Conf-920375--1

DATA BASE ON STRUCTURAL MATERIALS AGING PROPERTIES*

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CONF-920375--1

DE92 009010

ABSTRACT

The U.S. Nuclear Regulatory Commission has initiated a Structural Aging Program at the Oak Ridge National Laboratory to identify potential structural safety issues related to continued service of nuclear power plants and to establish criteria for evaluating and resolving these issues. One of the tasks in this program focuses on the establishment of a Structural Materials Information Center where long-term and environment-dependent properties of concretes and other structural materials are being collected and assembled into a data base. These properties will be used to evaluate the current condition of critical structural components in nuclear power plants and to estimate the future performance of these materials during the continued service period.

1. OVERVIEW

1.1 Introduction

Reinforced concrete structures in nuclear power plants are required to perform structural as well as nonstructural functions and to provide an adequate margin of safety to protect the public in the unlikely event of a severe accident. In future years, electrical utilities will submit license renewal applications seeking permission from the United States Nuclear Regulatory Commission (USNRC) to operate their nuclear power plants beyond the normal 40-year licence period. During this continued-service period, the concrete structures in these plants will be required to maintain the same level of performance and safety. Some of these structures, in fact, will need to remain in service after plant operations have been terminated to provide safeguard and security functions. The time period from start of operations until a plant is demolished could be as much as 100 years or more.

In order to assist the NRC identify potential structural safety issues related to continuing the service of nuclear power plants past the initial period for which they were granted an operating license, the Structural Aging (SAG) Program was initiated at the Oak Ridge National Laboratory (ORNL). The overall objective of this program is to prepare an expandable handbook or report

*Research sponsored by the Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission under Interagency Agreement 1886-8084-5B with the U.S. Department of Energy under Contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

which will provide NRC license reviewers and licensees with the following: (1) identification and evaluation of the degradation processes that affect the performance of structural components; (2) issues to be addressed under nuclear power plant continued-service reviews, as well as criteria, and their bases, for resolution of these issues; (3) identification and evaluation of relevant inservice inspection or structural assessment programs in use, or needed; and (4) quantitative methodologies for assessing current, or predicting future, structural safety margins.

1.2 Background

Reinforced concrete structures in nuclear power plants were designed in accordance with national consensus codes and standards to provide a safe and convenient working environment for operating personnel and to protect the public. The rules in these codes and standards were developed over the years by experienced people and are based on knowledge that was acquired in testing laboratories and supplemented with field experiences. Some of these rules were added to improve the chances for a long life. However, these codes and standards do not guarantee that a structure will be durable nor do they contain methods for assessing the current condition of an existing structure that has been exposed to hostile environmental conditions or for predicting the remaining service life.

One method for assessing the current condition of an existing reinforced concrete structure and for estimating the remaining service life focuses on a comparative approach. This method is based on the assumption that similar concretes which are exposed to similar environmental conditions will behave in the same way and will have the same life (Ref. 1). Researchers have used this approach over the years to study and understand material degradation. In this approach, the researchers compare control specimen behavior with test specimen results. This approach works well when materials are tested under actual service conditions. However, generalization of this comparative approach to predict the behavior of different types of materials exposed to natural weathering conditions, temperature fluctuations, or abnormal operating conditions is not always straightforward.

A methodology based on the comparative approach for estimating the remaining service life of reinforced concrete structures has not yet been standardized and, when this approach is used, it is not always easy to apply to reinforced concrete structures. This is particularly true for reinforced concrete structures in a nuclear power plant because of their operating conditions, safety significance, and longevity requirements. The first step in developing a methodology based on this approach requires a large knowledge base of data and information on the long-term and environment-dependent performance of concretes, reinforcing steels, prestressing tendons, and embedded structural steels used to construct these facilities.

