts, high efficacy light tubes, and the use of daylighting.

This project is a combined, cooperative effort between the U.S. Department of Energy (DoE), the Electric Power Research Institute (EPRI), Dubin-Bloom Associates and Ross & Baruzzini, Inc. (DB-RB), and the National Bureau of Standards (NBS).

The thermal performance of lighting systems in actual room environments will be examined using a calorimetric chamber and the large NBS environmental chamber. The environmental chamber will be used to provide the "outdoor" condition for the calorimetric chamber, in which various lighting system and room configurations will be tested. The NBS environmental chamber temperature can be controlled to maintain either steady-state or dynamic outdoor temperature cycles over ranges up to -50 °F to 150 °F. A calorimetric chamber will be constructed within the large NBS environmental facility. This chamber will emulate an office space with at least one wall capable of being exposed to the equivalent of exterior conditions. The chamber will be designed by DBA and R&B.

The use of the lighting/HVAC design and analysis procedures will enable the design of energy efficient buildings, resulting in a minimization of building energy requirements.

METAMERISM AND FEATURES OF SECURE DOCUMENTS

Belinda L. Collins, Building Environment Division, (301) 975-6456

Sponsor: Bureau of Engraving and Printing, Department of the U.S. Treasury

The objective of this project is to determine features such as color, line quality, design content, security devices, and lighting conditions.

The Bureau of Engraving and Printing of the Department of the Treasury prints about 35 billion postage stamps annually. Also, several hundreds of billions of dollars in paper currency circulate each year in the U.S. With improvements in copier technology, counterfeiting is becoming more sophisticated yet easier each year.

During FY 87, further assessment will be made of those features which appear to determine accurate identification of counterfeit and genuine banknotes and documents. The first step in the research program will be to understand those features most likely to serve as effective counterfeit deterrents. A detailed review of the literature will be performed and set(s) of innovative currency designs/devices for experimental evaluation will be developed. This assessment will include measurement of spectral reflectance and luminance using a spectroradiometer, and a psychophysical determination of the visibility of the test specimens. The latter procedure will include variation in lighting conditions including luminance and SPD, and changes in currency characteristics as color, OVD's and degree of wear. In addition, discussions on the noticeability of banknote and document features will be conducted with other researchers throughout the project and at the annual Document Security Conference.

This will be followed by determining common ink-source combinations most likely to be effective metamers and which could serve as counterfeit deterrents. Next, a computer analysis will be performed using the ink/light source database to explore both common and innovative ink-source combinations toward the goal of determining and developing spectra likely to be effective metamers under defined lighting conditions.

This research is expected to result in redesign of the current system of paper currency and ultimately in similar measures for other types of secure documents. Such measures are needed to reduce the threat posed by increasingly sophisticated counterfeiting operations.

BUILDING ENVIRONMENT IMPACT ON OFFICE PRODUCTIVITY

Arthur I. Rubin, Building Environment Division, (301) 975-6445

Sponsor: General Services Administration

The project's objective is to develop design criteria for automated offices, based on understanding the relationship of lighting and other environmental conditions on productivity.

It is unclear if automation in the office environments has enhanced productivity. Advanced systems are placed in settings where lighting and other environmental conditions were designed to accommodate office tasks.

Research "tools" are not available to perform such studies under "real world" conditions. The purpose of this research will develop, test, and refine such tools for use in federal and other buildings. With this information it will be possible to make more informed decisions about the design of workplaces that best accommodate technological advances, thereby improving the productivity of office workers. To accomplish this objective, it is necessary to develop work productivity measurement procedures of managerial and professional tasks. The first phase will develop and test appropriate field measurement tools and procedures and test them in new GSA buildings such as Portland, Oregon and Long Beach, California. The measurement techniques will be refined and used in full scale field studies; e.g. sampling a larger number of buildings, activities, environmental conditions. This work will be performed in several phases, linked to the delivery of new buildings by GSA. During each phase the measurement tools and findings will be refined over the previous one, leading to the development of a predictive model relating environmental and other design issues to productivity. This model will help in making improved cost-effective design decisions.

The use of the procedures, guidelines, and criteria will provide an important tool to decision maker to enhance productivity in high technology offices.

MEASUREMENT OF LUMINOUS BACKGROUNDS

James A. Worthey, Building Environment Division, (301) 975-6446

Sponsor: U.S. Coast Guard

The objective of the project is the measurement and spatial characterization of the luminous intensity, color, and location of lights in New York City Harbor at night from specified locations.

