NBSIR 80-2171

Selected Methods for Condition Assessment of Structural, HVAC, Plumbing and Electrical Systems in Existing Buildings

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
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U.S. DEPARTMENT OF COMMERCE
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November 1980

Sponsored by the:
Energy, Building Technology and Standards Division
Office of Policy Development and Research
Department of Housing and Urban Development
Washington, DC 20410

and

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
Washington, DC 20234

U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, *Secretary*

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

MOST COMMON SI UNITS AND THEIR EQUIVALENT VALUES IN CUSTOMARY UNITS

	INTERNATIONAL (SI) UNIT	CUSTOMARY UNIT	APPROXIMATE CONVERSION	
LENGTH	meter (m)	foot (ft)	1 m	= 3.2804 ft
	millimeter (mm)	inch (in)	1 mm	= 0.0394 in
AREA	square meter (m^2)	square yard (yd^2)	1 m^2	= 1.1960 yd^2
		square foot (ft^2)	1 m^2	= 10.764 ft^2
	square millimeter (mm^2)	square inch (in^2)	1 mm^2	= 1.55 x 10^{-3} in^2
VOLUME	cubic meter (m^3)	cubic yard (yd^3)	1 m^3	= 1.3080 yd^3
		cubic foot (ft^3)	1 m^3	= 35.315 ft^3
	cubic millimeter (mm^3)	cubic inch (in^3)	1 mm^3	= 61.024 x 10^{-6} in^3
CAPACITY	liter (L)	gallon (gal)	1 L	= 0.2642 gal
VELOCITY, SPEED	meter per second (m/s)	foot per second (ft/s)	1 m/s	= 3.2808 ft/s
	kilometer per hour (km/h)	mile per hour (mile/h or m.p.h)	1 km/h	= 0.6214 mile/h
ACCELLERATION	meter per second squared (m/s^2)	foot per second squared (ft/s^2)	1 m/s^2	= 3.2808 ft/s^2
MASS	metric ton (t)	ton (2000 lb)	1 t	= 1.1023 ton
	kilogram (kg)	pound (lb)	1 kg	= 2.2046 lb
	gram (g)	ounce (oz)	1 g	= 0.0353 oz
DENSITY	metric ton per cubic meter (t/m^3)	ton per cubic yard (ton/yd^3)	1 t/m^3	= 0.8428 ton/yd^3
	kilogram per cubic meter (kg/m^3)	pound per cubic foot (lb/ft^3)	1 kg/m^3	= 0.0624 lb/ft^3
FORCE	kilonewton (kN)	ton-force (tonf)	1 kN	= 0.1124 tonf
		kip (1000 lbf)	1 kN	= 0.2248 kip
	newton (N)	pound-force (lbf)	1 N	= 0.7376 lbf
MOMENT OF FORCE, TORQUE	kilonewton meter (kN·m)	ton-force foot (tonf·ft)	1 kN·m	= 0.3688 tonf/ft
	newton meter (N·m)	pound-force inch (lbf·in)	1 N·m	= 8.8508 lbf·in
PRESSURE, STRESS	megapascal (MPa)	ton-force per square inch ($tonf/in^2$)	1 MPa	= 0.0725 $tonf/in^2$
	kilopascal (kPa)	ton-force per square foot ($tonf/ft^2$)	1 kPa	= 10.443 $tonf/ft^2$
		pound-force per square inch(lbf/in^2)	1 kPa	= 145.04 lbf/in^2
	pascal (Pa)	pound-force per square foot(lbf/ft^2)	1 Pa	= 20.885 lbf/ft^2
WORK, ENERGY, QUANTITY OF HEAT	kilojoule (kJ)	British thermal unit (Btu)	1 kJ	= 0.9478 Btu
	joule (J)	foot pound-force (ft·lbf)	1 J	= 0.7376 ft·lbf
COEFFICIENT OF HEAT TRANSFER (U-Value)	watt per square meter kelvin (W/m^2.K)	Btu per square foot hour degree Fahrenheit (Btu/ft^2·h·°F)	1 W/(m^2·K) =	0.1761 Btu/(ft^2·h·°F)
THERMAL CONDUCTIVITY (k-Value)	watt per meter kelvin (W/m·K)	Btu per foot hour degree Fahrenheit (Btu/ft·h·°F)	1 W/(m·K) =	0.5778 Btu/(ft·h·°F)

NOTES: (1) The above conversion factors are shown to four significant digits, where appropriate.

(2) Unprefixed SI units are underlined. (The kilogram, although prefixed, is an SI base unit.)

REFERENCES: NBS Metric Guidelines, LC1056, August 1977;
NBS Special Publication 330, "The International System of Units (SI);"
NBS Technical Note 938, "Recommended Practice for the Use of Metric (SI) Units in Building Design and Construction;"
ASTM Standard E621-78, "Standard Practice for the Use of Metric (SI) Units in Building Design and Construction;"
ANSI Z210-1976, "American National Standard for Metric Practice;" ASTM E380-76, or IEEE Std. 268-1976.

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ABSTRACT

This report was developed with the intent of assisting government officials, designers, builders, code officials, and others involved with evaluating the condition of existing buildings to determine whether it is feasible to rehabilitate the building and its systems (e.g., structural, mechanical, electrical, etc.).

The report describes evaluation methods specifically for use with the structural materials of concrete, steel, masonry, and wood, as well as for use with the heating/ventilating/air conditioning, plumbing, and electrical support systems. Both commonly used field methods and other possible laboratory methods are described for the reader. Comparative tables are provided where possible to aid in making a selection of the evaluation method most appropriate for the particular parameter to be tested.

Keywords: Building rehabilitation; concrete; electrical; evaluation; HVAC; masonry; plumbing; steel; structural systems; test methods; wood.

ACKNOWLEDGEMENTS

The authors would like to extend appreciation to those individuals who generously provided information on many aspects of the assessment of existing buildings. Special appreciation is extended to Mr. James G. Gross, Chief, Building Economics and Regulatory Technology Division, CBT, NBS, for overall direction of the report; Mr. William J. Meese, General Engineer, NBS, for input in the electrical area; Dr. James R. Clifton, Research Chemist, NBS, for input on evaluation of concrete; Messrs. David P. Crist and Jeffrey F. Clark, students of engineering at Purdue University and Carnegie-Mellon University, respectively, for their overal assistance; and Mary M. Chaney, Secretary, Rehabilitation Technology Group, CBT, NBS, without whose clerical assistance the completion of the report would not have been possible.

It is with great appreciation, also, that the authors acknowledge the efforts of individuals outside the National Bureau of Standards in providing a review of the report for technical accuracy. In particular, appreciation is extended to Dr. V. M. Malhotra, P.E., Head, Construction Materials Section, Department of Energy Mines and Resources, Canada, for his review and comments on concrete evaluation; Mr. William L. Galligan, Project Leader, Engineering Properties of Wood, Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; and Mr. Alan H. Yorkdale, P.E., Director of Engineering and Research, Brick Institute of America.

PREFACE

The research to develop this report was conducted by the Rehabilitation Technology Group, Building Economics and Regulatory Technology Division, National Bureau of Standards. The report contains a general description of methods currently available for condition assessment of the following building systems: structural; heating, ventilating, and air conditioning (HVAC); electrical; and plumbing.

The intended audience for this report includes government officials, designers, builders, code officials, and others involved with making technical decisions on building rehabilitation. It is not aimed at a non-technical audience unfamilar with the performance of building materials and basic engineering principles.

The report was developed with partial funding from the Department of Housing and Urban Development (HUD) through the Division of Energy Building Technology and Standards of the Office of Policy Development and Research. Additional funding for the effort was provided by the National Bureau of Standards (NBS) Center for Building Technology (CBT) through the development of building condition assessment data in the structural area by the Building Rehabilitation Technology Group.

This report is not presented as an all-inclusive listing of building condition assessment methods. Additionally, neither NBS nor HUD endorses or claims to have evaluated all of the methods described in this report. It is anticipated that this preliminary report will be periodically updated, and the authors would appreciate comments and recommendations for revisions.

1. INTRODUCTION

The process of rehabilitating an existing building can present unique construction problems because most of the building systems within it may be affected. Thus, it becomes necessary to assess the condition of the systems in order to determine their ability to support the modifications.

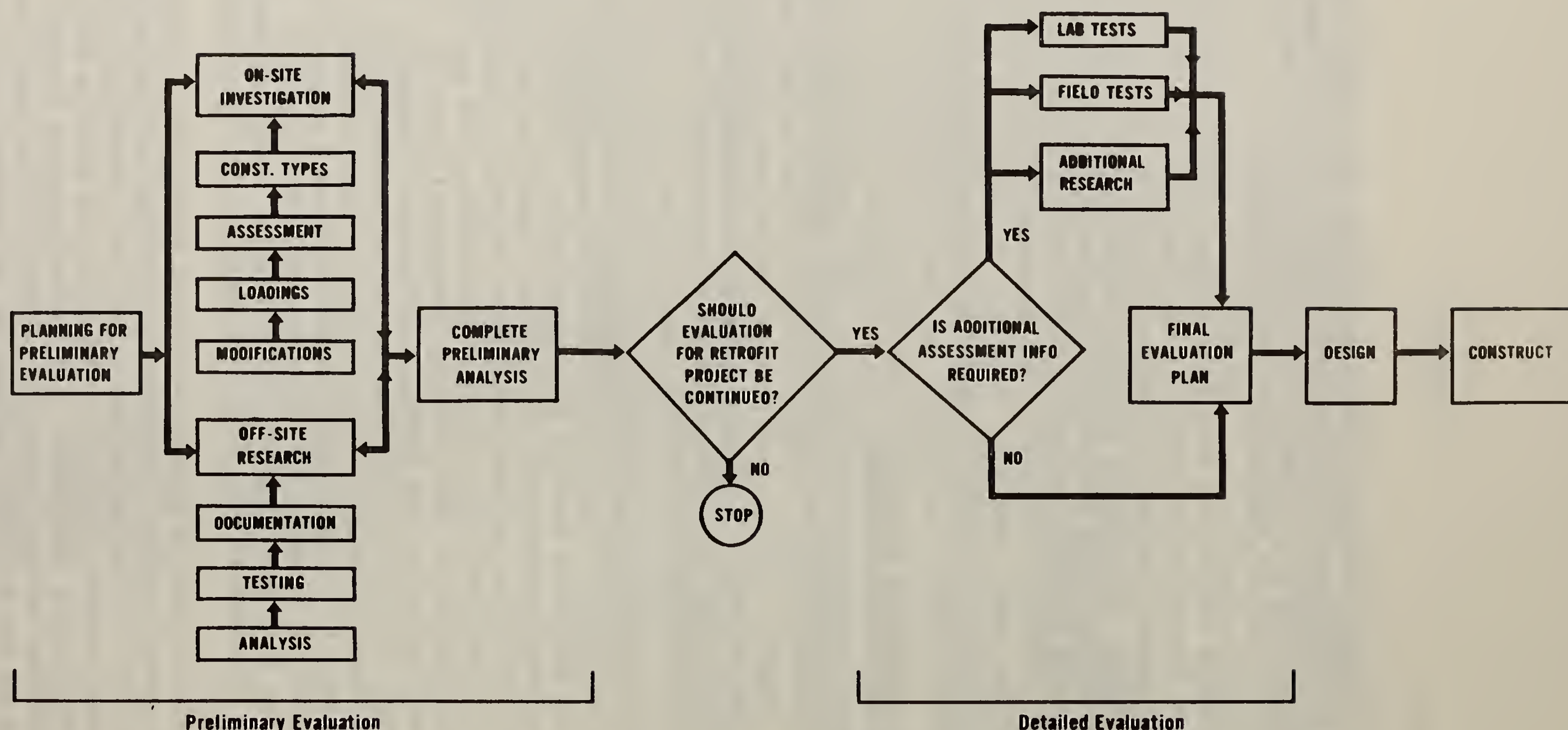
Condition assessment techniques vary from rather simple visual inspection to more complicated laboratory, or in-situ, testing which may require sophisticated equipment and operating personnel. While this report presents some information on visual techniques, its primary thrust is toward the more technically complex evaluation techniques. This report lists such methods currently available to assess the following building systems: structural; heating, ventilating, and air conditioning, (HVAC); electrical; and plumbing. Such information can assist the building owner, designer, builder, or regulatory official in making decisions on the type and magnitude of modifications required in a building undergoing rehabilitation.

1.1 CONDITION ASSESSMENT PROCESS

Building condition assessment is just one phase of the overall rehabilitation process which includes social, economic, and political as well as other technical facets. Figure 1 shows an outline of the various aspects of condition assessment as they relate to different stages of a rehabilitation project. Section 1.2 suggests how the information in this report can be useful in the building condition assessment process.

The preliminary evaluation phase of a rehabilitation project usually is based on information collected in both on and off-site investigations. The on-site investigation can include a general site examination, a building condition survey which includes sketches and photographs, selection and collection of specimens for analysis, document collection related to the configuration and performance of the building, simple field testing, and owner/occupant interviews. The purposes of this on-site investigation are to: (1) identify the types of construction in the building (structural, plumbing, electrical and HVAC systems); (2) provide data for an initial assessment of the condition and capacity of these components (e.g., extent of deterioration of concrete structural members); (3) determine the actual occupancy related loads (structural, plumbing, etc.) to which the structure will be subjected; (4) obtain indications of the past performance of the building (e.g., maintenance records); and (5) identify areas where more detailed analysis may be required.

Additional information may be obtained off-site during the preliminary evaluation to provide a more complete picture of a building and its potential for rehabilitation. Such investigation may consist of theoretical analysis of system performance, testing specimens removed during on-site investigations, and gathering and reading documents. The latter includes drawings, specifications, construction records, operation and maintenance data, records of alterations made to the building, information on original materials in the building, and site records. Documentation of this type may be available from the builder, facility engineer, building contractor, surveyor, building official, or the builder designer.



EVALUATION PLAN

Figure 1

The results of on and off-site investigations should be used together to assess the feasibility of rehabilitating a building. It should not be assumed that the actual construction of a building is as shown on drawings and specifications. If a decision is made to proceed with the rehabilitation and it is felt more information is needed, a detailed evaluation phase should be carried out. This could include in-situ or laboratory testing of specimens removed from the building, and more detailed analysis of the building based on better definitions of materials' properties and component performance. Building information collected in this systematic process provides the basis for the analysis and redesign of the building to be rehabilitated.

1.2 FORMAT AND LIMITATIONS OF REPORT

The building condition assessment methods in this report are organized as follows:

Chapter 2 - Structural Materials

Chapter 3 - HVAC Systems

Chapter 4 - Plumbing Systems

Chapter 5 - Electrical Systems

Since many assessment techniques are available, it is not possible to provide the level of detail which allows the user to apply each technique directly. Instead, a presentation format is used which includes either a summary table or a short discussion of the principles involved in using the technique, a listing of advantages and limitations of the technique, and references to additional information.

The intended audience for this report includes designers, consultants, builders, code officials, government officials, and others involved with making technical decisions on building rehabilitation. While the report is directed toward the technical audience, it also provides policy makers with an awareness of some of the economic and technical issues that affect rehabilitation decisions. For example, economic and technical data on the condition of a building must be made available to those making financial arrangements for rehabilitation programs.

Reference numbers at the end of each section are to indicate the general sources of information contained within that section.

1.3 EVALUATION METHODS

1.3.1 General

Finding and studying good documentary evidence of the design and/or construction phase of a building is the most satisfactory method to evaluate its behavior. If documents are not available, more costly and time consuming methods or performing field and/or laboratory tests may be the only way to obtain sufficient data on which to base an evaluation. The best solution, of course, is to obtain original design and construction contracts and to have the option of using field and laboratory tests to confirm the contract documents.

For the structural system, one of the most useful, but most expensive, methods to determine structural behavior is the full-scale load test of a building. The main drawback to this method is the possibility of causing permanent structural deflections or even structural failure. Many alternatives, such as the following, are available and should be considered:

1) Review any test previously conducted and interpolate the effect elapsed time may have on estimates of strength properties.

2) Field test certain structural components (using laboratory tests where needed) and analytically apply the test results to evaluate the entire structure.

3) Test scaled-down models (with either the same or analogous materials).

4) Analyze the performance of similar structures and apply the results of the analysis to the structure in question.

Evaluating existing HVAC, plumbing, or electrical systems presents a special problem since they usually are concealed. Often, inspection and testing of critical elements of these systems may not seem to be feasible after the initial construction of the building. Frequently, this difficulty results in a preference for new construction or total replacement rather than selective rehabilitation. However, techniques such as those mentioned in this report for evaluating these systems may provide a key to determining the performance of the system adequately enough to make a sound decision in favor of selective rehabilitation (even though complete inspection may not be possible).

Current methods of analyzing the properties of materials and systems can be very helpful in determining safe load capacities and performance levels as well as limit states (deflection, stability, etc.). But, the soundness of any evaluation still rests ultimately on experience and sound judgment on the part of the investigator. It should be remembered that, while the evaluation methods mentioned in this report generally are recognized as being good practice, it is advisable to consult local codes and building officials on any specific local performance requirements for the building and its systems.

1.3.2 Age of a Structure

Often it is helpful to know the date of construction of a structure so that the investigator can use the then-current codes and journals as a fairly reliable source of design practices and strengths of materials. In cases where conclusive documentation is not available, dates can be estimated by architectural style.

1.3.3 General Considerations in Selection of Test Methods

One of the keys to success in the evaluation of materials and/or systems of a building is to recognize the existing conditions which require evaluation and then to use testing techniques which are best suited to evaluating those conditions. Summary charts and brief descriptions of some appropriate test methods to use for given test conditions and for the specific parameters to be evaluated are provided.

While equipment operating costs and material costs are important factors to consider in selecting the appropriate test method to use, this report does not cover this cost aspect.

1.3.4 Definitions

A. Nondestructive Evaluation - The process of inspecting, evaluating, and/or measuring the properties of materials or systems without changing, damaging, or destroying the properties or affecting the service life of the test specimen.

B. Destructive Evaluation - The process of inspecting, evaluating, and/or measuring the properties of materials or systems in a manner which can change, damage, or destroy the properties or affect the service life of the test specimen.

1.3.5 References:

Kemp, E., "An Introduction to the Structural Evaluation of Historic Reinforced Concrete Structures," CONCRETE INTERNATIONAL, (October, 1979).

"Standard Method for Load Tests of Floors and Flat Roofs," E 196, American Society for Testing and Materials, (1974).

2. STRUCTURAL MATERIALS

2.1 CONCRETE

With the techniques available for evaluating concrete properties, the building official, contractor, designer, or owner can be selective in determining which, if any, of the components of a concrete structure need repair or replacement. This ability to evaluate and selectively rehabilitate has been a significant factor in encouraging rehabilitation of concrete buildings (as opposed to complete replacement).

The following discussion provides an overview of methods available to evaluate the concrete components of a building. Some of the techniques described can be accomplished easily with little or no special training, while others are complex in nature and will require a specialist to conduct the test and interpret the results. Tables 1 and 2 provide a guide for selection of the test methods available to determine various parameters of concrete which are discussed in more detail later.

2.1.1 Nondestructive Tests

The objective of this section is to present currently available methods for nondestructive evaluation (NDE) of concrete properties which assist the examiner to evaluate physical properties and performance.

NDE includes a system of test methods to: (1) estimate the properties of concrete material (such as compositional variations, hardness, strength, modulus of elasticity, and integrity), (2) detect harmful defects in the concrete (such as cracks, seams, voids, porosity, non-bonds, and inhomogeneities), and (3) determine physical dimensions of the concrete as well as location and size of reinforcement. NDE also can be used to determine conditions of internal stress without damage to the specimen.

This information is useful in: (1) determining the condition of concrete members (after they have been used for a long period of time), and (2) monitoring concrete to detect signs of failure. In many cases (such as the investigation of cracks in concrete) nondestructive tests may be the only reasonable means of determining the extensiveness of the damage.

Selection of the most appropriate and effective method for nondestructive evaluation of the concrete requires sound judgment based on the needed information and the cost of the evaluation. Generally, on-site nondestructive or destructive testing should be preceded by a visual inspection of the concrete in all accessible parts of the structure and is used to evaluate further the effects of already observed distress on the concrete members. A good general procedure to follow (in order of priority) is to use: 1) visual evaluation, 2) NDE, 3) destructive evaluation, and lastly 4) load tests. Past photos and written records which could reveal changes in the condition of the concrete should be reviewed when available. In other words, in-situ testing can be used to correlate strength and condition estimates already derived from the visual inspection.