1.3 Presentation Formats

The data and information collected at the Structural Materials Information Center are presented in two complementary formats. The *Structural Materials Handbook* is an expandable, hard-copy reference document that contains the complete set of data and information for each material, and serves as the information source for the *Structural Materials Electronic Data Base*. A report, which describes these two presentation formats, was prepared and published (Ref. 2). The appendix to this report includes pages from the *Structural Materials Handbook* and presents material properties for 11 different structural materials.

The *Structural Materials Handbook* consists of four volumes that are published in loose-leaf binders. Volume 1 contains design values which are used to compare material behavior and to estimate material properties. Volume 2 contains documentation that supports the design curves reported in Volume 1. Volume 3 contains material data sheets that are used to report general information and baseline data as well as material composition and constituent material properties. Volume 4 contains the appendices which provide documentation and reference information for the handbook and the electronic data base.

The *Structural Materials Electronic Data Base* is an electronically accessible version of the *Structural Materials Handbook.* This version was developed on an IBM-compatible personal computer using Mat.DB and EnPlot software (Refs. 3 and 4). This data base management system was designed specifically for maintaining and displaying properties of engineering materials and provides an efficient means for searching the various data base files to locate materials with similar characteristics.

1.4 Current Status

Research activities at the Structural Materials Information Center have focused on five main categories of materials including portland cement concretes, metallic reinforcements, prestressing tendons, structural steels, and rubbers. So far, material properties, data, and information for 61 materials have been collected, formatted, and entered into the *Structural Materials Handbook* and the *Structural Materials Electronic Data Base.*

Continuous efforts are being made to locate candidate materials for entry into the Structural Materials Information Center (Ref. 5). These efforts have been successful, and a significant number of portland cement concretes for which long-term mechanical properties are available have been identified (Refs. 6 and 7). In addition, candidate metallic reinforcement, prestressing tendon, and structural steel materials have been identified from building codes and standards dating back to the 1950's. Although some of these materials are used primarily for nonnuclear-related construction, baseline, mechanical, thermal, physical, and other properties for all of these structural materials are being collected.

1.5 Proposed Activities

Proposed research activities at the Structural Materials Information Center will focus on collection, assembly, and formatting of data and information for the materials noted previously as well as for other metallic and nonmetallic materials typically used to make nonstructural components such as electrical conduits, pressurized and non-pressurized piping, water stops, etc., that are often embedded in concrete. The performance of these materials may be significant to the overall assessment of reinforced concrete structures in nuclear power plants because degradation of these materials can adversely affect safety-related structural behavior.

2. MATERIALS AND PROPERTIES

2.1 Data and Information Management System

A materials property data base is a collection of data files where information on a number of materials are organized and stored. Each data file is unique because it only contains material properties, data, and information for one particular material. At the Structural Materials Information Center, a comprehensive data and information management system has been established to standardize the way in which long-term and environment-dependent structural material properties are presented in the *Structural Materials Handbook* and the *Structural Materials Electronic Data Base.*

This system includes provisions for identifying and selecting candidate materials suitable for use by the NRC, license reviewers, and licensees as well as formats for organizing and presenting material properties, data, and information, and procedures for assessing the relative quality of the reported properties.

Before a material is considered suitable for entry into the Structural Materials Information Center, certain types of general and compositional information about the material must be reported so that the material can be uniquely identified and distinguished from other materials with similar characteristics. For certain types of materials such as metals, common names or recognizable designations based on consensus documents such as ASTM standard specifications have been established. For other materials such as concretes, standardized ways to distinguish one material from another have not yet been established. In addition to these material designation requirements, baseline and long-term or environment-dependent properties must also be available.

2.1.1 Data and Information Sources

High-quality, time-dependent and environment-dependent properties of concrete are being obtained at the Structural Materials Information Center from open-literature references and through technology exchanges with U.S. and foreign research establishments, and through procurement of material samples from aged concrete structures (Ref. 3). Material properties, data, and information on metallic reinforcements, prestressing tendons, structural steels, and rubbers are being collected from open-literature references and world-wide publication sources.