A serious problem facing mariners attempting to negotiate waterways at night is the visual clutter created by numerous bright, colored, flashing lights. There is need to increase the conspicuity of lighted aids and signals against the background which they must be seen. The first step in increasing conspicuity is to characterize the background lighting conditions in harbors through detailed measurements and observations.

A two-part technical approach using photometric and photographic techniqes will be used. Three locations in New York City Harbor were selected to perform detailed photometric measurements of illuminance and luminance and a series of color and black and white photographs. Frequency counts of the number of lights meeting specific criteria for illuminance, flash rate, and color in selected segments will then be made. The visual scene from the observation point will be divided into segments 5° by 5° for the three sites. Information such as illuminance, average luminance, color and histograms of illuminance within these segments will aid in the characterization of the harbor.

SKY LUMINANCE DISTRIBUTION

Stephen J. Treado, Building Environment Division, (301) 975-6444

Sponsor: Naval Civil Engineering Laboratory

The project's objective is to characterize sky luminance distribution for actual skies based on detailed measurements and analysis.

The calculation of interior daylight levels requires knowledge of the light from the sky, typically the sky luminance distribution. Little information is available about the luminance distribution of many classes of real skies, including partly cloudy and hazy conditions. This uncertainty in sky luminance leads directly to uncertainty in predicting interior daylight levels, and prevents the accurate evaluation of fenestration systems with solar-optical properties that are directionally dependent.

The Naval Civil Engineering Laboratory (NCEL) will provide NBS with a sky luminance scanning system. Measurements will be made of sky luminance conditions under various sky conditions and solar positions. Contour maps of luminance levels will be generated and analyzed to explore the characterization of luminance distribution in analytical form to be used for sky luminance calculations. This work will extend the state of daylighting evaluation procedures and lead to improved envelope designs and components.

BUILDING SECURITY

GUIDELINES AND TEST METHODS FOR BUILDING MATERIALS AND EQUIPMENT USED IN CORRECTIONAL FACILITIES

Robert D. Dikkers, Building Environment Division, (301) 975-5863

Sponsor: National Institute of Corrections, Department of Justice

The project will develop guidelines, test methods, and the technical bases for standards to assist in the selection, application, and maintenance of building materials, hardware, and equipment for use in correctional facilities.

In 1983, more than $3 billion was spent on federal, state and local correctional projects. In many projects, equipment and systems have not operated properly and have required constant maintenance. In one survey, respondents reported that security perimeter systems and window construction (glazing, casing, framing) pose problems in one-half of the institutions.

During the first year of this project, CBT, in cooperation with various agencies and associations (e.g., American Correctional Association, AIA Committee on Architecture for Justice), will identify and collect technical data and information on the performance of building materials, hardware and equipment used in correctional facilities. Collected data and information will include: field successes, problems and failures; available standards and standards under development; and available test data. At the end of the first year, CBT will have compiled and assessed the data and information and prioritized a listing for recommended research and standards development activities.

COATINGS

QUANTITATIVE CHARACTERIZATION OF BUILDING MATERIALS SURFACES BY COMPUTER IMAGE PROCESSING

Jonathan Martin, Building Materials Division, (301) 975-6717

Sponsor: National Bureau of Standards

The project's objective is to advance the technology of surface characterization of building materials using computer image processing and photon emission properties of the surfaces of materials.

The service-life of building materials, like all engineered materials, is determined by the chemical and physical properties of the material's surfaces. Examples include incipient flaws in steel and concrete and the creation of flaws in roofing membranes and stone surfaces resulting from the effects of environmental factors. The surfaces of building materials must be characterized to understand the causes and mechanisms of failures.

CBT developed a new procedure for characterizing the roughness of blasted steel surfaces. With a thermal gradient imposed through the thickness of a material, the infrared emissions from the material surface are detected by a thermographic camera; it digitizes the image and mathematically transforms it into a two or three-parameter description of the surface roughness.

CBT has characterized the roughnesses of a standard series of blasted panels using fractal analysis techniques. Presently, CBT is mathematically modeling the emissions from well-characterized roughness standards to demonstrate the geometric characterization of blasted surfaces.