CONCRETE TEST METHODS AND PARAMETERS

	NONDESTRUCTIVE TESTS																	DESTRUCTIVE TESTS	
PARAMETERS	Visual-Optical	Rebound	Pullout	Penetration	Dynamic	Electrical	Magnetic	Load	Acoustic Emission	Acoustic Impact	Ultrasonics	Radiographic	Microwave Absorption	Neutron Moisture Gage	Neutron Activation	Radar	Infrared	Core Drilling	Petrography
Dimensional Characteristics																			
Thickness of Slabs	●					●					●	●				●		●	
Size and location of reinforcing and other electrically conductive components						●	●					●	●			●		●	
Quality and Strength Characteristics																			
Quality of Concrete	●	●		●	●						●	●	●					●	●
Quality of Aggregate	●																	●	●
Uniformity	●	●		●	●						●	●						●	●
Variable Compaction											●	●						●	●
Compressive Strength		●	●	●	●						●							●	
Moisture Content						●							●	●					
Cement Content															●			●	●
Density and Internal Structure of Concrete											●	●		●				●	●
Modulus of Elasticity					●			●		●	●								
Condition of Reinforcing	●					●												●	●
Flaws																			
Surface Flaws	●	●							●		●							●	●
Internal Flaws (Voids, cracks, etc.)	●								●	●	●	●					●	●	●
Voids in grouting of post-tensioned prestressed concrete												●							
Deficiencies in joints	●																		
Substratum Voids																●			
Load Distribution and Stress/Strain																			
Load distribution and strain as detected by surface distortion patterns	●																		
Bonding Stress												●							
Failures Under Stress								●											
Differential Structural Movements	●																		

Table No. 1

TABLE 2 TEST METHODS FOR CONCRETE

METHODS	CAPABILITIES	DEGREE OF SENSITIVITY	APPLICATIONS	ADVANTAGES	LIMITATIONS	REFERENCE[1] PAGE NO.
VISUAL/OPTICAL Visual Inspection	Detection of surface flaws	Detection of cracks 2-3 microns wide on a smooth surface (smaller with a handheld magnifier).	Concrete samples or in-situ concrete structural components.	Inexpensive because no special or power equipment is needed. Can yield defects not detectable by other methods.	Only surface information is given. Relationship between surface appearance and condition of total sample must be determined.	13
Surveying, Vertical and Horizontal Movement	Measures differential movements with time.	Structural movement may be detected within the precision of the surveying equipment.	Long-term observations to determine critical movements of concrete structures.	Cyclical relationships between deformation and temperature or load can be derived.	Immediate data interpretations cannot be made because of the long-term, cyclical observation periods. A trained surveyor is necessary for data collection and evaluation.	14
Joint Survey	Checks for a variety of joint conditions which may indicate problems with concrete, such as spalling; D-cracks; absence, excesses and condition of joint fillers; seepage; and chemical attack.	Depends upon the manual measuring device used (calipers, etc.).	Expansion, contraction or construction joints in concrete.	An initial step of a more indepth investigation of concrete problems. Inexpensive because survey is limited to visual inspection and manual measurements.	This method is most applicable to foundation walls and slabs. A trained evaluator is necessary for data collection and evaluation.	14
Fiber Optics	Detects internal cracks, voids, or flaws if path to surface is available.	Working length of 30 to 1330 mm, depending on equipment used.	Can be used to look into cracks or areas where cores have been removed.	Clear, high-resolution image of remote inspection subjects.	Many boreholes are required to give adequate success. Expensive.	15
REBOUND Schmidt Rebound Hammer	Measures surface hardness. Useful for determining relative quality of concrete. Strength properties of concrete with rebound distance.	Calculation of strength from calibration curve. Sensitivity of calculation depends upon accuracy of curves.	Concrete samples or in-situ concrete structural members.	Inexpensive, fast, and can be operated by laymen.	The indication of concrete strength is not accurate, results are affected by condition of concrete surface. Requires a correlation curve between rebound value and concrete strength.	16

[1] See more detailed description on page indicated.

TABLE 2 (CONTINUED)

METHODS	CAPABILITIES	DEGREE OF SENSITIVITY	APPLICATIONS	ADVANTAGES	LIMITATIONS	REFERENCE[1] PAGE NO
PENETRATION Windsor Probe	Measures depth of penetration. Compressive strength is correlated with penetration.	Depends upon the location of the test and the precision of the calibrated depth gauge.	Concrete samples or in-situ concrete structural components.	Equipment is simple, durable and can be used by field personnel with little training.	Slightly damages a small area of concrete that is 25 to 50 mm in diameter. Does not provide accurate determination of strength without a correlation curve showing correlation between depth of penetration and concrete strength.	17
ELECTRICAL Dielectric	Can determine the varying degrees of moisture content of concrete by its insulating capabilities.	Has an accuracy of ± .25% moisture content.	Has been used in the past only on laboratory samples.	The equipment is readily automated.	Equipment is very expensive and is capable of testing only for moisture content.	18
Electrical Resistivity	Can determine slab thickness and rebar location by measuring electrical resistance through the concrete.		Applied to in-situ pavements and slabs.	Equipment is simple and easy to use.	Method is limited to testing of pavements and on-grade slabs and has only specialized applications. Results are inaccurate and are affected by air entrainment, concrete density, moisture and salt content, and temperature gradients.	19
MAGNETIC Cover meters and Pachometers	Used to locate ferromagnetic and electronically conductive components in concrete (both location and depth below surface).	Can detect ferromagnetic components only within 180 mm of concrete surface.	Concrete samples or in-situ concrete structural components.	Light, portable equipment. Easy to operate and relatively inexpensive.	Portable battery equipment will not operate satisfactorily in freezing temperatures. Good results are obtained only if one layer of rebars is present. Will not work well with mesh reinforcement.	20

[1] See more detailed description on page indicated.

TABLE 2 (CONTINUED)

METHODS	CAPABILITIES	DEGREE OF SENSITIVITY	APPLICATIONS	ADVANTAGES	LIMITATIONS	REFERENCE[1] PAGE NO.
ACOUSTIC Acoustic Emission	Monitoring of high frequency acoustic signals (stress waves) leads to detection of growing internal flaws, usually cracking.		Concrete samples or in-situ concrete structural components.	Equipment is simple and easy to operate. Data gathering requires minimal training.	Interpretation of results requires an expert. Background noise distorts results. A computer is recommended for triangulation of flaw location. Very expensive. Can be used only when the structure is loaded and when flaws are growing.	21
Acoustic Impact	Measuring of impact energy to detect and evaluate debonds, hairline cracks, and voids.		Concrete samples or in-situ concrete structural components.	Equipment used is portable, easy to operate, and can be automated.	Used mainly for pavements or slabs-on-grade. Most of the equipment is expensive, is in the developmental stage, and is not commonly used.	22
HIGH ENERGY ULTRA-SONICS	Evaluating the thickness, quality, and uniformity of a concrete by measuring the velocity of a high energy ultrasonic pulse.	Thickness measurements of concrete accurate to $\pm$ 5.0%.	Concrete samples or in-situ concrete structural components.	Measurements are very accurate. Currently, it is the only method to measure slab thickness accurately and nondestructively.	Large and heavy power supply equipment is required, data interpretations are limited to thickness measurements. Both surfaces of the concrete must be accessible.	23
RADIO-GRAPHICS X-ray and Gamma ray	X-rays: Density and internal structure of concrete, location of rebars and bonding stress points. Gamma rays: Location and condition of rebars, voids in concrete and grouting, determination of density and thickness of concrete.		X-ray equipment: can use only on concrete lab samples. Gamma ray equipment: can only be applied to concrete samples samples or in-situ concrete structural components.	Provides a permanent record of problems on film.	Very heavy and expensive for field use with concrete. Both radiation sources are injurious to organic tissue and the operators must be adequately shielded. Both surfaces of the concrete must be accessible.	23
MICROWAVE ABSORP-TION	Application of the principle of microwave absorption to determine moisture content.	Yields values of moisture content within 30% of the mean value.	Concrete samples or in-situ concrete structural components.	Easy to use, and is moderately priced.	Low degree of accuracy, and two opposite faces of specimen must be accessible.	25

[1] See more detailed description on page indicated.

TABLE 2 (CONTINUED)

METHODS	CAPABILITIES	DEGREE OF SENSITIVITY	APPLICATIONS	ADVANTAGES	LIMITATIONS	REFERENCE[1] PAGE NO.
DYNAMIC OR VIBRATION Ultrasonic pulse velocity, and resonant frequency.	Measures travel time of ultrasonic pulses through concrete to determine quality and strength (modulus of elasticity, rigidity, and durability) of concrete.	The estimations of uniformity and continuity are very qualitative in nature and cannot be discussed in terms of degree of sensitivity.	Concrete samples or in-situ concrete structural components.	Excellent for determining concrete uniformity.	Skill is required to analyze results. Does not provide an estimate of strength. Equipment is expensive and requires field calibration. Background vibrations can affect results.	26
NUCLEAR Neutron Scattering	Measurements of decreased neutron energy results in an evaluation of moisture content.	Adequacy of this method for field application on buildings has yet been proven.	Concrete samples or in-situ concrete structural components.	An approximate method for measuring moisture content.	Equipment is very sophisticated and expensive and is not widely used. Calibration procedures have not been standardized as yet.	27
Neutron Activation Analysis	The cement content in concrete can be estimated by comparing the neutron activity of the test sample with a reference standard.	Accuracy is questionable. Performance of this test method in the field has yet to be proven.	Concrete samples or in-situ concrete structural components.		Equipment is expensive and complex. Calibration procedures have not been standardized as yet.	27
INFRARED Infrared Test	Various passive heat patterns are identified with defects such as internal flaws, voids, and growing cracks.	At this stage of development, results are relatively unreliable.	Concrete samples or in-situ concrete structural components.	Has the potential to become a relatively inexpensive and accurate method of detecting concrete defects.	Not very reliable, subject is being researched.	28
LOAD Load Testing	Application of a design load (lead, concrete, or water) to a concrete structural system to verify load carrying ability.		Applied to in-situ concrete structural systems.	Provides a high degree of reliability on a structure's ability to perform under normal loading.	Validity for long range performance is questionable. May cause cracks, distortion or even premature failure. Also requires large amounts of preparation and clean up time.	29

1 See more detailed description on page indicated.

TABLE 2 (CONTINUED)

METHODS	CAPABILITIES	DEGREE OF SENSITIVITY	APPLICATIONS	ADVANTAGES	LIMITATIONS	REFERENCE[1] PAGE NO.
RADAR	Detection of substratum voids.	80% reliability of void detection.	Concrete samples or in-situ concrete structural components.	Far less destructive than "guess and drill" methods; and scanning of large surface areas can be done quickly.	Not reliable with slabs containing reinforcing mesh; very expensive; operator needs technical training.	30
PULLOUT TEST	Measures in-situ strength of hardened concrete.	Comparable to pull-out of cast-in-place anchors (ASTM C 900).	In-situ concrete structural components.	Fast, simple, inexpensive. Easy to apply in the field. Offers direct determination of strength parameters.	Within-test variations can be expected to occur because of lack of standardization of test procedures and equipment. Design of split-sleeve assembly is critical. Epoxy grout must cure at least 24 hours before commencing test.	31

1 See more detailed description on page indicated.

NDE methods cannot now be expected to yield a value for strength (although developments in metals are beginning to show promise in this respect). These methods attempt to measure other properties from which the evaluator can estimate the strength and related parameters of the concrete. Examples of these properties are listed in Table 2 which shows the relationship between test method, the parameters checked by the test, and advantages and limitations of the test.

REFERENCES - 2, 4, 7, 8, 14, 37, 38

2.1.1.1 Visual/Optical Inspection

A. Test Method - *Visual - Optical Inspection*

Material - Concrete

Parameter - Surface Flaws (Finish, Roughness, Scratches, Cracks, Color).

Discussion

Visual inspection is one of the most widely used methods for evaluating surface condition of concrete. It can be performed with or without the use of optical aids such as low-power magnifiers. Defects such as missing components, cracks, erosion, corrosion, and misaligned joints, etc., can often be detected with the naked eye. And, with the use of five to 10 power magnifiers, even surface flaws as small as a few microns wide can be detected.

Advantages and Limitations

The most obvious advantage of using the visual method to evaluate surface flaws in concrete is that it is inexpensive and requires little or no special equipment. It sometimes can be used to find defects which otherwise cannot be found. However, the visual inspection method can be time consuming and is completely dependent upon the visual acuity and the experience and training of the inspector. It should be understood that no subsurface information can be obtained using this technique and that, even for surface conditions, a correlation already must have been established between surface conditions and serviceability of the concrete.

REFERENCES - 1, 2, 3, 4

B. Test Method - *Surveying-Horizontal and Vertical Movement*

Material - Concrete

Parameter - Differential Structural Movements

Discussion

Differential measurements of structural movement can be made by making use of horizontal and vertical control standards. Survey points are established at various key areas on a structure, and their movement in both horizontal and vertical directions is measured over extended time intervals. These movement measurements can be compiled into history plots that may cover months or even years. The history plots may reveal normal cyclical movements associated with temperature moisture condition, or applied load, and may also reveal some type of structural deficiency. The observed movements must be interpreted relative only to the structure under observation, and only those movements that exceed the expected values should be considered as a source of deficiency.

Advantages and Limitations

This method requires a long period of time to compile enough data to make accurate judgments of the structure's stability. Many times an evaluation of the structure is needed quickly which makes the surveying method impractical. This method requires trained personnel to operate the surveying equipment and to gather data. Surveying is very useful only when some form of structural distress is suspected and structural movement is believed to be the cause.

C. Test Method - *Joint Survey*

Material - Concrete

Parameter - Deficiencies in Joints

Discussion

A periodic inspection of all expansion, contraction and construction joints should be made when considering the condition of concrete structural members. It must be determined whether or not each joint is in good condition and functioning as designed. Consultation of construction drawings may be necessary for a complete listing of the joints and their designated function. The inspection of each joint should include an examination for spalling or D-cracking (cracking along a joint in a "D" shape), evidence of seepage, chemical attack, or erosion. Openings in each joint should be measured. A measurement of surface offsets on either side of the joint should be included in the inspection procedure.

Advantages and Limitations

The joint survey is an inexpensive and fast method of assessing the quality of the various types of joints. Since joints are essential in the construction of all concrete structures, there exists a probability that at least some of these joints are not functioning as designed and may be a source of some type of concrete deficiency. A trained inspector is necessary to complete a thorough inspection. Caution should be taken to evaluate the entire joint when making the final decision as to its overall condition.

REFERENCE - 3

D. Test Method - *Fiber Optics*

Material - Concrete

Parameter - Detection of Internal Cracks, Voids, or Flaws

Discussion

The innovation of fiber optic inspection techniques came from the need for remote visual inspection of areas accessible only through small diameter openings. The principle of fiber optics makes use of a 1.0 - 2.7 mm (.04 - .11 in) diameter single glass fiber with a graded index of refraction surrounded by flexible light-conducting fiber bundles that are approximately 20 microns in diameter. The larger glass fiber acts as the lens that transmits the remote image that is illuminated by the light-conducting fiber bundles. The entire fiber assembly is covered by a stainless steel sheath to protect it from damage while inspecting. The probes range in working length from 30 to 1330 mm (1.2 to 52 in). The probe is attached to a portable halide or cold light source that is adjustable and provides 150 watts of concentrated white light to the fiber bundles. The application of this method to a concrete structural member involves inserting the probe into a crack or drilled hole and looking through the eyepiece for various flaws such as cracks, voids, or aggregate de-bonds. The fiber optic apparatus is adaptable to photographic and television equipment for permanent records of inspection. It is most commonly used to look into cracks or areas where cores have been removed.

Advantages and Limitations

Fiber optical equipment can provide clear high-resolution images of remote inspection subjects. This equipment is also easy to handle and operate. However, its applications to a material such as concrete are limited. A complete visual inspection of a concrete member using fiber optics requires a large number of boreholes which might weaken the member. The equipment is also quite expensive; and many times, more than one size of probe (costing about $150 each) is necessary to complete a detailed inspection. Fiber optic equipment is best applied to inspections of machined parts or other mechanical assemblies, but can also be used, when necesary, for inspection of small areas of a noticeably deficient structural member.

REFERENCES - 5, 6

2.1.1.2 Rebound Test

Test Method - *Schmidt Hammer*

Material - Concrete

Parameter - Quality and Uniformity, and Compressive Strength Estimates

Discussion

An instrument which can be used to estimate the compressive stength of concrete by measuring the height of rebound of a hardened steel hammer dropped on concrete is the test hammer developed in 1948 by Ernst Schmidt, a Swiss engineer. The Schmidt Rebound Hammer consists of a spring-actuated hammer and plunger mounted within a tubular housing. To operate the hammer, the impact plunger is placed against the surface of the concrete specimen and the hammer housing is pressed down until the plunger almost disappears into the housing. The hammer then will release itself. A built-in scale measures the rebound value in percent of the forward movement of the hammer mass after it strikes the concrete surface. The amount of rebound is affected by many factors such as the composition of the concrete, aggregate properties, surface texture and hardness, moisture content, and mass of the concrete specimen. User's charts (provided with the equipment) are based on empirical correlations which have been established between strength properties, hardness, and the rebound number. ASTM Standard C805 "Test for Rebound Number of Hardened Concrete" describes this test method.

Advantages and Limitations

The Schmidt Hammer provides the advantages of being able to compare quality of concrete from different areas of the specimen, thereby detecting areas of potentially low strength. Since the equipment is so lightweight, simple to operate, and inexpensive, it is suitable for both laboratory and field use.

Use of published calibration data to estimate strength of concrete from rebound readings is of only limited value and is not recommended because of the number and nature of the factors affecting the rebound. Therefore, the user should use strength estimates derived from this test method with extreme care. It is advisable to calibrate the test equipment frequently with the strength of cores drilled from the structure. By doing so, the user will be able to determine the degree of reliance that can be placed on the strength estimates from the rebound readings.

The user of this test should be aware that no correlation has been determined to exist between rebound readings and modulus of elasticity. Its use should be limited to determining the quality control and uniformity of concrete and estimating the compressive strength with a maximum accuracy of $\pm$ 20 percent. Even then, these accuracies can be expected only if the specimen has been cast, cured, and tested under conditions which were identical to those from which the calibration curves were established.

REFERENCES - 3, 7, 12

2.1.1.3 - Penetration Test

Test Method - *Windsor Probe Device*

Material - Concrete

Parameter - Quality and Uniformity, and Compressive Strength

Discussion

The Windsor Probe device consists of a driving gun which uses a powder charge to drive a high-strength steel probe into the concrete to be tested. Generally, three probes are driven in a triangular pattern; and the amount of penetration is determined by measuring the length of the probe extending from the surface of the concrete. Then, the depth of penetration measurements can be converted to concrete strength determinations by using calibration curves supplied by the manufacturer of the Windsor Probe device.

Advantages and Limitations

The Windsor Probe equipment is simple, durable, requires little maintenance, and can be used by laymen in the field with little training. It is fast - three tests are made in approximately five minutes. ASTM Standard Test for Penetration Resistance of Hardened Concrete (C 803) describes this test method.

The Windsor Probe primarily measures subsurface hardness and does not yield precise measurements of the in-situ strength of concrete. The probe test, however, is useful in assessing the quality and relative strengths of concrete. As with the Schmidt Hammer (rebound) test, interpretation of test results depends on other known factors which are based on correlation plots. When used on concrete which is 40 to 50 years old, this test method may yield a higher strength than actually exists.

The Windsor Probe Test does minor damage to the concrete over an area of approximately 25 to 50 mm (1 to 2 in) in diameter, leaving holes about 8 mm (0.3 in) in diameter for the depth of the probe. It may also cause minor cracking, necessitating superficial repairs.

Care should be taken to insure that the user observes normal safety precautions concerning its use and handling.

REFERENCES - 3, 7, 9, 13, 14

2.1.1.4 Electrical Tests

A. Test Method - *Dielectric Measurements*

Material - Concrete

Parameter - Moisture Content

Discussion

The technique of using dielectric measurements to determine the moisture content of concrete is based on the principle that the dielectric properties of concrete change with changes in its moisture content. To conduct this test, the dielectric testing equipment is placed on the specimen, the oscillator is energized, and the overall capacitance of the specimen is measured between two co-planar electrode plates. The two electrode plates are separated by insulation to prevent short circuiting and to assure that the measurement is of the current traveling through the specimen.

It has been determined by developers of dielectric measurement equipment that the best frequency range to use when measuring the dielectric constant is 10-100 MHz. By using these high frequencies, the effects of conductance caused by dissolved salts and faulty contacts with the electrodes are greatly minimized.

Advantages and Limitations

The greatest advantage to using dielectric measuring equipment is that it is readily automated. However, dielectric measurement equipment is very costly due to the need to use high frequency currents. This limits its use to only those specialized applications which can justify the expense. The test method is further limited by the fact that it can test only for moisture content of the concrete. Also, successful use of dielectric techniques is contingent upon careful and frequent calibration of the measuring instruments.

Another limitation to consider carefully is the fact that the dielectric properties of concrete are highly dependent on the moisture, salt content, and temperature of the specimen. This can pose problems in the interpretation of test results.