2.1.2 Organization and Presentation Formats

The data and information that are collected at the Structural Materials Information Center for a candidate material are organized into broad categories that represent general and constituent material information, compositional parameters, and material properties data. These categories apply to composite and noncomposite materials, but the data and information requirements for each of these types of materials can be somewhat different.

Information that describes a material is considered general information. General information is required so that a unique identity for the material can be established. For certain types of materials such as metals and alloys, standard designations have been established by organizations such as the American Society for Testing and Materials. For certain other materials such as concrete, comprehensive material identification systems have not yet been developed. At the Structural Materials Information Center, each material is assigned a unique seven-character material code that is used consistently in both the *Structural Materials Handbook* and the *Structural Materials Electronic Data Base* to distinguish one material from another. The arrangement of these material codes is illustrated in Fig. 1. Procedures for establishing material codes are described in detail in the Appendix to Reference 2.

All manufactured materials, except pure chemical elements, are composed of constituent materials that are combined together during the manufacturing process to produce a particular material. These materials may be either chemical elements or other materials that have their own unique identity. Sufficient data and information about constituent materials, proportions, and processing must be reported so that materials from the same group and class can be distinguished from each other.

Since mechanical, thermal, physical, and other types of material properties are used to assess the service life of reinforced concrete structures, data for one or more of these properties must be available before a material can be considered for entry into the Structural Materials Information Center. As a minimum, these data must include baseline or reference properties as well as time-dependent or environment-dependent data. At the Structural Materials Information Center, each

Fig. 1. Material code arrangement.

Typical Material Code (01CB001) for a Normal-Weight Portland Cement Concrete made with Gravel Aggregate			
0 1	C	B	0 0 1
Chapter Index (01-99)	Group Index (A-Z)	Class Index (A-Z)	Identifier Index (001-999)

property is assigned a unique four-digit property code that corresponds to the property code ranges shown in Table 1.

Table 1. Property code range description.

Property Code Ranges	Property Code Range Description
1000-1999	General Information
2000-2999	Constituent Material and Plastic Concrete Properties
3000-3999	Mechanical Properties
4000-4999	Thermal, Physical and Other Properties
5000-9999	Available for Data Base Expansion

2.1.3 Quality of Material Properties

The relative quality of time-dependent and environment-dependent material properties may be extremely high or very low depending on the information source, the extent of the reported data and values, and the type of testing methods that were used. In order for data and values to be reported consistently at the Structural Materials Information Center, criteria for assessing the quality of data and values have been developed, and five quality levels, which are are shown in Table 2, have been established.

After the process of collecting and organizing data and information for a particular material has been completed, an evaluation of each material property is conducted. A significant part of this analytical process focuses on evaluating the quality of the data and values based on the eleven requirements listed in Table 3. Data in this context represents the numerical results of tests performed to determine properties of a material, and values represent the results of evaluations performed on the data to produce a useful representation of the data. These eleven requirements were established to standardize the quality evaluation process.

Properties with quality level ratings of C or higher are considered good, and materials with properties of this quality are usually suitable for entry into the Structural Materials Information

Table 2. Quality level definitions.

Quality Levels and Corresponding Term Definitions		
Quality Level	Quality Level Term Description	Relative Quality Level Rating
A	Recommended Property	Highest
B	Selected Property	.
C	Typical Property	.
D	Provisional Property	.
E	Interim Property	Lowest

Center provided certain other types of material-specific data and information are available. The additional data and information requirements that have been established for portland cement concretes, metallic reinforcements, prestressing tendons, and structural steels are identified in the following sections.

2.2 Portland Cement Concretes

Concrete is a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregates. In portland cement concrete, the binder is a mixture of portland cement and water (Ref. 8). Concretes that are used for structural applications in nuclear power plants are made from manufactured constituents, such as portland cement, chemical admixtures, and mineral admixtures, and from natural constituents, such as crushed stone or gravel aggregates, sand, and water.