ORGANIC COATINGS

Mary McKnight, Building Materials Division, (301) 975-6714

Sponsor: Tri-Services Committee of Department of Defense

The objective of this research is to develop improved procedures for selecting, using, and specifying coating systems and to transfer the technology to DoD personnel responsible for maintaining coatings on structures.

The annual cost of organic coatings in the U.S. exceeds 10 billion dollars, more than half of which stems from the use of protective coatings in buildings and structures. If effective criteria for the selection, specification, and use of protective coatings were available, as much as 25 percent of these expenditures could be saved. An essential element of selection and use criteria for protective coatings is service life.

CBT staff will visit military installations and attend coatings meetings to learn about existing and potential problems; perform laboratory studies to develop improved test procedures; provide leadership in standards activities to solve these problems; and implement the results by authoring manuals, presenting talks, and publishing papers.

During FY 87, CBT will continue development of the ASTM specification for interior flat latex paint, VOC related problems will be addressed, the revision of the Tri-Service Coatings Manual will be completed, and advisory and consultative service, based upon laboratory and field tests, will be performed.

PERFORMANCE TESTS AND CRITERIA FOR COATINGS

Mary McKnight, Building Materials Division, (301) 975-6714

Sponsor: Federal Highway Administration

The program objective is to develop improved procedures to predict service-life of coatings for steel.

This project addresses two needs. The first is for improved short-term tests to aid quantitative service life prediction of coating systems for bridges. Selection of traditional coatings usually has been based on in-service data. For new coatings, there is inadequate in-service data available to make cost-effective selections. Short-term tests that predict performance are needed to select coating systems. The second need is for improved guidance for coatings engineers to select coating systems based on the best available knowledge.

To meet the first need, three coatings will be exposed in a warm seacoast environment and in controlled laboratory environments. Results from laboratory and field tests and results of previous FHWA sponsored coatings work will be used to further the understanding of the relative importance of degradation factors and to develop reliable tests methods, evaluation criteria and predictive models. To meet the second need, CBT will develop guidelines for coating engineers to select cost-effective systems.

DEGRADATION OF ORGANIC PROTECTIVE COATINGS

Tinh Nguyen, Building Materials Division, (301) 975-6718

Sponsor: National Bureau of Standards

The project objective is to develop improved methods to detect and quantify blistering and corrosion under coatings, and to develop models to aid in predicting the rates of formation and growth of blisters.

Corrosion-related problems in the United States cost more than $70 billion annually. The use of polymeric coatings is an effective, economic, and widely used means to prolong the life of corrosion-prone construction materials used in the infrastructure. However, coatings are susceptible to degradation under in-service environments.

Research will concentrate on 1) characterizing and quantifying molecular behavior at the steel/coating interface of epoxies and other high performance coatings before and after exposure, 2) proposing degradation mechanisms for those materials and 3) characterizing coating reactions and properties that control interfacial changes. The research builds on previous work by obtaining knowledge about the fundamental mechanisms of interfacial degradation between high-performance coatings and steel substrates, including identification of chemical reactions which contribute to the interfacial degradation. Methods to measure and understand the processes and factors which affect the permeation of water, oxygen, and ions through protective coatings will be assessed. The data will be used to develop and validate models that predict the service-life of protective coatings. The research relies on Fourier Transform Infrared Spectroscopy (FTIR-RA) to study the molecular behavior and changes at the steel/epoxy coating interface. The method will provide new data on chemical changes at the interfaces of high performance coatings and steel. Nondestructive methods to measure the pore size and pore size distribution of coatings will be explored. Development of a method will permit data which are essential for advancing the predictive modeling phase of the coatings research to be obtained.

BOND STRENGTH OF ORGANIC FILMS ON METALS DURING SERVICE USING REFLECTION/ABSORPTION FOURIER TRANSFORM INFRARED SPECTROSCOPY

Tinh Nguyen, Building Materials Division, (301) 975-6718

Sponsor: Office of Nondestructive Evaluation, National Bureau of Standards

This research will establish the relationship between reflection/absorption Fourier transform infrared spectroscopy (FTIR-RA) band shifts with adhesion (bonding strength) test data and using these band shifts, assess the durability of a bond between a polymer film and a metal substrate. Two types of adhesion tests, pull-off and scratch, will be performed following FTIR-RA analyses for two different metal/polymer systems before and during accelerated testing exposures.

This research will provide a nondestructive procedure for use in quality control and as a research technique to monitor the bond strength and durability of thin and thick films on metal.