REFERENCES - 2, 4, 7

B. Test Method - *Electrical Resistivity Test*

Material - Concrete

Parameter - Thickness of Slabs and Location of Reinforcing Steel

Discussion

Electrical resistivity tests are based on the principle that different materials offer different degrees of resistance to the passage of electricity. Thus, a concrete pavement has a resistivity characteristic which differs from that of the underlying subgrade layers; and this change in resistivity is measurable with electrical equipment. To conduct the test, four electrodes are placed in a line on the concrete specimen at equal distances. A voltage is applied across the inner two electrodes. For practical purposes, the penetration of the applied current is considered to be equal to the spacing between the electrodes.

After testing, resistivity is computed by using the following formula:

$P = 2\ SE/I$ where S = Spacing between electrodes, cm.
E = Potential drop between inner two electrodes, volts
I = Current flowing between outer two electrodes, ampheres

Resistivity is then plotted against electrode spacing (or depth) and slab thickness, and the location of reinforcing steel is determined from the curves.

Advantages and Limitations

Although electrical resistivity test methods and equipment are simple and easy to use, the one major drawback is that they are limited to testing of concrete pavements. Furthermore, the test results are affected by air entrainment; mix proportions and density of the concrete; and the presence of steel reinforcement, moisture, salt, and/or temperature gradients. Hence, the effectiveness of the test results may be questionable. Another limitation to the widespread use of this test method is the high cost of the generators required to produce the high frequency currents needed to satisfactorily determine the desired results.

REFERENCES - 2, 4, 7

2.1.1.5 Electro/Magnetic Test

Test Method - *Magnetic Electric Field Evaluation*

Material - Concrete

Parameter - Location and Size of Internal Reinforcement or Other Electrically Conductive Components

Discussion

The magnetic-electric test is based on the principle that ferromagnetic and electrically conductive materials effect the field of an electromagnet. It is used primarily to detect ferromagnetic components, such as rebars in concrete, but also is effective in locating electrically conductive components in masonry and other nonconductive materials.

Several portable, battery-operated, magnetic electric field test devices are now commercially available. Generally, those that measure the depth of reinforcement cover in concrete are known as cover meters, and devices that measure both the cover and the size of reinforcement bars are called Pachometers. Typically, these devices weigh about 14kg (9 lb).

The devices are easy to use and require only that the user place the attached probe device over the reinforced concrete and move it about until the reinforcement is determined to be parallel to the length of the probe at which time a reading is obtained on the dial of the instrument. For a known diameter of a rebar, the dial gives a direct reading of the cover to steel.

Advantages and Limitations

The biggest advantage to using the magnetic electric field evaluation method for detecting internal reinforcement and electrically conducting components is its portability of operation. It is limited, however, to detecting concealed ferromagnetic and electrically conductive components located within 180 mm (7 in) of the surface of a nonconductive base specimen. Also, in heavily reinforced sections, the effects of secondary reinforcement cannot be eliminated, and the cover of the steel cannot be determined accurately.

An operational characteristic that could prove to be a drawback (depending on geographic location) is the fact that the battery pack for portable units will not perform satisfactorily in temperatures less than 0°C (32°F).

REFERENCES - 1, 7, 15, 16

2.1.1.6 Acoustic Tests

A. Test Method - *Acoustic Emission Evaluation*

Material - Concrete

Parameter - Structural Integrity (Cracks, Non-bonds, Inclusions, Interfaces, Etc.)

Discussion

Acoustic emission evaluation consists of monitoring and evaluating high frequency acoustic signals (stress waves or pulse) which are produced naturally by the test materials themselves when placed under stress. These acoustic signals are related to the internal physical changes taking place within the specimen being tested. Detection of the stress waves is accomplished by affixing sensors to the specimen, amplifying the acoustic emissions, and recording them on a tape recorder or processing them through a digital computer for recording and analysis.

The technique is based on the Kaiser Effect - the principle that, under a load, almost all materials produce a significant level of small-amplitude elastic stress waves above the base level of stress waves produced without a test load (unless a flaw occurs or the original load is exceeded). A high emission rate above the base level of emission at operating load, design load, or test load level indicates that a flaw is growing.

Advantages and Limitations

Although the equipment is relatively portable and easy to learn to operate, the interpretation of the results requires an expert who has had considerable experience in this specialized field. Detection of crack growth is only the beginning of the evaluation. Determining the location of a crack with this equipment is very complex and often requires the use of a microcomputer (for high speed triangulation). This test is very advantageouly combined with load testing.

A significant disadvantage to this method of crack evaluation is the large expense involved. It is the type of test that is most appropriately accomplished by contracting the service from a testing company that specializes in nondestructive testing. Also, the reliability of the detection of flaws is affected by noise sources other than structural defects. Research currently is going on to develop methods for noise source identification and discrimination to minimize this problem.

REFERENCES - 1, 2, 4, 7, 13, 17, 18, 19, 20

B. Test Method - *Acoustic Impact Evaluation*

Material - Concrete

Parameter - Integrity (De-bonds, Cracks, Voids, Etc.) and Modulus of Elasticity

Discussion

Acoustic impact evaluation equipment utilizes the principle that the acoustic and impact energy transmission characteristics of a material are related to the geometry and mass effects (e.g., shape, density, and structure) of the material. As compared to the characteristic energy transmission patterns for an unflawed specimen, these patterns will be changed due to flaws or changes in the internal structure of the specimen to be evaluated. In other words, a specimen with flaws (de-bonds, hairline cracks, voids, etc.) will dissipate acoustic energy more rapidly than a specimen in sound condition.

For certain cases, these energy transmission patterns can be detected audibly, amplified electronicaly, and displayed on an oscilloscope, a computer interfaced cathode ray tube (CRT) or graphic printer, or a voice print spectrograph.

Advantages and Limitations

Acoustic impact evaluation equipment is mounted on a trailer, is easy to operate, and can be automated. It provides a method of detecting and evaluating de-bonds, hairline cracks, and voids in specimens (although its reliability has not been demonstrated clearly to date). Either acoustic or rebound energy sources can be used to stimulate the test energy pulse which is measured.

It should be realized that before test results can be interpreted, a standard acoustic pattern must be determined for each given application on specific materials. Also, when using acoustic impact sources, acoustic isolation is required because of the possibility of outside acoustical interference with test results.

A disadvantage of this test method is the expense of the equipment. It is still in the developmental stage and is used mainly by the Department of Transportation for determining properties of pavements. A potential use is seen in slabs-on-grade for structures.

REFERENCES - 1, 2, 4, 7, 13, 17, 18, 19, 20

2.1.1.7 Ultrasonic Test

Test Method - *High Energy Ultrasonics*

Material - Concrete

Parameter - Thickness, Quality, and Uniformity

Discussion

Measuring thickness and estimating the quality of concrete by the high energy ultrasonic evaluation method is accomplished by measuring the travel time of a large unit of acoustic energy driven through the concrete specimen. A high energy ultrasonic source (one million electron volts energy with pulse duration of a few nanoseconds) is required to produce measurable ultrasonic indications, since the signal from a standard ultrasonic unit is scattered through the concrete so completely that no information from the reflected signal is available.

Advantages and Limitations

Some manufacturers of this equipment claim that high energy ultrasonics can measure thickness of concrete masses with an accuracy of ± 5 percent. This technique is limited to measuring thickness of only heterogeneous materials such as concrete. Also, the information received as a result of the test is limited to thickness measurement and does not include information on internal flaws.

Another limitation to the use of this equipment is the weight and size of the electrical power supply. Although the power supply is considered to be portable, available products weigh approximately 91 to 181 kg (200 to 400 lb).

REFERENCES - 1, 2, 4, 7, 13, 17, 18, 19, 20, 42

2.1.1.8 Radiographic Tests

Test Method - *Radiographic Evaluation*

Material - Concrete

Parameter - A. Using X-Ray:
Density and internal structure of concrete, size and location of reinforcement, and bonding stress.

B. Using Gamma Ray:
Location, size, and condition of rebars, voids in concrete, voids in grouting on post-tensioned prestressed concrete, variable compaction in concrete up to about 600 m (20 ft) thick, density of structural concrete members, thickness of concrete slabs, and density variations in drilled cores from concrete road slabs.

Discussion

Radiographic evaluation techniques are based on the principle that the rate of absorption of x-rays or gamma rays is affected by the density of the test specimen. X-rays or gamma rays are emitted from a source (x-ray tube, radioactive isotope, etc.), penetrate the specimen, and exit the opposite side of the specimen where they are recorded on a sensitive film as radiographs (pictures) or viewed on an electro-optical imager (screen).

Flaws having a diameter as small as about 1 percent of the material thickness (in the direction of the radiation penetration) can be detected in a wide range of materials. Orientation of the defect (parallel or perpendicular to the beam) will affect detection of the flaw. Voids or relatively low-density areas of the specimen allow a relatively higher rate of passage of the rays which will appear as dark indications on the film (as compared to the relatively lighter background). The reverse holds true for areas of higher density, such as steel reinforcement, which are clearly detected and recorded on the film.

Advantages and Limitations

Radiographic evaluation techniques offer the advantage of providing a permanent record on film for inspection, or a "live" image on an electro-optical system.

Since x-ray evaluation equipment for concrete evaluation is heavy and costly, it has very limited application as a field test. It lends itself better to an application in a laboratory environment. On the other hand, gamma ray equipment is easily portable because sources (such as cobalt 60, iridium 192, and cesium 137) do not require electrical power. Thus, gamma rays are becoming increasingly accepted as a viable field test method. Gamma radiography can be carried out only by personnel who are licensed by the Nuclear Regulatory Commission. As a word of warning, x-ray and gamma ray sources are harmful to organic tissue; and the test environment must be shielded (or isolated) as necessary to prevent radiation hazards. Lead shielding required for gamma ray sources can be very heavy, sometimes weighing up to 227 kg (500 lb).

Other drawbacks to the use of radiographic evaluation equipment are the high initial cost of the equipment and film, the time delay required to develop film, and the requirement that access to both sides of the test specimen is necessary to set up and use the equipment.

REFERENCES - 1, 2, 4, 7, 41

2.1.1.9 - Microwave Absorption Test

Test Method - *Microwave Absorption Test*

Material - Concrete

Parameter - Moisture Content and Quality, Rebar Size and Location

Discussion

Microwaves are electromagnetic wave emissions which lie between television and infrared emissions in wavelength and frequency. Due to the fact that they are electromagnetic in nature, they can be reflected, diffracted, and absorbed by different materials at differing rates. Water, for example, absorbs microwaves at a much higher rate than concrete. Microwave testing methods employ this principle of absorption to measure the moisture content and quality of concrete and other porous building materials and to measure size and location of reinforcement.

The testing apparatus consists of a portable 3,000 MHz (100 mm wave-length) radio transmitter which is modulated at 3 kHz by a square wave, and a 3kHz receiver which has attached to it an attenuator calibrated in decibels. The transmitter and receiver are attached to opposite sides of the specimen and switched on. The receiver attenuator is adjusted to a null reading both with and without the specimen present. The difference between the two null readings then is translated into moisture content by use of a calibrated chart which is developed by the user. Instruction for developing the calibrated chart and for making the test measurements are supplied by the test equipment manufacturer.

Advantages and Limitations

Although microwave absorption testing equipment is easy to use and is moderately priced, the major limitation to its widespread use is its low degree of accuracy and the difficulty in interpreting test results. For measuring moisture content in concrete, the expected accuracy is no better than 30 percent of the mean value. This low accuracy is due partially to the fact that concrete is a heterogeneous material which causes internal scattering and diffraction of the microwave emissions (scattering is caused, also, by reinforcement).

REFERENCES - 1, 2, 7

2.1.1.10 - Dynamic Tests

Test Method - *Dynamic Tests (Ultrasonic Pulse Velocity and Resonant Frequency)*

Material - Concrete

Parameter - Quality and Uniformity, Strength, Modulus of Elasticity

Discussion

The ultrasonic pulse velocity test method works on the principle that vibrational wave propagation is affected by the general quality of a dense medium such as concrete. Assuming concrete to be an inherently heterogeneous medium, the path of travel of the ultrasonic pulses must be long enough to test an "average" section of the structural member. The equipment makes use of an electro-acoustic transmitter and a receiver that are placed in contact with the concrete surface. The distance between them is measured to a high degree of accuracy by the travel time of an ultrasonic pulse. The average pulse velocities have been correlated with general concrete conditions and strength qualities in the following table:

Pulse Velocity (m/sec)	Condition/Strength Evaluation
Above 4575	Excellent
3660 - 4574	Good
3050 - 3659	Questionable
2135 - 3049	Poor
Below 2135	Very Poor

The main point to remember is that the less impedance (velocity slowing) that the ultrasonic pulse experiences, the higher the quality of the concrete.

The resonant frequency test method is applied almost exclusively in the laboratory and is used to determine the natural frequency of vibration of a standardized concrete prism or cylinder. The vibration frequencies found in the test are used in turn to calculate Young's modulus of elasticity and rigidity, Poisson's ratio, and durability ratings. A simplified description of the testing process is as follows: 1) a drive unit applies standardized mechanical vibrations to a concrete sample, 2) the vibrations are picked up by piezoelectric sensors, and 3) the vibrations are fed into a cathode-ray oscilloscope that gives a digital and graphic readout of the natural reasonant frequency of the sample.

Advantages and Limitations

Both test methods yield an accurate assessment of concrete quality and uniformity. Strength then can be estimated by preparing calibration charts. The accuracy of estimation is ± 15 to 20 percent. Both methods are applicable only to laboratory tests and require a trained operator to evaluate the results. They are in frequent use, and the equipment is relatively inexpensive to purchase.

REFERENCES - 7, 21, 42

2.1.1.11 - Nuclear Tests

A. Test Method - *Neutron Scattering Methods (Neutron Moisture Gages)*

Material - Concrete

Parameter - Moisture Content

Discussion

The neutron scattering method for determining moisture content in concrete is based on the principle that hydrogen containing materials (such as water) decrease the speed of fast neutrons (greater than 0.1 mev.) in accordance with the amount of hydrogen produced in the test material. In the case of concrete, the moisture in the concrete is the major source of hydrogen and calcium hydroxide.

Thus, the evaluator can obtain an estimate of the hydrogen content of the specimen by counting the slowed-down neutrons which result from interaction with the hydrogen. Most neutron moisture gauges use isotopic neutron sources.

Advantages and Limitations

Although neutron moisture gauges are satisfactory for measuring moisture content in concrete, they have not been used widely since procedures for calibration and measurements have not been adequately standardized. One of the biggest drawbacks is the fact that gradients of moisture content near the surface of the test specimen and the presence of neutron absorbers within the specimen can cause erroneous results. The adequacy of this test method for field application has yet to be proven.

REFERENCES - 1, 7

B. Test Method - *Neutron Activation Analysis*

Material - Concrete

Parameter - Cement Content

Discussion

The neutron activity method of nondestructive evaluation is based on the principle that concrete becomes radioactive when bombarded by neutrons. The unstable radioactive isotopes that are formed emit beta and/or gamma radiation which allows a clear characterization of the radioisotope and its parent nuclide.

To perform the test, a reference standard (of the element being determined) is activated under the same conditions as the unknown sample. Then, the weight of the element in the sample under investigation can be determined by comparing the activities induced in both the test sample and the reference sample.

The major use of neutron activation analysis techniques for evaluating concrete is to determine the cement content of concrete. Since the neutron activation process is independent of chemical bonding and the internal physical condition of the specimen, these respective properties cannot be measured using this method of evaluation.

This test is not widely used for several reasons, the first of which is that it is expensive and complex. Since it is a recently developed test method, the procedures for calibration and measurement have not been standardized adequately. Then too, the accuracy of the test results is questionable due to the fact that gradients of moisture content near the surface of the concrete and the presence of neutron absorbers within the concrete will induce errors in the test measurements. Performance of this test method in the field has yet to be proven.

REFERENCES - 1, 7

2.1.1.12 Infrared Test

Test Method - *Infrared Test*

Material - Concrete

Parameter - Internal Flaws, Crack Growth, Internal Voids in Slabs

Discussion

Infrared evaluation techniques detect flaws in concrete by using selective infrared frequencies to detect various passive heat patterns which can be identified as belonging to certain defects. There are three commonly used variations of this technique of nondestructive evaluation of materials - one based on steady-state heat patterns, one based on transient heat emission, and one based on low amplitude vibrations.

1) Steady-State Heat Pattern Method. In this method of infrared evaluation, the heat pattern in the specimen is produced by a boron-epoxy laminate during cyclic loading at 30 Hz. The heat pattern is caused by the dissipative nature of the internal friction inherent in the specimen material. As fatigue damage develops, changes in the heat pattern can be observed.

2) Transient Heat Emission. The heat pattern resulting from the transient heat emission method is produced by the dissipative part of the strain energy released when a material fractures. This strain energy released at the time of fracture is partly in the form of heat which produces the image seen by the infrared camera. For this test, a boron-aluminum laminate is used on the test specimen to produce the heat patterns.

3) Vibrothermography. Rather than inducing a cyclic (fatigue) loading in the specimen, low amplitude vibrations can be used to produce heat patterns without the need for a fatigue machine. Standard shaker tables or transducers are used to produce the vibrations needed to conduct the test.

Advantages and Limitations

The greatest advantage of using the transient heat emission method is the ability to monitor quantitatively energetics of fracture events by reviewing images produced on infrared film. The steady-state heat pattern method for detecting flaws in concrete currently is not reliable enough to make its use widespread. It shows great potential and is undergoing research and development. Concrete is a good material to use with these two test methods because it is a good insulator, it has a low specific heat value, and it has high heat capacity.

Vibrothermography has four advantages over the other two infrared test methods in that 1) the low level of input energy does not damage the test specimen in any way, 2) the equipment is less expensive and easier to use, 3) the frequency of the excitation can be varied over a wide range, and 4) often flaws can be selectively discriminated by varying the frequency of the excitation.

Infrared evaluation techniques can be used advantageously in conjunction with load testing.

REFERENCES - 22, 23, 24

2.1.1.13 Load Test

Test Method - *Load Testing*

Material - Concrete

Parameter - Performance Under Load (Rigidity, Failure Under Stress)

Discussion

Load testing verifies design load carrying ability of a structure (unless failure occurs during the test). The test procedure is based on the principle that any structure which is capable of withstanding the stresses of a design load should perform satisfactorily under actual loading conditions.

To conduct the test, a test load is applied to the structure in a manner that will simulate the load pattern under design conditions. The test failure indications (such as leakage, distortion, or even structural failure) then are monitored and measured visually or with detection devices. Structural loading can be accomplished by the use of heavy dead weights such as concrete, lead, or water.

Advantages and Limitations

The advantage of using load testing for nondestructive evalution of concrete is that it provides a high degree of reliability on the structure's ability to perform satisfactorily under normal loading conditions during the present time. However, its validity concerning the long-range performance of the structure is questionable.

A serious limitation to the use of this test method on old buildings is the fact that it may cause cracks or distortion, or may even cause premature failure of the structure or some of its elements. Load testing has the disadvantage of requiring a significant amount of preparation and clean-up time before and after the test. Because of its high cost, it has limited application.

REFERENCES - 1, 25, 40

2.1.1.14 Radar Test

Test Method - *Radar*

Material - Concrete

Parameter - Detection of Substratum Voids

Discussion

Since slab-on-grade is one of the most common construction techniques used in buildings, it is useful to know that an alternative test method is being developed to check the integrity of the subgrade material. Some manufacturers claim that radar, which employs the use of transmitted electromagnetic impulse signals, has an 80 percent reliability of substratum void detection. This new test method is more time and cost efficient and less destructive than the previously used "guess and drill" techniques.

Advantages and Limitations

Radar equipment is expensive. A major disadvantage of the radar system is that the reliability of void detection is greatly reduced if the slab contains reinforcing bars or mesh. In such cases, the data must be interpreted by an expert trained in the field of electromagnetic impulse analysis. This test method may also have further applications in geotechnical and highway engineering where void detection is important in determining the strength and service life of a concrete slab.

REFERENCE - 26

2.1.1.15 Pullout Test

Test Method - *Pullout Test*

Parameter - In-Situ Pullout Strength of Hardened Concrete

Discussion

A modification of the ASTM C 900 pullout test of cast-in-place plugs has been developed for determining pullout strength of hardened concrete using drilled and set-in-place wedge anchors. The test is based on the determination of the pull force required to cause shear failure of the concrete. The pull force is derived from a tension ram connected to the anchor at one end and a portable hydraulic pump at the other end.

Two types of wedge anchors currently are considered acceptable for use in this test; namely, 1) the split-sleeve assembly, and 2) epoxy grouted bolts. The split-sleeve assembly consists of a tapered steel rod threaded at the small end and a specially designed high-strength sleeve that includes a split shell at one end. The other end of the sleeve is threaded so that it can be screwed to the base plate of a tension ram. To prepare for the test, holes measuring 19 mm (3/4 in) in diameter and 38 mm (1 1/2 in) deep are drilled in the hardened concrete with special drilling equipment designed to permit rapid drilling of holes perpendicular to the surface of the concrete sample. A description of the remainder of the two test methods follows:

Using Split-Sleeve Assembly

1. Insert and secure the steel rod and split-sleeve assembly in the drilled hole with tapered end down.
2. Screw the assembly to the base plate of the ram.
3. Gradually apply a pullout force on the rod through the tension ram until the plug breaks out of the concrete.
4. Record the maximum pull reading observed.