At the Structural Materials Information Center, data and information for four different groups of portland cement concretes are being collected. These groups include insulating, structural lightweight, normal-weight, and heavyweight concretes. The data and information that are collected for each candidate concrete are subdivided into categories that represent general information, constituent material information, material composition information, plastic concrete properties, and hardened concrete properties.

2.3 Metallic Reinforcements

Reinforcing steel bars and wires are embedded in structural concrete to provide crack control and to enhance structural performance. These structural elements are typically manufactured from low-alloy carbon steels that have been rolled or drawn into standard sizes and shapes. Occasionally, stainless steel bars are rolled for special applications. The surfaces of these materials may be either smooth (plain) or provided with lugs or protrusions (deformed) to inhibit the movement of the bar or wire relative to the surrounding concrete. Fabricated metallic reinforcement

Table 3. Requirements for evaluating the quality of data and values.

Requirements for Determining the Quality of Data and Values	
Requirement Number	Requirement Description
1	Completeness of the material description
2	Stability of the material
3	Type of input from the references or sources [actual experimental observations (data) or results of previous analyses (values)]
4	Completeness of the data or values search
5	Completeness of the resources (completeness of the consideration given to all available data or values)
6	Quality of the references or sources
7	Availability of the data or values (completeness of data or values field coverage)
8	Consistency of the data or values with respect to related properties
9	Precision or scatter of the data or values
10	Uncertainty of the data or values (systematic error or bias)
11	Method used to determine the reported property (averaging, curve fitting, synthesization, derivation or extrapolation of the source data or values)

assemblies are also produced by welding different combinations of plain and deformed bars and wires together to form steel bar mats or wire fabric.

At the Structural Materials Information Center, data and information for plain, deformed, coated, and uncoated carbon and stainless steel bars, wires, mats, and welded wire fabric are being collected. The data and information that are collected for each candidate metallic reinforcement are subdivided into categories that represent general information, material composition information, and metallic reinforcement properties.

2.4 Prestressing Tendons

Structural concrete components are often post-tensioned to reduce cracking and to enhance structural performance. A post-tensioning system consists of a prestressing tendon and other hardware components that are assembled, stressed, and anchored to hardened concrete. These tendons may be individual high-strength steel bars, single or multiple seven-wire strands, or a number of steel wires. High-strength nonmetallic materials are being considered for post-tensioning systems, but these materials have not yet been used to construct or repair nuclear power plant structures.

At the Structural Materials Information Center, data and information for plain and deformed carbon steel bars, wires, and strand are being collected. The data and information that are collected for each candidate prestressing tendon material are subdivided into categories that represent general information, material composition information, and prestressing tendon properties.

2.5 Structural Steels

Structural steels are embedded in concrete to provide additional strength or to distribute loads and stresses to the concrete. These materials are made from either carbon or stainless steels that have been formed into plates, shapes, bars, tubes, or pipes.

At the Structural Materials Information Center, data and information for hot- and cold-rolled carbon and stainless steels are being collected along with bolting materials and special structural materials. The data and information that are collected for each candidate structural steel are subdivided into categories that represent general information, material composition information, and structural steel properties.

2.6 Rubbers

Many types of elastomeric or rubber components are used in nuclear power plant applications to create boundaries between fluids and gases or to serve as bearing pads and shock absorbers. Rubber is a material that is capable of recovering from large deformations quickly and forcibly.

At the Structural Materials Information Center, data and information for nine groups of rubber materials are being collected. The data and information that are collected for each candidate rubber are subdivided into categories that represent general information, material composition information, and rubber properties.