VOLATILE ORGANIC CONTENT (VOC)

Mary McKnight, Building Materials Division, (301) 975-6714

Sponsor: Air Force Engineering and Services Center

The project will develop a work plan for DoD to meeting the need to purchase documents for volatile organic content (VOC) compliant coatings on military facilities.

About half of U.S. specifications currently used to purchase paints for facilities use do not meet some of the Environmental Protection Agency's VOC rules that take affect in 1987. With the possibility of even more restrictive rules will be established, purchasing criteria for new compliant materials will be needed. CBT is developing a work plan to help DoD respond to the need for purchasing documents. The work will be accomplished by 1) examining federal, state, and local rules governing VOC in paints, 2) determining VOC of government specification paints used for facility maintenance, 3) surveying commercially available low VOC products, and 4) listing needs for new specifications. Input will be obtained from industry, trade associations, users, standards-setting organizations, and the literature to formulate the plan.

TEST METHOD FOR FRIABILITY OF SPRAYED FIREPROOFING AND INSULATING MATERIALS

Walter J. Rossiter, Building Materials Division, (301) 975-6719

Sponsor: General Services Administration

The project objective is to develop a field test method to measure the friability of soft, loosely bound, sprayed-applied fireproofing and insulating materials containing asbestos fibers.

The predominant use of asbestos-containing material in buildings has been sprayed-on fireproofing and thermal and acoustical insulation on structural members and on walls and ceilings. These friable materials may be readily crumbled or pulverized which could release airborne asbestos fibers into the building environment. No quantitative field test is available.

A two-phase study will be conducted. In the first, a test method for measuring the friability of asbestos-containing materials will be established. Appropriate test methods (that have been used or have potential for use) for friability of spray-applied fibrous materials will be reviewed. Key properties that need to be measured to characterize friability will be determined. Scientific principles that serve as a basis for development of test methods that determine these properties will be identified. Test methods identified as having potential for measuring friability will be selected for evaluation. Current tests such as air erosion and resistance to tumbling will be considered. A proposed test based on the use of sound energy to determine the ease of breaking loose friable materials will be evaluated. Preliminary laboratory testing will be conducted on selected test methods to further assess their potential for measuring friability. Recommendations will be made to identify those test methods which are considered to offer the most potential for the field measurement of friability.

In Phase Two, promising field test methods, identified in Phase One, will be evaluated. In-depth laboratory and field studies will be conducted to determine the effectiveness of candidate methods to quantitatively measure friability. Work includes preparation of a set of friability evaluation samples, design and fabrication of field test equipment, and laboratory and field evaluation studies to determine the effectiveness of the developed test methods.

ROOFING SYSTEMS

QUALITY ASSURANCE OF USPS ROOFING SYSTEMS

Walter J. Rossiter, Building Materials Division, (301) 975-6719

Sponsor: U.S. Postal Service

The objective of this project is to provide technical assistance to the U.S. Postal Service (USPS) in implementing NBS recommendations that improve the quality assurance practices for USPS roofing.

Unacceptable roofing performance is a major USPS facilities problem. USPS annually spends over $30 million for roofing repair, replacement, and new construction. The work includes technical review of roofing documents prepared by USPS, or individuals under contract to USPS, and failure analysis of selected USPS roofing materials and systems.

CRITERIA FOR MODIFIED BITUMEN ROOFING MEMBRANE MATERIALS

Walter J. Rossiter, Building Materials Division, (301) 975-6719

Sponsor: Department of Defense

The objective of this research is to develop preliminary criteria for selecting and specifying polymer-modified bituminous roofing membrane materials.

Criteria have not been developed to select and specify these membranes materials. Although an ASTM task group was formed to meet the needs for standards, the ASTM standards will not be available for at least four years. Interim criteria are needed to provide the technical basis for voluntary consensus standards.

CBT will perform a two-phase study. In the first phase, existing test methods that characterize polymer-modified bitumens will be reviewed and summarized as a starting point for the development of the criteria. Recommendations for new test methods will be made. Laboratory testing will be conducted to obtain data needed in preparating the criteria. Field visits to observe selected polymer-modified bitumen membranes will be conducted to assess performance and identify failure mechanisms. Recommendations on interim criteria for modified-bitumens will be produced.

In Phase Two, laboratory and field research, based upon the needs identified in Phase One, will be continued to develop the database needed for the final criteria.