Using Epoxy Grouted Bolts

1. Clean and dry the drilled hole.
2. Fill the hole with a flowing epoxy.
3. Place the anchor bolt (a threaded steel rod) into the epoxy with a slow rotary motion (to avoid the formation of entrapped air at the interface).
4. Hold the bolt in a perpendicular position until the initial set of the epoxy takes place.
5. After proper curing of the epoxy (usually 24 hours), the bolt and resulting concrete plug is pulled out using a tension ram assembly. The load is applied uniformly until failure of the concrete occurs.

The test results of the pullout test on hardened concrete indicate good correlation with the strength results obtained from compression tests on cylinders and drilled cores. In fact, the correlation coefficient values of around 0.81 to 0.85 are comparable to those reported from the pullout test of cast-in-place anchors (ASTM C 900).

Advantages and Limitations

The pullout test on hardened concrete is a simple, quick, and inexpensive test which can be carried out easily in the field on in-situ concrete. It offers the advantage of direct determination of some strength parameters and shows a good degree of correlation with the standard strength test (compression test on cylinders or drilled cores). However, due to the lack of standardization of the test procedures and the equipment, high within test variations may be expected to occur. For this reason, at least 6 pullout determinations per test should be performed.

For the split-sleeve assembly method, the effectiveness of the test is dependent upon the design and geometry of the split-sleeve assembly itself. Proper design of the split-sleeve assembly is important because it is the mechanism used to transmit the whole pullout force to the concrete.

For the epoxy grouted bolt method, the epoxy must have suitable pot-life characteristics and provide satisfactory bonding action with the concrete. It also must be able to develop high elastic and strength properties at a very early age under variable ambient temperatures. Preliminary use of this test method indicates that research is needed to develop epoxies that will allow the pullout tests to be performed in a matter of hours rather than after 24 hours of set time.

REFERENCE - 38, 39

2.1.2 Destructive Tests

In contrast to the many and varied nondestructive test methods available to evaluate concrete, there are fewer destructive methods which have been developed thoroughly for this purpose. This section on destructive evaluation methods shares a similar objective with Section 2.1.1 on nondestructive evaluation, namely, to present the most commonly used methods for destructive evaluation of concrete structures and their components which will assist the examiner in evaluation of physical properties and performance.

Destructive test procedures include the test methods of core drilling and petrography which can be used together to determine the strength and internal quality of concrete and its cement and aggregate components. Such characteristics as deleterious chemical reactivity betwen components, and physical condition and composition of the cement and aggregate can be determined best by these destructive test methods.

REFERENCES - 2, 4, 7, 8, 14, 37, 38

2.1.2.1 Core Drilling

A. Test Method - *Core Drilling*

Material - Concrete

Parameter - Strength and Internal Quality

Discussion

The existence of some surface aberrations such as scaling, leaching, pattern cracking, and freeze-thaw weathering may suggest the need for an investigation of the internal condition of a concrete structural member. A widely accepted destructive test method to check for internal quality is core drilling.

Drilled cores of 50-250 mm (2-10 in) in diameter and of varied lengths are obtained using a gasoline or electric powered drill rig. Cores from older members with rehabilitation potential tend to be 50-150 mm (2-6 in) in diameter. The drill bits are either calyx (steel shot) or diamond (bort). The diamond bit drills are much faster and cleaner but require a more skilled operator and are much more expensive. Cores should be catalogued when drilled. They should then be labeled carefully and packaged for transport to a test laboratory. The sample types can be placed in two broad categories: 1) samples that are intended to be representative of the concrete in place, and 2) samples that display specific features of interest, such as a core taken at the site of a cracking pattern.

Subsequent tests performed on the sample vary significantly. The core size requirements vary with the type of test to be performed. The basic testing list includes: 1) visual inspection (surface condition, depth of deterioration, fractures, unusual deposits, coloring or staining, distribution and size of voids, location of construction joints, and contact with the foundation or other surfaces); 2) compressive and tensile strength; 3) transverse, longitudinal and torsional frequencies; 4) static modulus of elasticity; and 5) Poisson's ratio of concrete in compression. Other tests that might be warranted are dynamic loading and seismic loading tests. These last two test methods require cyclic loading techniques used with various time intervals.

ASTM C 42 "Standard Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete" gives a more complete description of this test.

Advantages and Limitations

This is the most widely accepted method to determine strength and quality of in-place concrete. The process of drilling and analyzing concrete cores is expensive and requires a relatively long time period (1 to 3 weeks) for a thorough analysis. This test method is termed destructive because repeated core drilling in a concrete structural member could affect its integrity. Cores obtained from appropriately located drilling sites are a very accurate representation of the internal composition of the concrete. Core drilling is best suited to concrete structural systems such as walls and foundations. It should be used very judiciously when dealing with structures being evaluated for rehabilitation purposes.

REFERENCES - 3, 23, 27, 29, 30

B. Test Method - *Petrography*

Material - Concrete

Parameter - Physical Quality of Aggregate and Concrete

Discussion

Petrographic examination uses microscopy and/or x-ray diffraction and differential thermal analysis in conjunction with core testing to aid in determining the physical and chemical properties of aggregates and concrete.

1) Aggregates

By the use of this test, the aggregate is identified according to mineralogical and chemical differences, and the following properties of the aggregate may be determined:

a) The extent to which the particles are coated.
b) The nature of the coating substance.
c) Particle shape.
d) Potential deleterious reactivity with cement alkalies.
e) Chemical reactivity.
f) Condition of the aggregate.
g) Cement-aggregate reactions.
h) Composition of fine and coarse aggregate.

To accomplish this test of aggregate found within a concrete core sample, the aggregate is examined by a hand held lens or a microscope. The aggregate then is analyzed in accordance with the following three criteria:

Petrographic Identity

An experienced petrographer can examine the aggregate samples to identify whether the particles are coated with either mineral or organic coatings, to identify the coatings, and to determine the potential physical and chemical effects of the coating on quality and durability of the concrete. The particles are examined further to determine their classification (type).

Physical Condition

Aggregate samples are examined to determine their shape, flatness, angularity, and other pertinent properties than can lead to classification of the aggregate as: 1) satisfactory (contributes to high or moderate strength, abrasive resistance, and durability of concrete), 2) fair (contributes to moderate strength, durability and abrasive resistance under ideal conditions, but concrete might breakdown under rigorous conditions), and 3) poor (contributes to low strength and poor durability of concrete or breakdown of concrete).

Anticipated Chemical Stability in Concrete

The amount of deleterious aggregate particles (alkali reactive rock types such as opal) may be determined. The deleterious particles can be responsible for producing adverse effects on the concrete through chemical reactions with the cement alkalies.

2) Concrete

The condition of the concrete also may be evaluated by using petrography. For this purpose, the most useful samples of concrete are diamond-drilled cores with a diameter of at least two to three times the maximum size of the coarse aggregate used in the concrete. For concrete with 150 mm (6 in) aggregate, a core of 200 to 250 mm (8 to 10 in) diameter is commonly used rather than the more costly and harder-to-handle 305 to 457 mm (12 to 18 in) cores prescribed by this general rule-of-thumb.

The following features of concrete can be studied and evaluated:

a) Denseness of cement paste.
b) Homogeneity of the concrete.
c) Occurrence of settlement and bleeding of fresh concrete.
d) Depth and extent of carbonation.
e) Occurrence and distribution of fractures.
f) Characteristics and distribution of voids.
g) Presence of contaminating substances.
h) Evidence of cement-aggregate reaction.
i) Proportion of unhydrated granules of cement.
j) Presence of mineral admixtures.
k) Volumetric proportions of aggregate, cement paste, and air voids.
l) Air content and various parameters of the air void system.

Care should be taken in selecting core samples to assure a maximum true representation of the material and to avoid unusually poor or unsound materials. Sampling should include near-surface concrete as well as concrete at depth because of the possible affect of depth on the properties of the materials and the defects. Also, the number and size of samples should be carefully selected to permit all necessary laboratory tests. It is important to use virgin samples in order that there be no influence from previous tests.

Evaluation should be performed only by a qualified petrographer who is familiar with problems commonly encountered with concrete. The petrographer should be consulted before proceeding with the core sampling and should be provided with as much preconstruction, construction, and post-construction performance information as possible to assist in the evaluation. Following petrographic examination and analysis, the petrographer prepares a report summarizing observations and conclusions regarding the suitability of the aggregate under the anticipated conditions of service and indicating any possible effects the aggregate may have had on problems encountered with the concrete.

ASTM C 295 "Recommended Practice for Petrographic Examination of Aggregate for Concrete," and ASTM C 856 "Recommended Practice of Petrographic Examination of Hardened Concrete" give a more complete description of this test.

REFERENCES - 3, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41

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2.2 WOOD (STRUCTURAL TIMBER)

The practice of evaluating wood must focus on identification of those characteristics of the wood (such as density, knots, moisture content, etc.) that define its performance. This is because, as contrasted with man-formed materials (such as concrete & metals), timber must be segregated into use classes (graded) according to predicted performance. This means that the building industry's control over the quality of wood is limited to the proper application of these use classes.

In existing structures, questions of performance of wood products must address: 1) the presence of the properly specified product grade and size, 2) the proper joining of these products, and 3) evidence of degradation of these products by the environment (e.g., moisture, temperature, chemicals, etc.).

One of the greatest aids available for evaluating structural timber is the grade mark stamped on it at the mill. Because grade marks usually can be related to a recommended design value (by reference to the National Design Specification for Wood Construction, Ref. 16, or other relevant documents), it is helpful in determining the quality and strength properties of the existing timber structure of a building if they can be discerned. Doing so may require removing the finish on the members, and this usually is not done because of the considerable costs of such explorations compared to the benefits derived.

If, on the other hand, the grade marks are not discernible, it may be necessary to engage an evaluator who is experienced in identifying and grading wood products to make the evaluation of the quality and strength properties of the in-situ structural members in question. In order to accomplish this task, many nondestructive and destructive evaluation procedures are available, the most common of which are listed in Table 3. This table is arranged according to the properties or parameters to be evaluated, the corresponding capabilities of the test, and the advantages and limitations associated with the test methods.

TABLE 3 TEST METHODS FOR WOOD

TEST METHOD	PROPERTY OR PARAMETER	CAPABILITY	ADVANTAGES	LIMITATIONS	REFERENCE[1] PAGE NO.
VISUAL/ OPTICAL Visual Inspection	Extent of Decay. Species.	Visual inspection to search for characteristics of decay that are typical of different structural components such as siding, roofs, etc.	A good preliminary step in structural assessment to yield an overall evaluation.	Inspection should be followed by other test methods to assess internal stability.	44
Visual Stress Grading	Strength and Grade	Examination of such qualities as sizes and frequency of knots, grain slope, and wane lead to a stress reduction factor (compared to stress value of clear wood).	It is well suited for grading inspection. Provides a measure of structural adequacy related to conventional practices under accepted ASTM/ALS grading practices.	Limited to accessibility. May be impractical if grade mark or wood is covered with paint.	45
Manual Probing	Extent of Decay	Pulling out of surface splinters of decayed wood and comparing with splintering and breaking characteristics of sound wood.	A good detection method for surface decay. It is fast, easy, and decay characteristics are easy to identify (if they are in an advanced stage of development).	Inspection should be used in conjunction with another test method to assess internal quality. In existing buildings, not all surfaces may be accessible. Cannot measure decay. unless it proceeds inwards from the surface.	46

[1] See more detailed description on page indicated.

TABLE 3 (Continued) TEST METHODS FOR WOOD

TEST METHOD	PROPERTY OR PARAMETER	CAPABILITY	ADVANTAGES	LIMITATIONS	REFERENCE[1] PAGE NO.
PENETRATION TESTS PILODYN PENETROMETER	Density (Strength) and Degree of Degradation	Can estimate approximate in-situ strength properties and degree of decay.	Equipment is portable, simple, durable, and can be used by field personnel with appropriate training.	Does not provide a precise determination of strength. Readings must be calibrated with known samples. Cannot measure decay unless it proceeds inwards from the surface. Measures only advanced stages of decay.	46
ELECTRICAL Dielectric-Type Moisture Meters	Moisture Content	Capacitance meter: Measures a change in oscillation frequency due to moisture content/dielectric constant of the wood or change in the capacitance of the electrode as an impedance element when in contact with the specimen. Power-loss meter: Measures a loss of amplitude of an electrical wave emission resulting from amount of moisture in wood.	Both types are easy to use. There is no physical disturbance of the surface.	Useful range of the dielectric type moisture meters is from 0% to approximately 30% moisture content. Sensitive principally to the surface of the sample. Accuracy is relatively low, particularly when moisture gradient is present. Readings are affected by specimen density, chemical treatments, or decay.	48
Resistance-Type Moisture Meter	Moisture Content	Moisture content of any size piece of lumber is determined by measuring its electrical resistance between two probes inserted in the lumber.	Equipment is simple and rugged. Readout is in direct units, calibrations available for other grades and species.	Yields approximate results in only the 7% to 30% moisture content range. The data are influenced substantially by some preservatives, fire retardants, and decay.	49

[1] See more detailed description on page indicated.

TABLE 3 (Continued) TEST METHODS FOR WOOD

TEST METHOD	PROPERTY OR PARAMETER	CAPABILITY	ADVANTAGES	LIMITATIONS	REFERENCE[1] PAGE NO.
Electrical Resistance Probe	Moisture Content	Moisture content is measured by the electrical resistance between two electrode faces on a small wooden probe inserted into a test sample.	Long-term moisture content changes can be measured by remote means. Can be built into the structure.	Has only been used in research, therefore in-situ use is questionable. The probes often show long time drift and hysteresis. Useful range is 7 to 35% moisture content.	50
PULSE VELOCITY Ultrasonic and Impact-induced Pulse Velocity Equipment (Longitudinal Wave Propagation)	Strength, Modulus of Elasticity	Major variations in the velocity of a longitudinal wave propagation indicate possible discontinuities. The transmission time for a longitudinal wave propagation is measured and then translated into modulus of elasticity that is used to estimate degree of decay and to assist in determining strength from tables of sound wood.	Equipment is portable and readily adaptable for field use. Relatively fast measurements.	Velocity can be affected by wood characteristics that are not flaws (such as moisture content), reducing accuracy.	50
Stress Wave Progagation Equipment	Strength, Modulus of Elasticity	The propagation or velocity of transverse stress waves is influenced by inconsistencies in the wood that may affect strength. The density and wave velocity in a sample are measured to yield a modulus of elasticity. Strength evaluations are based on that value.	Portable, lightweight, low cost.	Requires trained personnel to operate.	51

[1] See more detailed description on page indicated.

TABLE 3 (Continued) TEST METHODS FOR WOOD

TEST METHOD	PROPERTY OR PARAMETER	CAPABILITY	ADVANTAGES	LIMITATIONS	REFERENCE[1] PAGE NO.
WEIGHT TEST Oven-drying	Moisture Content	Samples of wood are taken from a structural member and differentially weighed to determine moisture content (before and after drying).	Accurate results can be expected at any level of moisture content.	Requires lab test equipment. Takes considerable time.	53
RADIOGRAPHIC EVALUATION	Grain direction, irregularities, decay, splits, knots, moisture content, insect damage, location and size of members in a floor or wall system.	Capable of measuring thickness variations over four percent in 1/2 inch thick materials (10 percent in 1 inch thick materials). Can detect internal density variations.	Provides a permanent record. Equipment for wood evaluation is lightweight, portable. Test is easy to perform.	Radiation is harmful to organic tissue and must be shielded. High initial cost. Time delays for film development. Must have access to opposite sides of test specimen.	53

[1] See more detailed description on page indicated.

2.2.1 Visual Tests

A. Test Method - *Visual Inspection*

Material - Wood

Parameter - Extent of Decay

Discussion

Visual inspection and probing with a sharp instrument are usually the first and most comprehensive test methods employed when inspecting wood structural members. Decay is mainly the result of fungus associated with moisture accumulation. Characteristics of decay to be noted in different types of structural components are given in the following table.

Component	Characteristics of Decay
Siding	Abnormal coloring (deeper than normal brown color); Cubical checking (indicates an advanced stage of decay); Bleaching (with or without the presence of fine black lines); Softening (especially where siding ends butt against trim or each other).
Foundations	Fanlike fruiting bodies of fungi (located between subfloor and finish floor, and between joints and subfloor).
Roofs	Cubical checking, warping, softening, shredding, breakage (location of all these deficiencies may be underside of roof sheathing).
Porches	Same as siding (check especially concavely worn areas that may trap water).
Windows & Doors	Brown or black discoloration near joints. Stains on sash (from condensation). Softening and mold growth (from accumulation of condensate).

Advantages and Limitations

Visual inspection is the preliminary step in evaluation of a member's strength properties. An estimate of the in-situ surface condition obtained in this manner gives a first estimate of the presence of decay (any such evidence suggests possible serious strength loss at that point). Since this a subjective type of test, the accuracy of the results is dependent on the skill of the inspector. The results are not indicative of structural capacity if there is any suspicion of internal decay.

REFERENCE - 1

B. <u>Test Method</u> - *Visual Stress Grading*

<u>Material</u> - Wood

<u>Parameter</u> - Strength and Grade

Visual stress grading is a non-destructive method of identifying and categorizing lumber according to its defects which can assist in placing it in broad categories of anticipated load bearing capacity by: 1) the formulation of grading rules; and 2) the application of successive reduction factors to the strength values obtained from small clear tests to take into account the different strength-reducing influences involved. In this manner, an estimate can be made of the percentage of the test specimen's strength compared to the strength of perfect material of the same size and species (e.g., 50 percent, 75 percent, etc.). The characteristics that determine a visual stress grade include size and frequency of knots, checks, splits, and pitch pockets; slope of grain; density; and wane.

A test specimen often will have several characteristics that can affect a particular strength property. Consequently, only the characteristic that gives the lowest strength ratio is used to derive the estimated strength.

When using the visual stress grading method, the modulus of elasticity assigned to a grade is an estimate of the mean modulus of the lumber grade. The average modulus of elasticity for a clear wood of the species is used as a base and can be obtained from reference 2. This clear wood modulus of elasticity is multiplied by empirically derived "quality factors" to obtain the reduction in modulus of elasticity that occurs by lumber grade. See reference 13 for a description of this procedure.

<u>Advantages and Limitations</u>

Visual stress grading: 1) provides an assessment of the conformance of lumber grades in a structure to current practices (ASTM/ALS), and 2) permits an assignment of design values based on current practice. When applied to in-situ lumber, the procedures are limited to assessibility and may possibly deface the test pieces (damage to paint, etc.). When properly applied, it yields an approximate, and generally conservative, estimate of a member's strength due to the fact that: 1) there is little allowance made for specific gravity of the wood, and 2) only the surface is available for inspection. It has to be assumed that a defect has the maximum effect that can be deduced from a surface examination. It has the limitation that it cannot differentiate the modulus of elasticity for different grades which means that, where deflection is a limiting factor, there is little advantage given to the higher grades. Actual modulus of elasticity for individual pieces of the grade probably will vary from the mean assumed for design. The properties derived from visual grading criteria should be modified for design use by considering the influence of size, moisture content, and load duration. A discussion of these adjustment factors is given in references 13 and 14 (chapter 6). The test requires a trained grader (or careful attention to both grading and stress assignment procedures). Both hardwoods and softwoods can be assessed with this technique, but many hardwoods will require interpretation for development of stress values.

REFERENCES - 2, 13, 14

C. Test Method - *Manual Probing*

Material - Wood

Parameter - Extent of Decay

Discussion

Prodding or probing a suspected piece of decayed wood with a sharp tool and observing the resistance to marring gives an idea of the stage of decay. A loss of hardness can be determined by comparison with sound wood of the same species. Sound wood tends to lift out of the stock as one or two long slivers with splintery breaks when jabbed with a pointed tool. Decayed wood tends to lift out and break off squarely across the grain with little splintering and little resistance.

Advantages and Limitations

Manual probing will yield an accurate assessment of in-situ surface decay if it is extensive, but it must be used in conjunction with other test methods as described in table 3 to determine the internal quality. The probing method is best suited to framework, siding, and fences. Penetrometers often are used to determine the quality and uniformity as well as strength properties of wood (see also Pilodyn Penetration Device).

REFERENCE - 1

2.2.2 Penetration Test

Test Method - *Pilodyn Non-destructive Wood Tester (Penetration)*

MATERIAL - Wood

PARAMETER - Degree of Degradation and Associated Reduction in Strength, Density, and Shock Resistance of Structural Wood

DISCUSSION

This test is based on the principle that the degree of penetration of a steel pin into wood is dependent largely on the nature and extent of decay present in the wood. In other words, the pin will penetrate deeper into a decayed wood than it would into healthy wood. Research indicates that there is an inverse proportionality between penetration (density) and amount of energy required for the penetration, and a parabolic relationship between penetration (density) and pin diameter. Research further indicates that there is a correlation between density and strength of the material.