SERVICE LIFE OF SINGLE-PLY ROOFING MEMBRANES

Jonathan W. Martin, Building Materials Division, (301) 975-6717

Sponsor: National Bureau of Standards

The goal of this research is to provide the technical basis for developing an improved knowledge base for criteria and methods for predicting service-life of single-ply roofing membranes.

In the mid-1970's, single-ply membranes were only 2 percent of all low-sloped roofing membranes. By 1985, they were 25 percent, and they will be about 50 percent by 1990. The annual costs of installed single-ply membranes in 1986 were about $3 billion. The phase of this work include problem definition, pre-testing, experiment and evaluation, analysis, and interpretation of data. The service life of adhesively-bonded joints of EPDM single-ply membranes was selected as the focus for this study. Factors considered in the selection of this aspect of single-ply roofing were both economic and technical. EPDM is presently used in approximately 60 percent of all single-ply applications. Based on CBT field observations and on information from the NRCA and from industry leaders, failure of bonded joints is the most prevalent mode of failure. The key factors indentified as potential contributors to failure of bonded joints were mechanical stress, temperature, moisture and application parameters, such as surface cleanliness, application temperature, and force applied to ensure bond contact.

Research will be performed through field inspections of single-ply roofing installations (at time of installation and after installation); interactions with consultants, manufacturers, researchers, other agencies, and standards-setting organizations for better knowledge of failure mechanisms; a Round Table of industry leaders; and laboratory studies of bonded specimens with known flaws and defects in the joints. The latter task will involve the pulse-echo method to monitor flaw and defect growth.

Laboratory research will determine the effect of surface contaminants, particularly talc, on bond integrity and experimental results will be incorporated into a probabilistic model. Computer image analysis will quantify the surface contamination prior to creep-rupture experiments.

ASSESSMENT OF EXTERIOR CONDITION OF METAL BUILDINGS AND ROOFING SYSTEMS

Jonathan W. Martin, Building Materials Division, (301) 975-6717

Sponsor: Tri-Services Materials Committee of Department of Defense

This project's objective is to develop a procedure using computer image processing for the quantitative assessment of the degradation state of a building for use as the basis for maintenance decisions.

This research builds on CBT's research to quantify the degradation state of the exterior of metal buildings and roofing from visual or infrared pictures using computer image processing techniques. The research expands on the previous developed methodology for systematically assessing the condition of the exterior siding of metal buildings. The procedure was based on the use of visual standards. Products of this research include a detailed report on a semi-quantitative way of assessing the condition of a building.

FACTORS AFFECTING INITIAL BOND OF SEAMS IN SINGLE-PLY RUBBER MEMBRANES

Walter J. Rossiter, Building Materials Division, (301) 975-6719

Sponsor: Department of Defense

The objective of this project will determine the effect of application conditions on the initial bond strength of adhesive-bonded seams in single-ply rubber membranes as a function of time, application temperature, and surface cleanness.

Performance of adhesive-bonded seams in single-ply rubber membranes is dependent on application conditions. Seams may be fabricated under a variety of environmental conditions. Workmanship plays an important role for the amount of sheet surface contamination, applied pressure, and adhesive thickness and coverage. In spite of the number of parameters that may contribute to improper application, criteria are not available to judge whether seams are assembled in the field as intended.

CBT is developing a test method to evaluate the quality of seams at the time of fabrication. The test will assess the quality of newly-prepared seams; it will be sensitive to detecting variations in bond strength due to application conditions or workmanship. The combined effects of time, temperature, and surface cleanness will be investigated. Seams, prepared from properly cleaned and uncleaned (contaminated) rubber sheets, will be tested using a T-peel test within hours after bond formation. Seam formation will be performed over a range of temperatures which are encountered during field application.

QUALITY ASSURANCE OF DoD ROOFING SYSTEMS

Walter J. Rossiter, Building Materials Division, (301) 975-6719

Sponsor: Department of Defense

The objective of this project is to provide technical assistance to the Department of Defense (DoD) to improve the quality assurance of its roofing practices.

Unacceptable roofing performance is a major facilities problem. In the late 1970's, the U.S. Air Force estimated its built-up roofs were lasting, on the average, 12 years instead of the intended design life of 20 years or more.