Some of the applications for which this test method is best suited are:

1) Estimate the strength of bio-deteriorated wood.
2) Estimate the condition of wood foundations.
3) Assess the degree of chemical or thermal decomposition on wood.
4) Assess the residual strength of poles decaying from the outside.
5) Estimate the density (strength) of sawn timber (stress grading of high quality timber).

The test is conducted by loading the penetrometer device, pressing it firmly onto the wood surface to be tested, and pulling the trigger to release the striker mechanism. The degree of penetration for a known constant energy and pin diameter then is measured by a scale reading from 0 to 40 mm (0 to 1-1/2 in). The instrument measures the fracture surface area created by a constant amount of energy. As an example, the "impact work" of a typical test might be of the order of 80 kJ/m^2 (5,484 ft.lbf/sq.ft.).

The test should not be made on cracks, fissures, or areas of excessively rotted wood since the results would not be indicative of the overall sample.

Advantages and Limitations

The equipment is portable and easy to use with limited amount of training, and its weight is only about 1.2 kg (2.6 lb). It can be used either on unimpregnated or salt impregnated wood. Unreliable values may result from the test if the wood is frozen or in an extremely dry condition.

The correlation between depth of penetration and the associated effective reduction in the strength of the structural wood member is affected to some degree by: (1) type of wood, (2) moisture content, and (3) the normal variations in density. For this reason, it is advisable to calibrate the scale readings by means of comparative tests on known samples of wood.

The test is reliable if used under uniform moisture conditions. It is known that moisture content influences the penetration, but further research is necessary in order to establish a fully reliable relationship. Research has shown that this device is suited best to use on wood where the strength loss due to degradation occurs on or near the specimen surface.

REFERENCES - 3, 4, 5

2.2.3 Metered Tests

A. Test Method - *Dielectric-type Moisture Meter*

Material - Wood

Parameter - Moisture Content

Discussion

Capacitance-type moisture meters use the principle that the frequency of an oscillator changes according to the effect the specimen has on the circuit capacitance or, in other words, according to the dielectric constant of the specimen. A frequency discriminator generates a signal, which can be read on a meter, that is proportional to the changes in frequency. Using the relationship between the dielectric constant and moisture, the meter then can be calibrated to read moisture content in-situ.

Radio-frequency power-loss moisture meters use the relationship between moisture content and power loss factor as a measure of moisture content. The wood specimen is penetrated by the electric field radiating from an electrode that is coupled to a low-power oscillator. The amplitude of the oscillation is indicated by a micro-ammeter. As the wood absorbs power from the oscillating field, the amplitude of oscillation is reduced, which results in reduced meter current. Because of the correlation between moisture and power loss factor, the meter can be related to percentage of moisture content. The calibration is empirically related to the average density of a given species of wood. Readings should be taken near the middle of the widest surface at least 500 mm (20 in) from the end of the specimen.

Advantages and Limitations

Dielectric type moisture meters are relatively easy to use. The useful range of the measurement of moisture content is from 0 to 25 percent. Measurements are less accurate, however, when moisture gradients exist in the wood since they are very sensitive to surface moisture. The accuracy of readings can be affected by: (1) calibration of the meter, (2) the species of wood being tested, (3) temperature, (4) operator skill, (5) chemicals in the wood, (6) specimen thickness, (7) moisture distribution, and other factors. Species and temperature correction factors must be applied if the species or temperature of the test sample are different from those of the material used for calibrating the meter. Treatment of the wood with salt preservatives or fire retardants, or long time exposure of the wood to seawater, will give unreliable meter readings.

REFERENCES - 6, 7, 8

B. Test Method - *Resistance-type Moisture Meter*

Material - Wood

Parameter - Moisture Content

Discussion

Generally, resistance-type moisture meters are portable, battery operated, wide-range ohmeters. The meters are of a direct reading type, calibrated for one species of wood with correction tables provided for other species. For the resistance-type meter, penetration of the wood specimen by metal electrodes is necessary to measure its electrical resistance. The method of contact must be reproducible to provide consistent and meaningful results. The points of contact are pin-type electrodes that penetrate the surface of the specimen to a specified depth. The most common types of electrodes are: two-pin, four-pin, and insulated-pin. The insulated pin is useful because it allows testing of lumber that has a high superficial moisture content (such as is caused by rain or dew). One of the major differences between the electrode types is the depth of penetration. The four-pin penetrates approximately 8 mm (5/16 in), the two-pin penetrates approximately 25 mm (1 in), and the insulated pin penetrates approximately 25 - 76 mm (1-3 in). Two nails may also be used for electrodes and calibration data for two-pin electrodes applied. Measurements on wood 6 mm (1/4 in) or less in thickness are made with an electrode consisting of approximately 6 to 12 short fine needles. Readings should be taken near the middle of the widest surface at least 500 mm (20 in) from the end of the specimen.

Advantages and Limitations

The instruments are relatively simple and rugged, and are especially useful for in-situ evaluation of structural wood members. The useful range of the resistance-type moisture indicator is from approximately 7 to 30 percent moisture content with an accuracy of ± 10 percent. Electrolytes from preservatives or fire retardants can produce erroneous readings, and this can be a serious limitation to its use. It should be realized that meters read only the wettest material in contact with the electrode. Thus, an uninsulated pin type test on wood with a high surface moisture content would give misleading readings. Species and temperature corrections must be applied if the species or temperature of the test sample are different from those of the material used for calibrating the meter. Needle type electrodes must be used (surface contact electrodes are not useable). Insulated electrodes are preferred because of the possibility that unknown moisture gradients may exist in the wood.

REFERENCES - 6, 8

C. Test Method - *Electrical Resistance Probe*

Material - Wood

Parameter - Moisture Content

Discussion

An electrical resistance probe has been developed by the U.S. Forest Products Laboratory using wooden elements as the moisture sensor. The principle is the same as for the other types of resistance measuring devices but the probe construction is unique. The probe consists of a rectangular element of wood having two of its opposite faces coated with an electrically conductive silver paint. Two silver painted electrodes are connected to a resistance-type moisture meter by two lead wires and measurements are taken based on the principle that the electrical resistance between the two electrode faces changes in response to change in moisture and temperature. The probe can be calibrated and located in remote areas and wired back to the meter for readout.

Advantages and Limitations

The wooden probe offers the advantage of reflecting the temperature and relative humidity conditions which influence the moisture content of the wood products to which it is placed. The probe will seek equilibrium of the material nearby and long-term moisture content changes can be indicated by remote means. It can operate over a moisture content range from 7 to 35 percent. The major application for this type of probe has been in research involving in-situ evaluation of structural wood members. These probes often show substantial long-time drift, hysteresis, and slow response to changing conditions.

REFERENCE - 9

2.2.4 Miscellaneous Tests

A. Test Method - *Ultrasonic and Impact-induced Longitudinal Wave Pulse Velocity Equipment*

Material - Wood

Parameter - Mechanical Strength, Defects and Decay, Density, Modulus of Elasticity.

Discussion

This test method operates on the principle that discontinuities (as well as other factors which affect modulus of elasticity) in wood will attenuate the velocity of longitudinal wave propagation through it. Major variations in the velocity at various time intervals would indicate irregularities in the wood such as knots, cracks, voids, etc. (This has not been quantified in practice.) The apparatus measures transmission time of longitudinal wave pulses from one piezoelectric transducer to another, both are attached to opposite surfaces of a piece of lumber. The frequency of the pulse is a function of the commercial equipment and usually varies between 150 and 1,000 kHz. (Frequencies above 500 kHz do not penetrate dry wood well.) The transmission time is translated into an estimate of strength and grade.

Advantages and Limitations

The properties derived from this test method should be modified for design by considering the influence of size, moisture content, and load duration. A discussion of these adjustments is given in references 13 and 14 (Chapter 6). Certain defects have not been studied enough to know if they can be detected reliably using this test method. The equipment requires specially trained operators. Although it is most applicable as a production-type lumber scanner, it can be adapted for field use. It can sense defects in boards and laminated beams up to 51 mm (2 in) thick and has a potential for locating surface and internal defects in lumber of all species, green or dry, and rough-sawn or surfaced.

REFERENCES - 2, 5, 10, 11, 12, 13, 14

B. Test Method - *Stress Wave Propagation Equipment*

Material - Wood

Parameter - Strength, Modulus of Elasticity, Presence of Mechanical Flaws and Decay

Discussion

This test method is based on the principle that the velocity of stress waves through a material depends on the density of the material and increases as density increases. Voids and decay in wood cause a reduction in the velocity as compared to the velocity in a healthy, denser, wood.

Stress wave propagation testing is somewhat similar to the ultrasonic vibrational method in that it is a dynamic test, but the frequency of excitation is approximately 1,000 times higher than the sonic vibration methods. The modulus of elasticity, E, is calculated by measuring the period of time that it takes a stress wave to cover a given distance in the wood (wave velocity, C), measuring the density, ρ, and applying this equation of approximate relationship:

$$E = \rho C^2$$

The simplified test procedure is as follows: (1) a high frequency stress wave is induced on a wood sample by an excitor mechanism, (2) the propagation time of the stress waves is measured between two electron sensors that are a standard distance apart, (3) the piece of lumber is weighed to determine its density, and (4) test results are entered in the equation and a value of modulus of elasticity is determined. The modulus of elasticity then can be interpreted further into strength properties and grade of the wood.

The modulus of elasticity assigned to a grade is intended to be an average value for that grade. Stress grading machines can be adjusted so that the modulus of elasticity for a grade varies less than it would in a visual stress grade. It has been demonstrated that strength ratio and modulus of elasticity used together provide a more efficient strength prediction than either by itself. Two types of stress waves are useful for grading lumber, namely: 1) the longitudinal stress wave induced in the end of a piece of lumber, and 2) the flexural wave. Research on dry wood indicates that the longitudinal stress wave typically yields a higher estimate of E than the flexural stress wave. Although the various techniques yield somewhat different values of elasticity, the moduli determined with dry lumber have been shown to correlate well.

Advantages and Limitations

The propagation of the stress waves is influenced by the mechanical and physical properties of the timber sample and somewhat by the shape of the piece. The cited equation for stress wave analysis generally assumes the medium to be isotropic and homogeneous, which is misleading--due mainly to natural inconsistencies in the wood. It has been found that the modulus of elasticity decreases with increasing moisture content up to fiber saturation, which is about a 25 percent moisture content. Thus, a false value of elastic modulus could be evident for data taken on wood above fiber saturation. It is necessary to consider this in interpreting results since moist wood could produce a short stress wave time, even though voids or decay might be present. The electronic measuring equipment is very sensitive and has been refined to the point of measuring only the wave movement pertinent to the needed results. The properties derived from mechanical stress grading criteria should be modified for design by considering the influence of size, moisture content, and load duration. A discussion of adjustment factors is given in references 13 and 14 (Chapter 6). Modulus of elasticity calculated from the basic longitudinal stress wave formula is much more dependent on moisture content than E calculated from the basic flexural stress-wave formula. The longitudinal stress wave method of stress-grading may overestimate the static E of incompletely dried lumber. More importantly, when used to grade on the basis of stress-wave speed over short spans, it may cause dry lumber containing wet pockets to be downgraded. Flexural wave stress grading may also be affected by wet pockets, depending on their position as well as their moisture content. The device can be used in relation to either calibrated standards or a heavy degree of technical interpretation. Lightweight, low-cost units are available. The test usually requires two persons to operate the equipment. One of them should be knowledgeable about the pathology of decay in wood and should understand the stress wave technology well enough to know when the readings are appropriate to the known conditions and be able to determine the properties of normal wood. Although this test is most applicable as a production-type lumber scanner, it can be adapted for field use.

REFERENCES - 2, 5, 13, 15

C. Test Method - *Oven-dry Test*

Material - Wood

Parameter - Moisture Content

Discussion

For this test method, the moisture content of a wood sample is calculated from weight values obtained before and after drying it in an oven which is maintained at 103 ± 2°C (217.4 ± 3.6°F).

To conduct the test, a full cross-section specimen is cut or core drilled from the host sample so that it is no less than 25 mm (1 in) along the grain, or longer as needed to provide a minimum volume of 33 cm^3 (2 in^3). The specimen is weighed immediately after cutting (or protected in a vapor-tight container until it can be weighed). Weighing must be to an accuracy of ± 0.2 percent. The maximum delay for weighing after cutting is 2 hours. Then the specimen is dried in the oven until it reaches a constant weight and is weighed again after removal from the oven. The moisture content then is calculated in percent as $[(A-B)/B] \times 100$, where A = original weight and B = the oven dried weight.

Advantages and Limitations

The greatest advantage to this test method for measuring moisture content in wood is its accuracy and time-tested reliability. Accurate results can be expected at all levels of moisture content. The major disadvantage is that it must be performed in a testing laboratory (not on-site).

REFERENCE - 8

D. Test Method - *Radiography*

Material - Wood

Parameter - Grain Direction, Internal Discontinuities, Moisture Content

Discussion

Radiography is the imaging of a radiation beam that has passed through an object under study. The test is based on the principle that radiation attenuation is caused by density variations in the test specimen. In the case of wood, it can be used effectively to determine changes in grain direction (as around knots and other irregularities), to detect internal discontinuities and gross density variations (such as, mineral streaks, decay, insect damage, splits, etc.), and detect changes in moisture content. It also can be used for "mapping" studs, joists, bracing, posts, and other structural elements of a wood frame building for the purpose of determining the strength of wall or floor systems.

To conduct the test, x-ray radiation is emitted from a source (e.g., x-ray tube, radioactive isotope, etc.), penetrates the specimen, and exits the opposite side of the specimen where it is recorded on a sensitive film as a radiograph (picture) or viewed on an electro-optical imager (screen). Voids or relatively low-density areas of the specimen allow a relatively higher rate of passage of the radiation which will appear as dark indications on the film (as compared to the relatively lighter background). Areas of higher density will provide the opposite effect on the film.

Generally speaking, the energy level used for x-radiation should be the lowest consistent with a reasonable exposure time. This allows detection of small changes in the test material thickness or density.

Advantages and Limitations

Radiographic evaluation techniques offer the advantage of providing a permanent record of the condition of wood specimens on film or a "live" image on an electro-optical system for greater speed of evaluation. Equipment for x-ray inspection of wood is available which is lightweight and readily portable. The test is relatively easy to perform. Radiographic sources are harmful to organic tissue, so the test environment must be shielded (or isolated) as necessary to prevent radiation hazards. Drawbacks to the use of radiographic evaluation equipment are the high initial cost of the equipment and the film, the time delay necessary to develop the film, and the requirement that access to both sides of the test specimen is necessary to set up and use the equipment.

For inspection material thicknesses up to 12.7 mm (1/2 in), thickness variations of about four percent are detectable. But, for thicknesses of 25.4 mm (1 in) or more only thickness variations of 10 percent or more are detectable.

REFERENCES - 17, 18

2.2.5 References

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2.3 METALS

2.3.1 Nondestructive Evaluation of Metals

Unlike bridge structures which are subjected to cyclic loadings, buildings generally are subjected to static loads (except for such conditions as seismic disturbances and vibrational loadings due to mechanical equipment). Consequently, flaws (such as cracks) in structural steel components of the building generally are not subject to progression from fatigue, and it may not always be critical to evaluate them. If, however, it has been determined that a structural component (a weldment, a splice plate, etc.) is suspect of degrading the structural integrity of the building, nondestructive evaluation methods can be extremely useful to evaluate the component. On the other hand, it is important to evaluate flaws other than cracks (such as corrosion, voids, pits, fabricating discontinuities, porosity, etc.).

Most NDE methods offer more than just a superficial examination of the surface conditions of metals. It now is possible to reveal facts concerning overall properties, quality, and dimensions of both the surface and the internal regions of many metal test specimens.

Although nondestructive evaluation is used primarily on structural steel, some of the evaluation methods available are applicable to other types of ornamental and structural metals (e.g., cast-iron, aluminum, etc.) as indicated in Table 4 under the column heading "Typical Applications."

The following is a list of factors to consider in selecting the appropriate test method to use:

1) What is the material to be tested?
    a. Is it magnetic or nonmagnetic?
    b. Is it electricity conductive?
    c. Does the metal have a nonconductive or nonmagnetic coating?

2) By what method was the metal fabricated (cast, wrought, powder metallurgy, welded, soldered, etc.)?

3) What is the geometry of the metal (surface condition, thickness, and shape, etc.)?

4) What types of defects are possible or expected such metal?

5) What degree of sensitivity and resolution is required from the test equipment?

6) What costs are involved?
    a. How much does the equipment cost?
    b. What are the operating and material costs of conducting the test?

7) Accessibility of the metal (e.g., behind a wall, pipe, or wiring, concealed by ductwork).

Table 4 indicates the most commonly used NDE methods for testing metals, cites examples of typical applications with their advantages and limitations, and describes the appropriate materials on which the test is used. A more detailed description of several of the most commonly used NDE methods follows.

<u>REFERENCES</u> - 1-12

TABLE 4. TEST METHODS FOR METALS

METHOD	PRINCIPLE OF OPERATION	PROPERTIES SENSED OR MEASURED	DEFECTS DETECTED	TYPICAL APPLICATIONS	ADVANTAGES	LIMITATIONS
Visual/ Optical	Special devices (borescopes, fiber optics, panoramic cameras, etc.) can be used to examine surfaces inaccessible to the naked eye. Magnifiers can be used to detect flaws too small to be seen by the naked eye.	Material characteristics open to a surface.	Surface flaws (cracks, voids, holes, gouges, fabricating discontinuties, corrosion, pits and other irregularities).	Surfaces of all metals.	Permits examination of hidden surfaces (if access is available).	Detects only defects visible to the eye. Limited to detection of surface flaws only.
Liquid Penetrant	Liquid penetrant containing dye is drawn into surface defects by capilliary action.	Material separations open to a surface.	Surface cracks, laminations, poor bonding, gouges, porosity, laps, seams, stress cracks, fabricating discontinuties.	Used on non-magnetic metals. Used with casting, forgings, weldments, and components subject to fatigue or stress-corrosion cracking.	Allows inspection of complex shapes in one single operation. Inexpensive. Easy to apply. Portable.	Will detect only defects open to the surface. It is messy. Irrelevant indications occur. Results are dependent on operator's ability to interpret results. Temperature of specimen, penetrant drain time, emulsifier soak and drain time, drying temperature, and developing powder dwell time must be controlled carefully to get true indications.

TABLE 4 (Continued) TEST METHODS FOR METALS

METHOD	PRINCIPLE OF OPERATION	PROPERTIES SENSED OR MEASURED	DEFECTS DETECTED	TYPICAL APPLICATIONS	ADVANTAGES	LIMITATIONS
Ultrasonic[1]	Vibrations above 20,000 Hz are introduced into metal sample. Waves are reflected or scattered by discontinuities.	Anomalies in acoustic impedence.	Cracks, voids, porosity, laps, segregated inclusions, poor brazing or bonding. Will detect both surface and subsurface defects.	Thickness gaging. Material inspection of castings, forgings, and extrusions. For all metals.	Locates small discontinuties. Portable. Instant results. Accurate measure of thickness.	Sensitivity is reduced by rough-surfaced parts. Odd-shaped pieces are hard to analyze. Requires skilled operator. Depends on operator's ability to interpret results and on orientation of the defect. Must couple transducer to surface of specimen carefully.
Magnetic Particle[2]	Magnetic particles are attracted to magnetic lines of leakage force and where breaks in the lines of force occur.	Anomalies in magnetic field flux at surface of test sample.	Cracks, seams, laps, voids, porosity, and inclusions.	Surface and slightly subsurface inspection of parts sensitive to magnetization.	Simple, inexpensive, senses flaws down to 1/4 inch below surface as well as surface flaws.	Not applicable to non-magnetic metals or materials. It is messy. Careful surface preparation is required. Irrelevant indications often occur. Depends on the operators ability to intepret results. Demagnetization after inspection may be necessary.

[1] See page 61 for more information.
[2] See page 65 for more information.

TABLE 4 (CONTINUED) TEST METHODS FOR METALS

METHOD	PRINCIPLE OF OPERATION	PROPERTIES SENSED OR MEASURED	DEFECTS DETECTED	TYPICAL APPLICATIONS	ADVANTAGES	LIMITATIONS
X-ray[1] or Gamma ray	The attenuation of x-rays is affected by the density of the test specimen. Voids, or low-density areas show as dark indications on the x-ray film.	Inhomogeneities in thickness, density, or composition.	Voids, porosity, inclusions, and cracks.	Used on castings, forgings, weldments, and assemblies to check for fatigue, thickness gauging, internal flaws, etc. For all metals.	Detects both internal and external flaws. Portable. Provides a permanent record on x-ray film.	High cost. Heavy. Health hazard. Not sensitive to defects less than about 2% of the total thickness of the specimen. Complex shapes are difficult to analyze.
Eddy[2] Current	The impedance of a probe coil is measured constantly. The coil is placed in contact with the metal specimen. The coil impedance changes in direct relationship with the specific material properties and constituent variations.	Anomalies in electric conductivity and, in cases, magnetic permeability.	Surface finish, discontinuities, dimensions, cracks, seams, variations in alloy composition or heat treatment.	Used to evaluate condition of wire, tubing, local regions of sheet metal and alloy sorting. Used for thickness gauging. For electrically conductive or magnetically permeable metals.	Moderate cost. Readily automated. Portable. Permanent record available if needed. Can be adapted to many comparative analyses.	Useful on conductive materials only. Shallow penetration. Reference standards often are necessary. No absolute measurement-only qualitative comparison.
Coupon[3]	Stress-strain relationship. Tension or compression tests.	Stress-strain.	Yield strength, yield point, tensile strength, elongation, modulus of elasticity, compressive strength.	Die castings, forgings, structural shapes, malleable iron, powdered metals.	Gives fast, accurate results of physical and mechanical values.	Test is destructive since a sample must be removed to be tested.