This project will provide technical assistance to implement practices that improve roofing performance. The study will include: participating in technical meetings of DoD's Tri-Services Roofing Committee to discuss in-service performance of roofing, field problems, and research needed to solve the problems experienced, providing technical reviews of roofing documents prepared by DoD and DoD contractors, and performing failure analysis of selected DoD roofing materials and systems.

CONCRETE

POLYMER CONCRETE SET TIME

Robert G. Mathey, Building Materials Division, (301) 975-6709

Sponsor: Air Force Engineering and Services Center

The project will obtain set time data for a particular type of polymer concrete (aggregate, resin, and catalyst) for a wide range of aggregate and resin temperatures and investigate the effects of water and ice on set time.

The Air Force has been conducting studies for many years on the repair of runways. Rapid repair of damaged areas of runway pavement is essential to restore the operation of aircraft as quickly as possible. There is a need to have available established means and materials for rapidly repairing damaged areas of pavement.

This study will produce technologies that better characterize the material's performance prior to use in the field. The set time of a particular type of polymer concrete will be controlled and measured in the laboratory for a wide range of aggregate temperatures and a corresponding wide range of resin temperatures. Dry and wet aggregate and wet aggregate containing a range of ice concentrations will be included in the study. The testing will be conducted to describe the impact of various resin and aggregate temperature combinations on set time. Temperature measurements will be made during the set time tests. A set time prediction model will be developed based on a simple thermodynamic analysis. It will include materials properties, their initial temperatures, their mass, and peak exotherm temperature. A limited number of tests will be conducted to determine the impact of temperature variations on the flexural strength of the polymer concrete. The flexural beam specimens will be tested at age 30 minutes.

INFLUENCE OF INTERFACIAL MICROSTRUCTURE ON BONDING IN CONCRETE

Leslie Struble, Building Materials Division, (301) 975-6715

Sponsor: Air Force Office of Scientific Research

The objective of the research is to develop an improved understanding of the relationships between the microstructure of hydrated cement paste in the region of its interface with other concrete constituents and fracture of paste in this interfacial region.

Concrete is a composite material, comprised of hydrated portland cement, coarse and fine aggregate, and often reinforcing steel and occasionally constituents such as steel or other fibers. The bonds that form between cement paste and each of the other constituents are important to concrete strength and durability. At its interface with aggregate, and probably with other concrete constituents, the microstructure of hydrated cement paste is known to be different than in regions away from the interface. It is not understood how this interfacial microstructure affects the fracture properties of the composite, and thus the strength of concrete.

During this second year of a three year project, the microstructure of cement paste near its interface with a number of other concrete constituents will be examined, and the influence of the microstructure on fracture near the interface will be studied. The microstructural examinations will concentrate on determining the morphologies of the hydrated cement phases present, i.e., their size, shape, and interrelationships. The principal technique for microstructure examinations will be scanning electron microscopy, using a backscatter detector to examine specimens that have been impregnated with epoxy and polished. Research will explore relationships between interfacial microstructure and mechanical properties of the bond, e.g., tensile strength, shear strength and, possibly, fracture toughness.

REPRESENTATION OF CONCRETE MICROSTRUCTURE

Hamlin Jennings, Building Materials Division, (301) 975-6720

Sponsor: National Bureau of Standards

The project's objective is to develop a method for the symbolic represention of the microstructure of cement paste and concrete that produces a quantitative representation of microstructure suitable for standardization.

Microstructure is the key to connecting the physics and chemistry of the hydration of cement to bulk properties of hardened cement paste and concrete. The project has two parts: 1) developing microscopic techniques to resolve the phases of interest including pores, aggregate, hydration products and anhydrous phases and 2) developing algorithms which translate the digitized image into mathematical representations which contain information about quantity, size, shape, distribution and connectedness of the phases present. Using results from analyzing air voids as a basis, algorithms will be developed to analyze the complex fine porosity. Also, microscopic and mathematical techniques will be developed for imaging aggregate.

ULTRA-HIGH STRENGTH CONCRETE

Hamlin Jennings, Building Materials Division, (301) 975-6720

Sponsor: Air Force Engineering and Services Center

The objective of this project is to determine the effect of various cement mixtures on fracture mechanics parameters (strength, effective surface energy, and Young's modulus) and the microstructure of the hardened material.

Advances in concrete technology have made possible the development of high-strength concrete with compressive strengths far in excess of 9000 psi (60 MPa) usually considered high for conventional concrete. Concretes with compressive strengths above 20,000 psi (140 MPa) have been prepared by the use of silica fumes and high-range water-reducers in the concrete mixture. It is possible to produce ultra-high strength concretes with compressive strength greater than 30,000 psi (210 MPa).