1 See page 63 for more detail.
2 See page 64 for more detail.
3 See page 68 for more detail.

Test Method - *Ultrasonic Pulse Velocity*

Material - Metal

Parameter - Internal Flaws (Depth of cracks and their rate of propagation, non-bonds, inclusions, corrosion, interfaces, etc.).

Discussion

Detecting flaws in metal by the use of ultrasonics is based on the principle that the velocity and amplitude of vibrational waves of acoustic energy propagated through a test specimen are affected by the elastic properties of the material being tested. To conduct the test, an ultrasonic pulse is generated by an electroacoustic transmitting transducer and is received by a receiving transducer. The pulse is amplified and its amplititude is displayed for analysis on a cathode-ray oscilloscope. If the wave of acoustic energy encounters a discontinuity in the test material (such as a crack or a void), it will be diffracted around the discontinuity thus increasing the distance and time of its travel from the transmitting transducer to the receiving transducer (which, in turn, decreases its amplitude). Therefore, all other conditions being constant, the travel time of the wave in sound material will be less than that for a material containing discontinuties.

There are three commonly used methods of introducing ultrasound into a specimen:

1) STRAIGHT BEAM (uses longitudinal waves)

   The transducer is placed directly on a specimen and sends a straight perpendicular beam of acoustical energy into it. Signals appear on the cathode ray tube (CRT) at the receiving transducer end (on the far end) which can be read and interpreted by an experienced evaluator. Any flaws large enough to intercept the sound beam will show as abnormal patterns on the CRT. Detection of defects may be either by the pulse-echo method or by the through transmission method. In the pulse-echo method, a transducer emits short pulses of sound and receives the reflections of these pulses resulting from discontinuities in the intervals between pulse emissions. For the through transmission method, two transducers (a transmitter and a receiver) are positioned on opposite sides of the specimen. Any significant reduction in amplitude of the signal received is an indication of the presence of flaws. If no signal is received, this is an indication that the flaw is large enough to block the sound beam completely. This two-transducer method is used where the shape or internal condition of the specimen does not allow the reflection of the beam back to the same transmitting transducer.

2) ANGLE BEAM (uses transverse waves)

   The transducer is mounted on an angle which causes the sound to bounce through the specimen until it strikes a flaw and reflects back to the transducer. This is used on specimens where mounting the transducer directly above the flaw is impractical. The CRT display is similar to the display produced by the straight beam method mentioned above.

3. SURFACE-WAVE (uses Rayleigh or Lamb waves)

When the transducer is mounted so that the angle of the sound emission is about 63° to the surface of the test material, all of the ultrasonic energy that enters the specimen does so as surface waves (which penetrate only to a depth of about one wavelength). Therefore, this method is useful only for detection of surface or near-surface discontinuities. An advantage to the use of this method is that surface waves will follow the contour of the test specimen.

Advantages and Limitations

Ultrasonic testing is one of the most popular nondestructive test methods for metal evaluation available today for many reasons, some of them are:

1) High sensitivity permits detection of defects about the size of a wavelength.

2) Ultrasound can penetrate thick materials and measure thickness.

3) It can determine position and approximate size of internal defects with accurate and fast readout of results .

4) It can be used with automated testing equipment.

5) It allows specimen testing when only one side is accessable.

6) There are no major hazards to personnel which require special shielding for safety.

7) It is portable and versatile.

8) It is well suited for detection of laminar type defects that are oriented perpendicular to the energy beam.

Ultrasonic waves do not travel through air effectively. Therefore, a liquid coupling material (such as oil, grease, or glycerine) must be used between the search unit and the test specimen. In immersion testing, a few inches of water is used between the search unit and the specimen.

Certain test conditions may limit the effectiveness (or prohibit the use) of ultrasonic testing; the most common of which are: 1) unsuitable geometry, and 2) unsuitable internal structure of the test specimen. Specialized training of an operator to interpret the results of this test is required, which makes the test very operator dependent.

Standard calibrated reference blocks must be used to determine operating characteristics of the instruments and transducers to established reproducible test conditions.

REFERENCES - 1, 6, 7, 10, 11, 12

Test Method - *Radiographic Evaluation (X-ray)*

Material - Metal

Parameter - Internal structure and thickness of metal.

Discussion

X-ray evaluation techniques are based on the principle that x-ray attenuation is affected by the density, chemical composition, and thickness of the test specimen. Equipment of various types is available for x-ray evaluation. The main ones use photographic emulsion, fluorescent screen, semiconductor conduction values, ionization of a gas or an electron multiplier (or combinations thereof) as the means of detection of the test parameters. Selection of the particular equipment to be used is affected by the following factors:

1) Density and thickness of the test specimen.
2) Number of radiographs required per unit of time.
3) Geometry of the material.
4) Whether the test specimen can be brought to the test equipment or must be conducted in place.

In nondestructive testing of the quality of metal materials, x-rays are used mainly to: 1) inspect for interior soundness; 2) to locate porosity, slag inclusions, incomplete penetration, cracks, icicles, burn-throughs, and other defects in welds; and 3) to detect defects within castings, pressings, and worked or formed metallic parts. Voids measuring 0.5 to 1.0 percent of the thickness of steel or aluminum alloy can be detected when using this technique of nondestructive testing under carefully controlled conditions; however, sensitivities of two percent are relatively easy to obtain and are used as the commonly accepted minimum variation.

Advantages and Limitations

X-rays offer the advantage of providing a high resolution picture on a permanent record (film) or a "live" image on an electro-optical imaging system. It is especially useful for detection of laminar type defects if they are parallel to the energy beam. Since the equipment is heavy and costly, it is used mainly in laboratory evaluations. X-ray sources are harmful to organic tissue, and the test environment must be shielded (or isolated), as necessary, to prevent radiation hazards. Another drawback is the high initial cost of the equipment and film, the time delay required to develop the film, and the requirement that access to both sides of the test specimen is necessary to conduct the test. The user should be aware that there are many films from which to choose; careful selection must be made of speed and resolution in order to obtain the desired results. The entire process of selecting the equipment, operating the equipment, and interpreting the test results requires a high degree of technical training.

REFERENCES - 1, 6, 8, 9, 10, 11, 12

Test Method - *Eddy Current*

Material - Metal

Parameter - Surface Flaws, Variation in Alloy Composition or Heat Treatment

Discussion

Eddy current testing is one of the most widely used of nondestructive testing methods. The test is based on the measurement of changes in the impedance of a coil due to changes in the flow of eddy currents induced in a conductor. Test material properties and constituent variations that affect the flow of the induced eddy currents sufficiently can be detected, measured, and analyzed. The basic properties of conductors that influence eddy currents are 1) electrical conductivity, 2) magnetic permeability, 3) mass, and 4) discontinuities.

Since so many factors affect the flow of the induced eddy currents, this test method can be applied to a wide variety of test situations. Typically, it is used for thickness gauging; flaw detection; measuring coating thickness; alloy sorting; monitoring hardness, grain size and heat treatment; and evaluating the condition of wire, tubing, local regions of sheet metal, and welded pipe.

The basic operation is as follows:

1. A signal (10 to 250 kHz) is generated by a variable oscillator and is applied through a modified Wheatstone bridge to a coil which is placed on a sound piece of material similar to the one being investigated.

2. The bridge is balanced.

3. When the coil is passed over a discontinuity of the test specimen, a change occurs in the impedance of the coil due to the effect of induced eddy currents. This unbalance is recorded on a microampere meter.

Many types of probes are used with eddy current testing equipment depending on the application. In some cases multiple coils are even used. For example, when used for detecting surface discontinuities in ferromagnetic materials, two driving coils are arranged around the pickup coil in the probe.

Advantages and Limitations

The advantages of using this test method are 1) high speed, 2) moderate cost, 3) it is readily automated, 4) the equiment is easily portable, 5) a permanent record can be obtained of the test results if needed, 6) the equipment is simple to operate, and 7) it can be adapted to many comparative analyses. Limitations to its use are 1) it is useful only on electrically conductive or magnetically permeable metals, 2) it has a shallow penetration, 3) the use of reference standards is essential, but, unfortunately, no generally accepted standards are available for ferromagnetic materials to establish the relationship between physical properties and the eddy current data, 4) only a qualitative comparison is possible rather than giving absolute measurements of the flaws, and 5) because eddy currents are distorted at the edge or end of a test specimen, it normally is not practical to inspect flaws any closer to the edge than 1/8 inch. Practical experiments have shown that a fairly good correlation between eddy current data and actual crack depth in ferromagnetic materials is available only up to approximately 0.6 mm (0.025 in) maximum depth. The test normally is not used to detect discontinuities deeper than 6 mm (0.25 in).

REFERENCE - 1

Test Method - *Magnetic Particle*

Material - Metal

Parameter - Surface and Subsurface Discontinuities

Discussion

The magnetic particle test is a convenient in-situ method of detecting surface and subsurface discontinuities in metals. To perform the test, an electrical current is used to induce a magnetic flux into a specimen which then produces a patterned magnetic field in the specimen. An indicator made of colored magnetic particles is applied to the test specimen where they form visible patterns around the discontinuities according to the magnetic leakage fields formed by the discontinuities.

The surface indicator buildups which are caused by surface discontinuities are thin and sharp, while buildups near subsurface discontinuities appear broad and less well defined.

Various types of electrical currents are used to produce the magnetic fields. Table 5 summarizes them and describes their uses, advantages, and disadvantages.

Table 5

TYPES OF MAGNETIZING CURRENTS USED IN MAGNETIC PARTICLE TESTING

Current	Use	Advantages	Disadvantages
Alternating Current (ac)	For detecting surface discontinuities.	Gives best sensitivity for detecting surface discontinuities. Relatively easy to demagnetize. No penetration of flux into specimen. Best for detecting fatigue cracks in ferrous structural members. Particle mobility is good.	Inefective for detection of subsurface discontinuities.
Direct Current (dc)	For detection of both surface and subsurface discontinuities. Best used mainly for subsurface.	Penetration of flux into specimen permits detection of subsurface discontinuities.	Must use a fixed voltage. Battery maintenance is required. Difficult to demagnetize.
Half Wave Rectification (HWAC)	For detection of surface and subsurface discontinuities. Most sensitive for subsurface discontinuities.	High flux density. Full penetration into specimen permits detection of subsurface discontinuities. Some ac equipment can be converted by adding a rectifier and switch. Particle mobility is good.	

There are many means for inducing a magnetic flux into a specimen and producing a magnetic field, all of which are discussed in detail in reference [1] for the reader who desires to learn more. Suffice it to say here that the means should be selected to meet best the application and the nature of the nature of the discontinuity to be detected.

The indicator particles are made of carefully selected magnetic materials of the proper size, shape, permeability, and retentivity. Two classes of magnetic particles are available for use with this inspection method - the wet method particles and the dry method particles. Wet method particles use a liquid vehicle, and dry method particles are borne by air. Particles used in the wet method are suspended in oil or water and are available as a powder or thick paste colored either black, red, or fluorescent. Fluorescent particles must be viewed under a "black light" in a darkened room. Particles used in the dry method are in the form of a dry powder in red, black, or gray color. In all cases, color is chosen to give the best contrast on the metal specimen being inspected. The powder is sprayed gently and evenly onto the metal surface where it is free to be influenced by the magnetic leakage field and to form indications of the discontinities.

The advantages to using this test method are:

1. It is relatively inexpensive.
2. It provides instant results.
3. It is portable.
4. It is easy to use with little training.
5. It is sensitive to surface cracks.
6. It is a nondestructive test method.

Limitations to its use include:

1. It requires external power supply.
2. It is limited to use on ferrous materials.
3. The evaluator must have a thorough knowledge of the test and be able to evaluate and record test results with accuracy.
4. Sharp, angular types of discontinuities are more easily found than round or streamlines types.
5. Surface discontinuities are more easily found than those located below the surface.
6. Retained magnetic fields hinder cleaning of the specimen.
7. The specimen may require demagnetizing after the test.
8. Wet particles are best suited for detection of fine surface cracks (such as fatigue cracks).
9. Dry particles are most sensitive for detecting subsurface defects and usually are used with portable equipment.
10. Some surface preparation is needed.
11. Coatings can affect the ability to magnetize the specimen.

<u>REFERENCE</u> - 1

2.3.2 Destructive Evaluation of Metals

When evaluating metal structures to determine their ability to perform well in a rehabilitation situation, the most important material properties to determine are:

1. Yield strength.
2. Yield point.
3. Tensile strength.
4. Elongation (ductility).
5. Modulus of elasticity.
6. Compressive strength.

Using destructive methods of tension or compression testing of samples, known as coupons, these properties are determined as follows:

Tension Testing	Compression Testing
Yield strength	Yield strength
Yield point	Yield point
Tensile strength	Modulus of elasticity
Elongation (ductility	Compressive strength (for some materials)

Test Method - *Coupon Test*

Material - Metal

Parameter - Strength, Ductility, Modulus of Elasticity

Discussion

To perform the coupon test, a test sample (known as the coupon) is removed from the metal being evaluated and is tested for the important material properties mentioned above.

The test machine must conform to the requirements of ASTM (Methods E 4), Verification of Testing Machines.

Test procedures for tension or compression testing of coupons are described in "Standard Methods of Tension Testing of Metallic Materials," ASTM E 8, and "Standard Methods of Compression Testing of Metallic Materials at Room Temperature," ASTM E 9, American Society for Testing and Materials, (1977). The tests are applicable for use on 1) die castings, 2) forgings, 3) structural shapes, 4) malleable iron, and 5) powdered metals. Coupon shapes can include:

1. Plate-type specimens.
2. Sheet-type specimens (sheet, plate, flat wire, strip, band, hoop, rectangular, etc.).
3. Round specimens.
4. Rectangular bars.
5. Pipe and tube shapes.

The test coupons can be substantially full size or machined, as prescribed in the product specifications for the material being tested. The shape of the ends of the specimen outside the gage length must be suitable to the material and must be of a shape to fit the holders or grips of the tension testing machine so that loads are applied axially. Figures 1 through 5 of ASTM E 8 describe gripping and snubbing devices used with tension testing equipment, while Figures 6 through 9 describe the shapes and dimensions to be used for tension coupons. Similarily, a description of coupons and jigs used for compression testing is provided in Tables 1 and 2, and Figures 1, 2, 3, and 4 of ASTM E 9.

Location of Coupons

Coupons are taken from locations in the metal material to be tested; and, generally, the axis of the coupon is located as follows:

A) At the center for products 38 mm (1 1/2 in) or less in thickness, diameter, or distance between flats.

B) Midway from the center to the surface for products over 38 mm (1 1/2 in) in thickness, diameter, or distance between flats.

C) For forgings, specimens are taken either from the predominant or thickest part of the forging; or, coupons may be forged separately as representative samples of the forging being evaluated. Unless otherwise specified in the applicable product specifications, the axis of the specimen should be parallel to the direction of grain flow.

Surface Finish for Coupons

Particular attention has to be given to the uniformity and quality of surface finishes of specimens for high strength and very low ductility materials since they can cause variation in test results. Surface finish of the coupons is described in applicable product specifications.

Procedures for Performing Test

Procedures for preparing and measuring test specimens and for conducting tension or compression tests are described in paragraph 5 of ASTM E 8 and paragraphs 5, 6, and 7 or ASTM E 9, respectively, and include a description of the speed of testing (rate of separation or closure of heads, total elapsed time, rate of stressing and straining, etc.).

Stress-strain diagrams for determining yield strength and yield point are provided in Figures 20 through 22 of ASTM E 8, and Figure 5 of ASTM E 9 for tension coupons or compression coupons, respectively.

REFERENCES - 13, 14

2.3.3 References

1. "Nondestructive Testing," reference manual for a home study and extension course, by the American Society for Metals, the American Society for Nondestructive Testing, and the Metals Engineering Institute, Metals Park, Ohio, (1972).

2. "Fundamentals of Nondestructive Testing," by the American Society for Metals and the American Society for Nondestructive Testing, reference manual for an extension course by the Metals Engineering Institute, Metals Park, Ohio, (1979).

3. DiGiacomo, G., Crisci, J.; and Goldspiel, S.; "An Ultrasonic Method for Measuring Crack Depth in Structural Weldments," MATERIALS EVALUATION, September 1970, Vol. XXVII, No. 9.

4. Dick, P., "Introduction to Nondestructive Testing," General Electric Company, written for the Metals Engineering Institute, (1922), page 1.4.

5. "Nondestructive Inspection and Quality Control," Metals Handbook, 8th Edition, Vol. II, American Society for Metals, Metals Park, Ohio, (1976).

6. McMaster, R. C., Ed., "Nondestructive Testing Handbook," Ronald Press, New York, (1959).

7. Krautkramer, J., Krautkramer, H., "Ultrasonic Testing of Materials," Springer-Verlag, New York, 2nd Ed., (1969).

8. Halmshaw, R., Ed., "Physics of Industrial Radiology," Heywood Books, London, (1966).

9. "Radiography in Modern Industry," Eastman Kodak Co., Rochester, New York, 3rd Ed., (1970).

10. McGonnagle, W. J., "Nondestructive Testing, Pergamon Press, New York.

11. Sharp, R. S., Ed., "Research Techniques in Nondestructive Testing," Academic Press, London, (1970), (1973), (1976), (1980).

12. Vary, A., "Nondestructive Evaluation Technique Guide," National Aeronautics and Space Administration, Washington, D.C., (1973).

13. "Standard Methods of Tension Testing of Metallic Materials," ASTM E 8, American Society for Testing and Materials, (1977).

14. "Standard Methods of Compression Testing of Metallic Materials at Room Temperature," ASTM E 9, American Society for Testing and Materials, (1977).

2.4 MASONRY

2.4.1 General

Since many existing buildings being considered for rehabilitation are constructed of masonry, it is important to know how to evaluate the condition of the masonry and to determine whether it is capable of supporting the loads imposed by the retrofit or rehabilitation work. This is especially true of load bearing masonry assemblages which are expected to support new heavy dead or live loads.

Several nondestructive evaluation methods have been used with various degrees of success to determine the physical properties of masonry units and mortar. However, these test methods have limited application and generally provide information only on the physical make-up of the masonry (continuity, location of voids, reinforcement, etc.). In only one case (low frequency ultrasonics) can an estimate of compressive strength can be obtained (by experienced operator's and evaluators), but it is prohibitively expensive to use in routine investigations. One manufacturer claims to be making progress in the development of a penetration device known as the Densicon Penetrometer which is based on the same principle as the Windsor Probe for concrete evaluation, and it might become an accepted test for measuring surface hardness (from which it may be possible to estimate strength). As of this time, definite conclusions concerning its effectiveness can not be drawn by the authors.

In contrast to the limited choice and undetermined reliability of nondestructive methods for evaluating in-situ strength properties of masonry, there are a large number of more thoroughly developed methods available for this purpose which are termed destructive or which require testing other than in-situ. Depending on the user's need for information, the practicality of performing these tests, funding availability, etc., these may be particularly applicable in rehabilitation projects.

To allow the reader the opportunity of selecting the most appropriate test, Table 6 shows a reasonably complete listing, and summary description, of the commonly used nondestructive and destructive test methods available to evaluate masonry. Test methods are grouped in the table according to the parameter being tested. A more complete reference list follows the table of commonly used evaluation methods. The reader's attention also is directed to two destructive methods which were described previously in the concrete section 2.1.2 of this report which are particularly applicable to masonry: 1) core testing, and 2) petrographic analysis.

REFERENCE - Fattal, S. G., and Cattaneo, L. E., Evaluation of Structural Properties of Masonry in Existing Buildings, NBS BSS 62 (Washington, D.C.: National Bureau of Standards, March 1977), 127 pages.

TABLE 6 TEST METHODS FOR MASONRY

MATERIAL	TEST PARAMETER	TEST METHOD	COMMENTS	REFERENCE
Masonry Assemblages (Units and Mortar)	Flexural Bond Strength. Brick sampled and tested per ASTM C 67. Concrete sampled and tested per ASTM C 140. Mortar selected and tested per ASTM C 270 and ASTM C 518.	Use either the third point loading method or air bag. Specimen is loaded as a simply supported beam and is placed horizontally on its supports in the testing machine.	Testing machine must conform to requirements of Method E 4.	10
	Diagonal tensile or shear strength.	Masonry assemblages are tested by loading them in compression along one diagonal, thus causing a diagonal tension failure with the specimen splitting apart parallel to the direction of load.	Use a 1.2 x 1.2 m (4 x 4 ft) masonry assemblage. This method eliminates the need for a hold-down force (to prevent rotation of the test specimen) as required in the racking load test prescribed in Methods E 72. Three test specimens should be used.	6, 11
	Modulus of Rupture	Stress test in accordance with ASTM C 67	Used mainly for paving units.	1
	Compressive Strength	Compressive Test in accordance with ASTM C 67, Method E 4.	Use gypsum capping (including rapid-set gypsum).	1, 5
	Water Absorption. Saturation coefficients (for prediction of durability).	Weighing dry and saturated conditions of test sample. Sample is saturated by submersion in boiling water for 5 hours and cold water for 24 hours.	Scale should have capacity of at least 2000 g; and should have a sensitivity of at least 0.5 g for brick or 0.2% of the weight of the smallest specimen for tile.	1
	Freezing and Thawing--resistance to damage.	Repetitive cycles of wetting, freezing, drying, and weighing.	Test is continued through 50 cycles of freezing and thawing unless specimen breaks or loses more than 3% of its original weight as judged by visual inspection.	1

TABLE 6 (Continued) METHODS FOR MASONRY

MATERIAL	TEST PARAMETER	TEST METHOD	COMMENTS	REFERENCE NO.
Masonry (continued)	Size	Visual measurement	Use either a steel metric (or 1 ft) scale, or a gauge or caliper with a scale ranging from 25 to 300 mm (1 to 12 inches) and having parallel jaws. Of no value in determining strength or durability.	1
	Warpage	Visual measurement using a scale or measuring wedge.	Use either a steel metric (or 1 ft) scale or a steel measuring wedge. The wedge shall be numbered to show the thickness of the units. Of no value in determining strength or durability.	1
Ceramic Glazed Facing Tile and Brick	Imperviousness	Permanent blue-black fountain pen ink is applied to the glazed surface of 5 dry specimens for 5 minutes. The surface is washed and examined for stain of the finish.	Of no value in determining strength or durability.	3
	Chemical Resistance	End portion of test specimen is dipped in 1 1/2 inches of a 10% solution of HCL for 3 hours. The opposite end is dipped in a 10% solution of KOH for 3 hours. Finishes are then rinsed, dried, and examined visually for changes in texture or color.	The solution must be maintained at 15 to 27°C (60 to 80°F) temperature. Of no value in determining strength. Could be be useful if certain chemials are anticipated to come in contact with the masonry.	3
Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units	Crazing	Autoclave crazing test. Test specimens are placed in an autoclave with 150 psi steam pressure for 2 to 2 1/2 hours. Specimens then are cooled slowly to room temperature. Then permanent blue-black fountain pen ink is applied to the glazed surfaces and a visual inspection is made to detect crazing.	Cooling should be extended over a minumum of 3 hours. Normal safety precautions should be observed concerning autoclave operation. Of no value in determining strength or durability.	3

TABLE 6 (Continued) TEST METHODS FOR MASONRY

MATERIAL	TEST PARAMETER	TEST METHOD	COMMENTS	REFERENCE NO.
Ceramic Glazed: Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units (Continued)	Opacity	Permanent blue-black fountain pen ink is applied to the test specimens along a 50 mm (2 in) length of the edge of the finished surface. After 5 minutes, the finish is visually examined for opacity.	Of no value in determining strength or durability.	3
Unit Masonry	Leakage (Water Permeance)	The masonry specimen is placed in a spray test chamber which has controlled air pressure. Streams of water impinge against the exposed surface of the specimen at a rate 139 ℓ/m^2 (3.4 gal/ft^2) per hour. The air pressure is raised to 479 Pa (10 lbf/ft^2) above atmospheric pressure. The specimen then is dried and the back (unexposed) face is painted with a thin coating of white wash and the test is repeated (after the white wash dries for a minumum of 24 hours). This final test is conducted for 3 days or until a rating has been attained.	The time for appearance of visible water on the specimen is observed. The rate of leakage is observed; and from this, the water permeance is rated in accordance with ASTM E 514 classification (Class E, G, F, P, or L). This test is used mainly for a comparison of masonry specimens. It is not good for an acceptance/rejection test. Simple modifications make it useful for testing of in-situ masonry walls.	9
Portland Cement-Lime-Sand Mortar and Masonry Cement-Sand Mortar.	Compressive Strength, Water Retention, Air Content, and Efflorescence.	Standard compression tests and water retention tests are used in accordance with ASTM C 91 with exceptions per BIA MI-72. Air content is determined in accordance with ASTM C 231. Efflorescence tendency is determined using the wick test described in BIA Research Report No. 15, Sec. 4.4, p. 14.	Types M, S, N, and O are included. Use type I, II, or III Portland Cement per ASTM C 150. Hydrated Lime per ASTM C 207. Sand per ASTM C 144. No air entrainment or antifreeze admixtures shall be used. Mixing and proportioning per BIA MI-72.	2, 4, 12, 13

TABLE 6 (Continued) TEST METHODS FOR MASONRY

MATERIAL	TEST PARAMETER	TEST METHOD	COMMENTS	REFERENCE NO.
Masonry (Face brick, sandlime brick, concrete block, structural clay tile, and mortar) including the full assemblage.	Compressive strength	Method B, (ASTM E 447), standard methods of test for compressive strength of masonry prisms is used to determine compressive strength of existing masonry built with the same materials as used in the test sample. A minimum of three test prisms are built with like materials (same as in-situ). No reinforcement is used (except metal ties). Compressive strength is determined from 7-day and 28-day tests, and Young's modulus can be determined in accordance with Method E 111.	Test apparatus must conform to requirements of Method E 4. Test of building and face brick is in accordance with ASTM C 67; sandlime brick, C 67; Concrete block, C 140; Structure clay tile, C 67; Mortar, Method C 109. Reliability of test results is uncertain because of the unlikely event that test materials are exactly the same as in-situ materials.	7, 8
	Structural soundness of units, bond with mortar, and to determine if cells are filled.	<u>Hammer Test</u> Lightly tap the masonry unit with a hammer. Listen to resonant sound. A very experienced evaluator might be able to determine the condition by the sound.	This test requires an experienced person with a good sense of hearing and a delicate touch. It is an unsophisticated test with questionable results. Test cores may be needed. to validate findings.	14
	Location and Uniformity of the inner cell grout and wall thickness.	<u>Probe Holes</u> Penetrate the area of investigation with a small masonry bit and probe the hole with a stiff wire.	Small holes may be patched easily. Surface damage is only minor.	14

TABLE 6 (Continued) TEST METHODS FOR MASONRY

MATERIAL	TEST PARAMETER	TEST METHOD	COMMENTS	REFERENCE NO.
Masonry Units and Mortar (Including the Assemblages)	Continuity (voids or cracks), and estimation of compressive strength.	Low Frequency Ultrasonics Soniscope and two transducers are used. Transmitter and receiver are placed on opposite sides of the masonry unit. Low frequency ultrasonic sound waves are transmitted. Travel time and relative strength of transmitted signals is measured. Voids or cracks in units will weaken the signal. Compressive strength can be estimated by correlation of pulse velocity thru units and mortar with compressive strength of cores or prism that were removed from the wall tested.	This equipment usually is available only through specialized consultants and requires operators and evalators who are very experienced with testing of masonry. The cost may be prohibitive for routine investigations.	14
	Location of voids and/or reinforcement.	Gamma Radiography The gamma source and x-ray film are placed on opposite sides of the test specimen. After exposure of the film for several minutes, the film is processed and read. Voids show on the film as dark irregular patches. Reinforcement shows as a light area on the film.	Access to two sides of the test specimen is required. Extensive safety procedures are required due to the health hazard of gamma ray exposure. The cost could be prohibitive for routine projects. It is used mainly for specialized cases such as distressed precast masonry units when a record is needed for possible litigation.	14
	Location of steel reinforcement.	Pachometer The pachometer is a magnetic detector. The operation is based on the principle that a ferromagnetic component (such as steel reinforcement) will cause a variation in the magnetic field induced into the masonry (a non-magnetic medium).	The surface of the masonry units is scanned with a probe. Readings indicate location, size, and depth of reinforcement. This test is used only for light reinforcement. If both joint and cell reinforcement are used, results are difficult to interpret.	14

2.4.2 References

1. "Standard Methods of Sampling and Testing Brick and Structural Clay Tile," C 67, American Society for Testing and Materials, (1978).

2. "Standard Specification for Masonry Cement," C 91, American Society for Testing and Materials, (1978).

3. "Standard Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units," C 126, American Society for Testing and Materials, (1976).

4. "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method," C 231, American Society for Testing and Materials, (1978).

5. "Standard Methods of Load Verification of Testing Machines," E 4, American Society for Testing and Materials, (1979).

6. "Standard Methods of Conducting Strength Tests of Panels for Building Construction," E 72, American Society for Testing and Materials, (1977).

7. "Standard Test Method for Young's Modulus at Room Temperature," E 111, American Society for Testing and Materials, (1978).

8. "Standard Test Methods for Compressive Strength of Masonry Prisms," E 447, American Society for Testing and Materials, (1974).

9. "Standard Test Methods for Water Permeance of Masonry," E 514, American Society for Testing and Materials, (1974).

10. "Standard Test Methods for Flexural Bond Strength of Masonry," E 518, American Society for Testing and Materials, (1976).

11. "Standard Test Method for Diagonal Tension (Shear) in Masonry Assemblages," E 519, American Society for Testing and Materials, (1974).

12. "Standard Specification for Portland Cement - Lime Mortar for Brick Masonry," MI-72, Tech Note 8A, Brick Institute of America, (Oct/Nov 1972).

13. "The Causes and Control of Efflorescence on Brickwork," Research Report No. 15, Structural Clay Products Institute (now BIA), (August, 1969).

14. Snell, L. M., "Nondestructive Testing Techniques to Evaluate Existing Masonry Construction, (August, 1978).

Other test methods for evaluating masonry products are available from the American Society for Testing and Materials (ASTM) as follows:

C 413-75	Absorption of Chemical-Resistant, Nonmetallic Mortars, Grouts, and Monolithic Surfacings
C 905-79	Apparent Density of Chemical-Resistant Mortars, Grouts, and Monolithic Surfacers
C 321-77	Bond Strength of Chemical-Resistant Mortars
C 67-78	Brick and Structural Clay Tile
C 608-71 (1977)	Brittle Ring Tensile Strength of Chemically Setting Silicate and Silica Chemical-Resistant Mortars
C 619-71 (1977)	Chemical Resistance of Asbestos Fiber-Reinforced Thermosetting Resins Used in Self-Supporting Structures
C 267-77	Chemical Resistance of Mortars
C 868-77	Chemical Resistance of Protective Linings
C 396-76	Compressive Strength of Chemically Setting Silicate and Silica Chemical-Resistant Mortars
C 579-75	Compressive Strength of Chemical-Resistant Mortars and Monolithic Surfacings
C 140-75	Concrete Masonry Units, Sampling and Testing
C 426-70 (1976)	Drying Shrinkage of Concrete Block
C 580-74 (1978)	Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, and Monolithic Surfacings
C 341-79	Length Change of Drilled or Sawed Specimens of Cement Mortar and Concrete (see Part 14)
C 531-74	Shrinkage and Coefficient of Thermal Expansion of Chemical-Resistant Mortars, Grouts, and Monolithic Surfacings
C 307-77	Tensile Strength of Chemical-Resistant Resin Mortars
C 308-77	Working and Setting Times of Chemical-Resistant Resin Mortars
C 414-77	Working and Setting Times of Chemical-Resistant Silicate and Silica Mortars

3. HEATING, VENTILATING, AND AIR CONDITIONING SYSTEMS (HVAC)

Several techniques have been developed which can help evaluate the performance of existing HVAC systems and to determine their capability to support retrofit systems; some of these are presented in this section. Also discussed are methods for evaluating the performance of the building envelope which contains the conditioned space. Techniques for measuring air leakage, as well as heat gains and losses, through the exterior of the building are valuable because space conditioning without proper humidity control can cause serious problems of condensation within the building structure.

A discussion of techniques for assessing the condition of the existing HVAC system and the envelope of the building follows.

3.1 BUILDING ENVELOPES

3.1.1 Evaluating the Amount of Air Leakage Using Air Pressure

Test Method - *Pressurization*

Subject - Building Envelope

Parameter - Air Leakage

Discussion

Pressurization of the space within a building, either positive or negative with respect to atmospheric pressure, is one means of gaining a quantitative measure of the air leakage of a structure. A fan, a metering station to determine air flow rate, and pressure sensors, along with temperature measurements, are needed to make the determination of leakage rate for the given pressure differential. Generally, a window or door opening can be fitted with a plywood partition through which the air required to pressurize the structure is introduced. The air is allowed to seek points of penetration in an effort to equalize the pressure between the space and the surrounding atmosphere. The amount required to maintain the pressure differential provides an indication of the overall performance of the structure with regard to air leakage. It is possible to isolate contributing points of leakage by selectively taping cracks and joints during a sequence of tests. Internal air leakage paths can be identified using a fan to generate negative pressures and infrared scanners to trace the path through the construction.

Advantages and Limitations

The technique is rather simple and not necessarily expensive (expense does vary with the complexity of measurements). The results using the air pressurization technique are not necessarily transferable to gain an indication of infiltration rates under natural conditions. The results provide a relative measure for assessing the structure to determine where within a range from "good to bad" the structure falls. The technique can be used effectively as a quality assurance procedure.

REFERENCES - 1, 2, 3, 4

3.1.2 Determining Air Exchange Using Tracer Gas

Test Method - *Tracer Gas Technique*

Subject Area - Building Envelope

Parameter - Air Leakage

Discussion

The actual air exchange rate within a structure can be determined through the use of a tracer gas which is released into the space to be measured, then the concentration of the gas is monitored over a period of time. The exchange rate can be expressed through the following relationship:

$$I = -{}^{1}/t \ln ({}^{c}/co)$$

where: I = air volume changes per hour

t = time

co = concentration of tracer gas at time zero (beginning of test)

c = concentration of tracer gas at a specific time within the test period

When the natural logarithm of the relative concentration (${}^{c}/co$) is plotted as a function of time, the rate of infiltration (I) is the negative slope of the best fit line through the data points. Several tracer gases, such as carbon dioxide, helium, nitrous oxide, ethane, methane, and others, have been used as indicators of concentration decay. Currently one of the most popular is sulfur-hexafluoride. Samples of the air within the structures are taken and analyzed on the spot or stored in sample bags during the test and later analyzed.

Advantages and Limitations

The tracer gas technique is probably the best measure of natural infiltration in that it does not introduce any unnatural constraints for making the determinations, other than some form of forced air circulation to maintain mixing of tracer gas and air. The use of sulfur-hexafluoride (SF_6) allows the use of very small amounts of harmless gas, generally on the order of 10-50 parts per billion, to be introduced into the space, thus altering to a negligible extent the composition of the air. At infiltration rates of greater than three air changes per hour, the tracer gas technique may give unreliable results because of the introduction of large amounts of unmixed air causing significant scatter in the data. At the higher rates of air exchange, the need for rapid sampling rates may also pose a problem.

REFERENCES - 1, 5

3.1.3 Determining Paths of Leakage Using Thermography

Test Method - *Thermography*

Subject - Building Envelope

Parameter - Heat Leakage

Discussion

Sources of high heat losses can be determined through the use of thermographic techniques. Thermography is a technique of portraying an object using the thermal energy radiating from the surface of the object. The energy radiated from the object (infrared region of the spectrum) is displayed on a cathode ray tube (either a black and white or color television monitor). On a black and white monitor, the intensity of the gray scale is proportional to the temperature of the object - within a given range, colder objects appear dark and hotter objects appear light. On a color monitor, the gradation of colors of the image indicates the surface temperature variation. Thus, since heat loss or gain leads to surface temperature variation, it is possible to detect areas of heat leakage through observations of the building's surface temperature. A photograph can be taken of the image on the screen of the monitor and a record of the thermal image can be obtained in the form of a permanent thermograph.

REFERENCES - 6, 7, 8

3.2 BUILDING INTERIORS

3.2.1 Determining Humidity with Color Changing Agents

Test Method - *Humidity Indication by Color Change*

Subject - Building Interior

Parameter - Moisture

Discussion

A rather simple, yet inexpensive, method of monitoring relative humidity within a structure is through the use of the color change humidity indicator. One such indicator uses cobaltous chloride as the basic ingredient for indicating the relative humidity. Blotting paper is used as the holder of the ingredients; and, as the cobaltous chloride is exposed to the atmosphere and equilibrium is reached, the color of the ingredient changes. A range of relative humidity indication from 10 to 80 percent can be obtained. There are plug-type indicators that may be used to indicate the relative humidity in wall cavities or enclosed roof ceiling cavities. The color change indicator can also be used to monitor the relative humidity of the occupied spaces.

Advantages and Limitations

The color-change type indicators are inexpensive and are relatively easy to use. The accuracy of the indicator can be affected by temperature changes and long-term exposure to high humidity, high temperature, or direct sunlight. As an indicator of acceptable levels of relative humidity in a space within a building or an unacceptable condition within a structural compartment, the color change indicator should perform adequately. Direct contact with water will cause the chemicals to leach out of the paper and thus lose calibration. It is possible to obtain an indication of relative humidity within a 5 percent range of the published equilibrium point. A 10°F change in temperature will affect the indicator accuracy by 2-1/2 percent. A limitation is that the equilibrium point varies with the specific chemical used, and it is a specific point (not a range).

REFERENCE - 9

3.2.2 Determining Humidity with an Electric Hygrometer

Test Method - *Electrical Impedance Hygrometer*

Subject - Building Interior

Parameter - Humidity

Discussion

With a change in humidity, many substances absorb or give up moisture and exhibit changes in electrical impedance. Sensors can be produced having dual electrodes or windings which are electrically separated by a thin film of binder material containing a salt solution (such as lithium chloride). Means are provided for measuring the AC electrical impedance between the electrodes through the salt film. The impedance through the salt responds to changes in relative humidity and temperature, so that accurate indications of relative humidity can be obtained.

Advantages and Limitations

The electrical impedance hygrometer is relatively sensitive to humidity changes and provides the capability for remote read-out. Precision on the order of ± 1.5 percent RH can be obtained and elements can be produced to cover the range from 10 to 90 percent RH. The electrical impedance hygrometer is susceptible to damage by air contaminants and water. Frequent calibration checks are required. The elements can be placed in remote places for monitoring changes in relative humidity in an effort to gain information on excessively high moisture conditions.

REFERENCE - 10

3.2.3 Determining Heating System Efficiency by Using Electric Co-Heating

Test Method - *Electric Co-Heating*

Subject - Building Interior

Parameter - Heating Efficiencies

Discussion

Electric co-heating is a technique used to determine the net efficiency of a system consisting of any heating appliance (a furnace, for example) and a house. Several portable, thermostated, and metered electric heaters are distributed throughout the house. First, the furnace is turned off and only the electric heaters are used to heat the house. Next the furnace is turned on and cycled manually (for example, four minutes on and sixteen minutes off) for about three hours. Throughout the procedure, the indoor temperature remains constant by appropriate reductions in the heat produced (and power consumed) by the electric heaters. Finally, the furnace is turned off and the electric heaters see the full load again. The indoor temperature is recorded and periodic measurements of the outdoor temperature are taken. Also, the air infiltration rate (through cracks in walls, etc.) is monitored using tracer gas techniques. The following steps are used to calculate the efficiency: First the heat load, including air infiltration, is determined through use of the electrical heaters. Second, the portion of the heat load supplied by the furnace is found from the difference in the load and the measured electrical power consumed by the heaters. Third, the efficiency is calculated by dividing the difference by the average furnace fuel consumption rate. Further capabilities of the electric co-heating technique include an evaluation of fireplace efficiency and determination of the fraction of the heating load needed for individual rooms in the dwelling.

Advantages and Limitations

Unlike some methods of efficiency evaluation, electric co-heating takes into account the effect of distribution heat losses (through ducts, etc.); in other words, the efficiency calculation includes only the heat that benefits the living space. Also, this method distinguishes between heating efficiency and the house's envelope performance. Electric co-heating, however, is still in the development stage. It is not practical for structures with a large number of rooms because of the difficulty in monitoring the infiltration losses and the power of the heaters.