This research will apply materials science concepts to i) study the factors which control the strength of ultra-high strength concrete, ii) form the basis for establishing the upper limit of strength, and iii) study the feasibility of developing ultra-high strength concrete (compressive strength greater than 30,000 psi (210 MPa) which can be cast under field conditions. The volume fraction of porosity will be held at two constant values using pressure compaction techniques. This will allow a series of experiments that can separate the influence of a number of different variables on fracture mechanics parameters, without having the difficulties of controlling the amount of pores. The variables of interest are curing temperature and the nature and quantity of aggregate, silica fume, and admixtures. The influence of shear mixing will be investigated and, as far as possible, the porosity will be similar to the porosity of the pressure compacted specimens. The microstructure of each type of specimen will be analyzed with special attention being given to the size and distribution of porosity. These results will be analyzed with a view towards establishing the influence of each variable on the fracture mechanics parameters and therefore determining the upper limit of strength that can be achieved for cement-based materials.

MINIMUM STRENGTH LEVELS FOR THE BOND OF REPAIR MATERIALS TO EXISTING CONCRETE PAVEMENTS

Larry Knab, Building Materials Division, (301) 975-6712

Sponsor: Tri-Services of Department of Defense

The objective of this work will establish preliminary minimum strength levels for the bond between repair materials and existing concrete pavements.

The bond strength between a repair material and its existing concrete substrate is a major factor in the repair of existing concrete pavements. The approach to establishing preliminary minimum bond strength levels will be to determine the bond strength of repair materials (e.g., new concrete or latex-modified concrete) to existing concrete using the NBS uniaxial tension and slant-shear tests concurrent with the direct shear test. Correlations between the test results for the uniaxial tension, slant-shear, and direct shear will be sought. The correlation will be used to establish preliminary minimum performance levels for the uniaxial tension and slant-shear tests corresponding to the direct shear minimum performance strength level of 200 psi.

CEMENT HYDRATION (COMPETENCE PROJECT)

Paul W. Brown, Building Materials Division, (301) 975-6708

Sponsor: National Bureau of Standards

The objective of this project is to improve: understanding of the physics and chemistry of cement hydration, development of microstructure in pastes of portland cements; effects of chemical admixtures on these processes; and development and validation of mathematical models based on physical and chemical mechanisms.

Over $4 billion each year is spent on cements used in concrete costing approximately $20 billion. Concrete could be a much more predictable material and a material capable of achieving higher levels of performance than are now achieved. Investment in cement research has the potential of producing significant benefits to the construction industry and the nation by providing the technical bases to improve the durability of concrete structures. Recognizing the increasing importance of chemical admixtures in advancing construction technology, CBT's effort emphasizes the development and testing of fundamental mathematical models based on conceptual models. Hydration and microstructural models will be developed to predict the effects of chemical admixtures. The chemistry and physics of the interactions between hydrating cement particles and surfactants will be investigated.

CBT's work on microstructural development and the effects of particle size distribution on hydration led to a model that simulates microstructural development which occurs when a single phase reacts with water. The hydration model developed for portland cements will predict, as a function of time, the degree of hydration, concentration of ions in solution, heat release, interparticle porosity, and volume changes. This approach will be extended to deal with the hydration of individual cement phases in the presence of surfactants.

Application of this knowledge will lead to improved standards for cements, greater uniformity of cements, improved cements, more effective use of material resources in concrete and other reaction-formed ceramics, greater productivity in the cement and concrete industries, and more durable concrete structures. Knowledge of the mechanisms by which chemical admixtures affect the rheology, hydration rate, and microstructure of cement pastes will permit the design of the microstructure of concrete to significantly improve its performance and durability.

QUALITY ASSURANCE OF LABORATORIES

AASHTO MATERIALS REFERENCE LABORATORY (AMRL)

James H. Pielert, Building Materials Division, (301) 975-6704

Sponsor: American Association of State Highway and Transportation Officials

The purpose of this effort is to provide on-site inspection of public and private construction materials testing laboratories and distribution of proficiency test samples.