REFERENCE - 11

3.3 MISCELLANEOUS TESTS FOR HVAC SYSTEMS

3.3.1 Physical Inspection

Test Method - *Physical Inspection*

Subject - Furnaces and Boilers/Heating Systems

Parameter - Efficiencies

Discussion

The current trends toward energy conservation and the subsequent reduction in heating loads in buildings have had an effect on the efficiencies of furnaces and boilers; the older ones tend to be oversized and often yield lower efficiencies. In such cases, a replacement may be desirable. However, several actions can be taken to increase the efficiency of the existing furnace or boiler. The combustion system should be carefully cleaned and checked for leaks. The air should enter the combustion chamber at controlled rates. To obtain optimum efficiencies, the oil nozzle size may need to be reduced or the gas burner may need to be replaced if the system will accommodate a replacement. The air-fuel ratio should be determined and adjusted for proper combustion. The O_2 and CO_2 content can be determined from an Orstat apparatus or other available analyzer such as the non-dispersive infrared spectrometer for carbon dioxide or oxygen specific electrodes to determine oxygen content. This, coupled with the stack temperature reading, will provide data for determining system combustion efficiency. The final decision on system replacement is generally made on the basis of economics -- the annual savings that can be expected as a result of purchasing and installing a new system.

Advantages and Limitations

This procedure gives only steady-state performance. In practice, most systems operate far from steady-state; however, this inspection should be undertaken for safety reasons whenever major retrofits of a building are planned. Physical inspection offers the advantage of hands-on experience and an immediate sense of condition of the furnace or boiler and the HVAC system. With physical inspection, there is the need for knowledge and skill gained through experience. The inspector carrying out the condition assessment inspection, should be technically trained. Replacement of furnace or boiler components should be made by qualified personnel only.

REFERENCES - 12, 13, 14, 16

3.3.2 Determining Wall Thickness of Containment Vessels

Test Method - *Ultrasonic Thickness Gauging*

Subject - Containment Vessels (heat exchangers, tanks, pipes, etc.)

Parameter - Corrosion and Wear

Discussion

It is possible to use ultrasonic techniques to determine the thickness of materials to obtain an indication of wear and deterioration. The pulse-echo ultrasonic thickness technique is recognized as an accurate method of measuring product thickness when the velocity of ultrasound is known. Ultrasonic transducers have been developed that allow the determination of piping and tubing wall thicknesses (and other forms) without physically penetrating the material. Ultrasonic pulses are generated and the time required for the pulse to be reflected back from the opposite surface is very accurately recorded. By knowing the transmission velocity of the material and using the appropriate electronic circuitry, a digital readout can be obtained which is a direct measure of the thickness of the material. The technique has been used to evaluate large boiler installations for heat exchanger deterioration from corrosion.

Advantages and Limitations

Small transducers are available to determine thickness of closed materials without physically penetrating the surface. By scanning the surface variations, wall thickness can be determined, thus gaining an indication of deterioration. Some distortion results from rough surfaces as the ultrasonic pulse is scattered, with a resulting lack of sharpness in the return echo. As surface curvature increases, the coupling efficiency between transducers and the material to be measured decreases, causing some loss in accuracy. Some materials have special acoustical characteristics and can cause scattering, velocity variation, and attenuation, with a resulting loss in accuracy.

REFERENCE - 15

3.4 REFERENCES

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14. ASHRAE Handbook and Product Directory, 1979 Equipment.

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4. PLUMBING SYSTEMS

The implementation of a design complying with the code requirements in new construction is fairly straightforward since inspection and testing of critical elements at key times is feasible as construction progresses and before the elements are concealed. However, this is not possible in rehabilitation work where evaluation of existing, largely concealed plumbing is required. Frequently, this difficulty has resulted in the preference for new construction or a tendency to totally replace aged plumbing rather than selectively rehabilitate. With modern techniques for evaluating plumbing systems, however, total replacement may possibly be avoided in favor of supplementing the existing system or replacement of only those components which absolutely require it.

The following is a description of some of the inspection and test methods available for evaluating the condition of existing plumbing systems.

4.1 PLUMBING SYSTEM COMPONENTS

4.1.1 Determining Condition of the Plumbing System

A. Test Method - *Physical Inspection*

Subject - Plumbing System Components

Parameter - Safety Functions

Discussion

A thorough inspection of the plumbing system should be carried out by a qualified plumbing inspector to gain a professional opinion on the condition of the system. The plumbing system is intended to function in a safe manner for the supply of potable water and the effective removal of waste products through sanitary drainage.

Physical inspection should include the following observations:

1) CONDITIONS WHICH COULD CAUSE AN UNSAFE BUILDING ENVIRONMENT:

   a. Excessively hot water (absence, inadequate design, or malfunction of temperature control devices).

   b. Explosion hazard due to absence, or defectiveness of, temperature and pressure limiting devices.

   c. Plumbing wall construction which will allow fire spread and passage of smoke or toxic gases in case of building fire.

   d. Water or drainpipe leaks, or leaks around fixture connections which could allow gradual deterioration of structural elements of the building.

2) CONDITIONS WHICH COULD CAUSE AN UNSANITARY BUILDING ENVIRONMENT:

a. Leaks in sanitary drains and vents (these leaks can contribute to the development of vermin, mold, odors, noxious or explosive gases, sewage saturation, etc.).

b. Overflowing of sewage from fixtures onto floor or under/behind cabinets, etc.

c. Emission of sewer gas or suds from fixtures.

d. Inoperative fixtures due to clogged drains or inability to obtain water.

e. Inoperative water heater, or inadequate supply of hot water.

f. Poor flushability of water closet.

g. Absence of potable water supply, or supply of inadequate quantity.

h. Backflow hazard; (e.g., submerged fixture supply fitting outlets below flood rim, WC ballcocks without vacuum breakers, flushometers without vacuum breakers, dishwashers without air gaps or air breaks, etc.).

i. Absence or inoperability of essential plumbing fixtures and plumbing services.

Advantages and Limitations

Physical inspection provides quick feedback on the identification of problems, but the value of the inspection may be diminished in cases where major portions of the system are concealed. Many of the features identified in the inspection listing (1 and 2 above) are items that must be accessible, so inspection can be made with little trouble. Accessibility will be difficult or impractical in some cases. Personal experience will be of value in gaining an opinion on condition assessment through physical inspection. The individual who has designed, repaired, and observed the dismantling of older systems should have an advantage in assessing the potential remaining useful life of the existing system or its ability to accept modifications.

REFERENCES - 1, 2, 3, 4, 5, 6, 7

B. Test Method - *Water Test*

Subject - Water Supply Lines

Parameter - Leaks

Discussion

A simple method to check for the existence of any leaks in the water supply lines of the building is as follows:

1) Close all the valves on plumbing fixtures on the supply line to be checked.

2) Be sure the main water supply valve (or valves) is open.

3) Listen for a gurgling or murmuring sound in the supply pipe.

4) If no leak can be determined to exist in the interior supply line, and a leak still is suspected, listen for signs of leakage in the supply pipe leading from the water main outside the building and call the water company to check that line for leaks if gurgling sounds are heard.

Advantages and Limitations

The method is fast and simple. The results are immediate when leaks are large enough to be heard and when they occur in pipes which are not embedded or concealed.

REFERENCE - 19

C. Test Method - *Water Test*

Subject - Water Supply Lines

Parameter - Adequate Water Pressure

Discussion

Clogged water supply pipes often cause a reduction in the water pressure at the faucets. One way to check the adequacy of the pressure is as follows:

1) Open the top floor sink faucets.

2) Open the bathtub faucets and flush the toilet. If the flow of water in the sink slows to a trickle, the piping may be of inadequate size or badly clogged with scale.

Advantages and Limitations

This is a fast and simple test method with results that can be obtained immediately.

REFERENCE - 19

D. Test Method - *Water Test*

Subject - Water Storage Tank

Parameter - Adequacy

Discussion

If the water supply is from a well, turn on as many faucets as possible and observe the water after letting it run for ten minutes. If the water becomes muddy, the storage tank probably is undersized for the demand of the building. The capacity and recovery rate should be indicated on the nameplate mounted on the tank. An electric heater should have a capacity half again as great as a gas fired water heater to compensate for its slower recovery rate. For either type, check to be sure there is a pressure relief valve installed for safety.

Advantages and Limitations

This is an inexpensive, fast method for determining in a very general way the adequacy of the size of the water storage tanks.

REFERENCE - 19

4.2 DRAINAGE AND VENT SYSTEMS

4.2.1 Water Testing for Leaks

Test Method - *Water Test*

Subject - Drainage and Vent Systems

Parameter - Leaks

Discussion

The water test can be used to test for leaks in a drainage system. It can be applied to the entire system or to sections. If applied to the entire system, all openings in the piping should be tightly closed (except the highest opening) and the system filled with water to the point of overflow. The same conditions apply if the system is tested in sections, but no section should be tested with less than a 10-foot head of water. The water should be kept in the system, or in the portion under test, for at least thirty minutes before inspection starts; the system should then be tight at all points.

Advantages and Limitations

The water test for leak determination is relatively inexpensive. Leakage of water, should a leak occur, could cause some cosmetic damage in the existing building. Because the total drainage system seldom will be fully exposed for easy inspection, the point(s) of leakage may be difficult to determine accurately. The test method should indicate the general area of failure when leakage occurs. Some exploration through the removal of building components may be required to pinpoint the exact location and carry out repairs of the pipe or joint. If severe leakage occurs, or leakage is in an inaccessible location, consideration should be given to replacement of system components or possibly the total system.

REFERENCES - 8, 9, 20

4.2.2 Air Testing for Leaks

Test Method - *Air Test*

Subject - Drainage and Vent Systems

Parameter - Leaks

Discussion

The air test can be used to test for leaks in a drainage or vent system; it should only be applied to the entire system. An air compressor or other testing apparatus is attached to any suitable opening and all other inlets and outlets to the system are closed tightly. Air is forced into the system until there is a uniform gauge pressure of five psi or 10" Hg. This pressure is held without introduction of additional air for a period of at least 15 minutes. Any reduction in pressure indicates the presence of a leak in the pipe.

Advantages and Limitations

The air test for determining leakage is a rather simple and inexpensive test and requires little skill. A source of compressed air and adequate controls are required to assure safe operating conditions and to guard against over pressurization of the system. The test procedure will give a quick indication of system quality with regard to leakage, but the source of leakage may require additional testing (such as the soap and bubble test or listening for escaping air at the point of leakage). It also is possible to charge the system with gas so that leaks can be identified through the use of gas detectors. Because most drain and vent systems are enclosed in non-accessible construction, the source of leakage may be difficult to locate.

REFERENCES - 8, 9, 20 (See smoke or peppermint test, p. 31 of ref. 20).

4.2.3 Trap Tests

Test Method - *Discharge Test*

Subject - Drainage and Vent Systems

Parameter - Siphonage of Traps

Discussion

To test for siphonage of fixture traps, one or more fixtures should be filled to an overflowing level and discharged, then measure the trap seal retention. Trap seal retention should be at least 50 percent or 1 inch (25 mm), whichever is greater, in all traps when tested for self-siphonage or for cumulative effects of induced siphonage. The seals in the traps should be measured before and after each of several repeated discharges. If excessive siphonage occurs, the discharge pipes should be enlarged, cleaned, or otherwise modified. The number of fixtures to be discharged simultaneously in testing for stability of the trap seal is dependent upon the number and type of fixtures on the drain stack and their spatial arrangement. The discharge load can be determined from the references listed below.

Advantages and Limitations

The indicated procedures to determine trap seal retention have been used for years and are a fairly good indication of anticipated performance. Judgment must be used in looking at alterations of existing systems which may be required to carry unusual loading. Because of the health and safety issue of sewer gas emission with reduced trap seal, a conservative selection of simultaneous loading (extra heavy load) should be chosen when future use conditions are uncertain.

REFERENCES - 10, 11, 12, 13, 14, 15, 16, 17, 18

GENERAL COMMENT

Where future stories are proposed to be added to a building, the water piping systems should be tested to reflect the added static pressure anticipated to be imposed by the added height.

4.3 REFERENCES

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5. ELECTRICAL SYSTEMS

Since most electrical wiring is concealed inside walls, a complete inspection of all the parts of the electrical system in a building may not be feasible. Some general items, however, are easily checked which can aid in determining the electric shock and fire safety aspects of the system, as well as detecting functional and energy loss problems which may exist. Nearly all aspects of the National Electric Code (ref. 1) in some way address the requirements for shock and fire safety. In older buildings there are potential problems through system overloads as new appliances and oversized fuses may be placed in the circuits.

The following are examples of evaluation techniques for assessing the condition of an electrical system in an existing building. While the evaluation methods mentioned in this section generally are recognized as being good practice, local codes and local officials should be consulted to determine whether any specific requirements apply to the individual geographical areas or type of building being evaluated.

5.1 ELECTRICAL BRANCH CIRCUITS

5.1.1 Determining the Condition of the System

Test Method - *Visual Inspection*

Subject - Electric Branch Circuits

Parameter - Circuit Faults
Discussion

One of the best techniques available for assessing the condition of existing electrical systems is visual inspection of the wiring system. This technique helps to determine the condition of the insulating material and the methods used in making connections within the circuit. When analyzing existing systems, it is important to determine not only the condition of the system but also how the system is used during normal operation. During inspection it is important that the following items be noted (if they occur):

1) Overfusing - Check to see that the proper size fuse or circuit breaker is used in the branch circuit. Frequently, a fuse having a greater capacity than the original design capacity will be placed in the circuit and will create a potential overload condition in the circuit. This could result in ignition of material near the conductors.

2) Overlamping - Observe the wattage of lamps to determine if they are within the recommended limit. This is especially critical in confined spaces such as recessed lighting fixtures. With oversized bulbs in confined spaces the potential for overheating and resulting ignition of nearby combustibles is greatly increased.

3) Size and Number of Conductors - Knowing the anticipated load, it is easy to determine if the proper size wire and fuse combination is being used. The National Electrical Code should be consulted to determine if the existing circuit has the required capacity. Check for the existence of an adequate number of circuits with the proper voltage and current ratings for any anticipated retrofit equipment. Some common symptoms of circuit overloading include: (1) presence of many 20 or 30 ampere fuses; (2) the smell of burning insulation near the panel; (3) fuses that have glass tops that are warm; (4) discolored copper contact points under the fuses; (5) overheating of wires as evidenced by melted insulation, and, in extreme cases, fire around outlet boxes, switches, etc., or wherever thermal insulation is tightly packed around wires; (6) fuses that blow frequently or circuit breakers that trip frequently, and (7) presence of surface mounted lampcord extension wiring or multiple cords plugged into a single outlet.

4) Type of Conductor - Examining the conductor will indicate its type (copper, aluminum, or copper clad aluminum), and the wiring method (non-metallic sheathed cable, armored cable, electric metallic tubing, rigid conduit, or flexible metal conduit).

5) Type and Condition of Insulation - Generally, the insulation around the conductor will be either rubber or plastic. The insulation should be physically examined to determine its brittleness. If there is any flaking or if any of the insulation falls off when bending occurs, it is deficient and should be replaced. An easy place to check for deficient insulation is in the exposed areas of the basement, around the circuit breaker or fuse box, and inside outlets or switches. Be sure to turn the power off to the circuit before removing outlet or switch plates or before probing any wires.

6) Connectors - Check for poorly functioning connectors which could cause excessive power losses and which might be a potential source of ignition. Power losses and low voltage can impair the functional operation of appliances and shorten the life of critical components.

Advantages and Limitations

Visual inspection provides immediate feedback on the condition of those parts of the electrical branch circuit that are accessible for inspection. To gain the most benefit from visual inspection it is best to have an experienced individual who has repaired or examined and dismantled older systems to gain first hand knowledge of potential problem areas. Visual inspection may detect only the most obvious defects because of the surface-only type of evaluation. It is recommended that only experienced personnel conduct electrical inspections.

REFERENCE - 4

Test Method - *Megohm Test (Megger Tester)*

Subject - Electric Branch Circuits

Parameter - Deteriorated Insulation

Discussion

If the insulation appears to be deteriorated (crumbling or cracking), it is important to either replace the wiring or check the condition of the insulation with a megohm test performed by an electrician. In this test, the wires for each circuit are disconnected at the power supply end, and a Megger tester applies a test voltage to the wires at the other end. Branch circuits should read at least one megohm to ground. If lights or appliances are connected, readings should be at least 500,000 ohms. (Feeders should be tested in accordance with Article 110-20 of the National Electric Code). If there are any indications of shorts in the circuit, the insulation is faulty, and the circuit wiring must be replaced.

Advantages and Limitations

This procedure for evaluating the condition of the wiring insulation is relatively easy, fast, and inexpensive. It is recommended that only a qualified electrician perform the test since high voltage is used and there are certain hazards associated with the test.

REFERENCES - 4, 5

5.1.2 Determining Electrical System Efficiency

Test Method - *Voltage Determination*

Subject - Electric Branch Circuits

Parameter - Excessive Voltage Drops

Discussion

The measure of voltage drop in a branch circuit is a good indicator of excessive impedance (e.g., excessive length) of the circuit. Conductors in branch circuits will provide a reasonable efficiency of operation if the following conditions are met:

1) The voltage drop at the farthest outlet of power, heating and lighting loads does not exceed 3 percent.

2) The maximum total voltage drop on both feeders and branch circuits to the farthest outlet does not exceed 5 percent.

If voltage drops much in excess of these values occur, the circuit needs replacement. Generally, available voltmeters can be used for making the determination of voltage drops in the circuit.

Advantages and Limitations

The procedure for making voltage drop determinations is relatively easy and inexpensive. The conventional, commercially available voltmeter can be used. Measurements must be made under load with current also being measured. It is suggested that only a qualified individual, knowledgeable of electricity and branch circuitry, make the required measurements because of the danger of electrical shock when untrained personnel work with these potentially dangerous levels of electricity.

REFERENCE - 1

5.1.3 Circuit Analysis

Test Method - *Circuit Analyzer*

Subject - Electric Branch Circuits

Parameter - Circuit Faults

Discussion

A commercially available electrical device has been developed for analyzing potentially hazardous circuits. The analyzer is designed to determine various faults in existing wiring systems. It is intended for testing newly wired circuits, but also may be useful in assessing the proper performance of existing systems. The circuit analyzer is said to be capable of checking the following circuit conditions:

1) open ground
2) open hot
3) open neutral
4) hot/ground reversed
5) hot/neutral reversed

Depending on the type of analyzer, one or more test lights will be activated if the outlet is functioning and safely grounded. If ungrounded outlets are discovered, they should be grounded by installing a ground wire (this is especially important in kitchens and bathrooms). The manufacturer's instructions for the particular receptacle analyzer being used should be consulted for the detailed meaning of the lighter indicators. The analyzer can be used on old two-wire circuits with a special adapter.

Advantages and Limitations

Measurements obtained through the use of the circuit analyzer indicate only design or operating faults such as improper connections. This method of analysis will not help determine the condition of materials which make up the branch circuit. The technique is simple and quick, and the analyzer is commercially available.

REFERENCE - 2

5.2 ELECTRICAL CIRCUITS

Test Method - *Circuit Breaker and Resistance Tester*

Subject - Electric Circuits

Parameter - Condition of Circuit Breakers

Discussion

A commercially available Circuit Breaker and Resistance Tester is claimed to provide the capability of evaluating circuit breakers by simulating an overload condition and proof testing the circuit breaker. A component of the Test Set allows evaluation of resistance of motor windings and other insulation resistance in the range from 1 megohm to 1000 megohms. The current is limited to five milliamperes short circuit current for maximum safety. The Test Set provides for quick assessment of the condition of electric circuit breakers to make sure that they operate in the intended range for overload protection. The resistance tester is intended to indicate potential problem areas relative to breakdown in electrical resistance of insulating materials.

Advantages and Limitations

Testing of the circuit breakers requires that the circuit breaker be removed from the panel. Because of potential danger in working with electric circuits a qualified electrician should be engaged to conduct the tests. In older buildings which may not have a master disconnect, the utility company may be required to cut off service to the building during the removal of the circuit breaker.

REFERENCE - 3

5.3 REFERENCES

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NBS-114A (REV. 9-78)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO.	2. Gov't. Accession No.	3. Recipient's Accession No.
	NBSIR 80-2171		

4. TITLE AND SUBTITLE

Selected Methods for Condition Assessment of Structural, HVAC, Plumbing, & Electrical Systems in Existing Buildings.

5. Publication Date

December 1980

6. Performing Organization Code

7. AUTHOR(S)

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8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, DC 20234

10. Project/Task/Work Unit No.

11. Contract/Grant No.

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

Department of Housing and Urban Development
451 7th Street, S.W.
Washington, D.C. 20410

13. Type of Report & Period Covered

NBSIR/Final

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

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

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

This report was developed with the intent of assisting government officials, designers, builders, code officials, and others involved with making technical decisions relative to building rehabilitation to evaluate the condition of existing buildings.

The report describes evaluation methods available specifically for use with the structural materials of concrete, steel, masonry, and wood, as well as, for use with the supportive systems of heating/ventilating/air conditioning, plumbing, and electrical. Both commonly used methods and other possible (but more technically complex) laboratory methods are described for the reader. Comparative tables are provided, where possible, to aid the reader in making a quick selection of the evaluation method most appropriate for the particular parameter to be tested. Considerably more information is included in the area of structural systems than in the rest of the report because of the fact that this report supplements a previous effort to develop a technical manual on structural strength for rehabilitation of existing buildings.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Building rehabilitation; concrete; electrical; evaluation; HVAC; masonry; plumbing; steel; structural systems; test methods; wood.

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