With the support of AASHTO Research Associates working under CBT supervision, services are provided to laboratories testing soils, aggregate and bituminous materials and frictional properties of highways. Procedures used in performing conventional quality assurance tests are observed for conformance to applicable national standards. Proficiency test samples of asphalt, soils, aggregates and bituminous concrete are developed and distributed at regular intervals to obtain information on laboratory performance.

This work improves the reliability of test measurements; provides data to quantify standard measurement techniques; and provides direct communications between testing laboratories and standards-writing committees.

CEMENT AND CONCRETE REFERENCE LABORATORY (CCRL)

James H. Pielert, Building Materials Division, (301) 975-6704

Sponsors: American Society for Testing and Materials and
U.S. Army Corps of Engineers

This work provides on-site inspection of public and private cement, concrete, aggregate, pozzolan and reinforcing steel, testing laboratories and the distribution of proficiency test samples.
Roads, bridges, water supply and sewage systems, buildings, airports, railroads, waterway systems, mass transit systems and other structures represent a substantial portion of the nation's wealth. Construction of such facilities is one of the nation's largest industries usually amounting to about 10 percent of the Gross National Product. Over $4 billion of hydraulic cement is produced in the United States each year. The productivity of the cement and concrete testing laboratories can be increased by using correct procedures and apparatus that reduce testing errors and provide a sound basis for acceptance of cement on the basis of mill certificates.

With the support of ASTM Research Associates working under CBT supervision, services are provided for on-site inspection of testing laboratories and the distribution of proficiency test samples. Test apparatus is checked with inspection equipment calibrated by NBS personnel. Proficiency test samples of portland cement, concrete, blended cement, and masonry cement are distributed at regular intervals to obtain information on laboratory performance. Participation in the work of the ASTM technical committees by CCRL staff is a mechanism used to provide the standards community with information developed by the inspection and proficiency sample programs. This work leads to improved quality of testing in U.S., Canadian and Mexican cement and concrete laboratories by i) providing measures of the reliability of test measurement techniques; ii) data to quantify standard measurement techniques; and iii) direct communications between testing laboratories and standards-writing committees.

CALIBRATION OF PAVEMENT ROUGHNESS MEASURING DEVICES

James H. Pielert, Building Materials Division, (301) 975-6704

Sponsor: Federal Highway Administration

The purpose of this project will be development of guidelines and criteria for calibration of road roughness measuring devices in the field.

The NBS Center for Manufacturing Engineering has an FHWA funded project to develop and demonstrate procedures that can serve as a basis for field calibration of inertial road roughness profilometers. The study involves the development and testing of procedures for calibrating the major components of the profilometer, a determination of the overall uncertainty of the profilometer's operation, and a field verification that this uncertainty is applicable to the dynamic field operation of the system. CBT will perform field testing, interact with state DoT's, and collect and disseminate data. CBT's AMRL staff will attend training sessions to use the profilometers to obtain a familiarity with the equipment, computer software and operating principles. AMRL will provide a liaison with state DoT staff.

This program will have broad impact on the nation's transportation system by providing data on the condition of the highway system and developing criteria for the design, maintenance, and rehabilitation of highways.

NBS-114A (REV. 2-8C)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET** *(See instructions)*	1. PUBLICATION OR REPORT NO.	2. Performing Organ. Report No.	3. Publication Date
			May 1987

4. TITLE AND SUBTITLE

Building Technology Project Summaries 1987

5. AUTHOR(S)

Noel J. Raufaste

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see Instructions)*

NATIONAL BUREAU OF STANDARDS
U.S. DEPARTMENT OF COMMERCE
GAITHERSBURG, MD 20899

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

The Center for Building Technology (CBT) of the National Bureau of Standards (NBS) is the national building research laboratory. It works cooperatively with other organizations, private and public, to improve building practices. It conducts laboratory, field, and analytical research. It develops technologies to predict, measure, and test the performance of building materials, components, systems, and practices. This knowledge is required for responsible and cost-effective decisions in the building process and cannot be obtained through proprietary research and development. CBT provides technologies needed by the building community to achieve the benefits of advanced computation and automation. CBT does not promulgate building standards or regulations, but its technologies are widely used in the building industry and adopted by governmental and private organizations that have standards and codes responsibilities. This report summarizes the projects underway in the Center during 1987.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

building research; building technology; criteria; measurement and test methods; performance criteria; project summaries; standards; technical bases

13. AVAILABILITY

☒ Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

89

15. Price

$13.95

USCOMM-DC 6043-P80