2.7 Other Materials

Many other types of metallic and nonmetallic material components are also embedded in or anchored to structural concrete. These components, which could be manufactured from aluminum, brass, cast iron, carbon steel, stainless steel, and plastic, are not intended to enhance the structural characteristics of the concrete but are required for other purposes such as process piping, floor and roof drains, electrical conduits, and leak-tight liners. Other components such as membranes, water stops, seals, and gaskets are used in nuclear power plant applications to restrict the flow of fluids through the concrete or between connected components. Except for structural steels and rubbers described in Sects. 2.5 and 2.6, properties for these materials are not currently being collected at the Structural Materials Information Center.

3. DESIGN CURVES

3.1 Long-Term and Environment-Dependent Material Properties

At least one long-term or one environment-dependent property is reported for each material in the Structural Materials Information Center. These properties are presented in the *Structural Materials Handbook* and the *Structural Materials Electronic Data Base* as design curves. Each design curve indicates either time-dependent or environment-dependent changes in material performance. Every design curve is assigned a unique four-digit property code. These codes provide a convenient way to distinguish one property from another and to identify material properties for comparison.

Each design curve is presented graphically and mathematically in Volumes 1 and 2 of the *Structural Materials Handbook*. These presentation formats provide two ways to evaluate time-dependent and environment-dependent behavior and to compute property values. The data and values that are used to develop each design curve are presented in Volume 2. The graphs that are reported in Volume 2 also appear in the *Structural Materials Electronic Data Base*.

Design curves can be used to establish material property values for current condition assessments of existing reinforced concrete structures in nuclear power plants and to estimate future material performance. The following sections describe how the design curves are developed and reported. A proposed method for using design curves is presented in Section 4.

3.2 Design Curve Development

Design curves are developed at the Structural Materials Information Center from test results obtained from references and information sources. Each design curve is unique because it represents material performance for only one particular material. When sufficient test data are not available, design curves may be synthesized using baseline values, reference properties, or minimum specified values. Synthesized design curves are validated by comparing them to design curves for other materials which have similar compositions and characteristics. The quality level evaluations of properties represented by synthesized design curves usually reflect gaps in the data or values and uncertainties in long-term performance. Each curve is presented graphically and mathematically in both the International System of Units (SI) and customary units.

3.2.1 Graphs

Design curves are prepared at the Structural Materials Information Center on a personal computer using EnPlot software (Ref. 5). EnPlot is an analytical engineering graphics program that was developed to operate on an IBM PC-AT or compatible using DOS 3.0 or higher. The computer must have a graphics adapter and compatible monitor and at least 512K of RAM. In order to run EnPlot efficiently, the computer must also include either a mouse or a digitizing tablet. EnPlot and Mat.DB (Ref. 4) are electronically compatible, but engineering graphs that appear in the *Structural Materials Electronic Data Base* can only be viewed using software features available in Mat.DB.

EnPlot is used to establish lines, polynomials, and other types of design curves and to plot data, values, and mathematical functions. Graphs produced with this software appear in Volumes 1 and 2 of the handbook and in electronic data base files.

3.2.2 Mathematical Equations

When sufficient supporting documentation or high-quality test results are available, design curves are developed by fitting data or values with mathematical equations using software features available in EnPlot. When a polynomial is used to represent a design curve, the curve is only valid between specified limits, and use of the equation to extrapolate beyond these limits is not recommended. When supporting documentation is insufficient, or when test results are not readily available, design curves are synthesized or derived using baseline values and reference properties.

The various types of long-term and environment-dependent properties that have been developed at the Structural Materials Information Center for concretes and metallic materials are identified in Tables 4 and 5. The methods and philosophy used to develop design curves are described in the following sections.

Table 4. Time-dependent and environment-dependent concrete properties in the Structural Materials Information Center.

Property Code	Property Description	Property Type	Notes
3612	Modulus of Elasticity vs Time	Temperature Dependent	1
3621	Compressive Strength vs Time	Time Dependent	2
3622	Compressive Strength vs Time	Temperature Dependent	1
3651	Bond Stress vs Slip	Environment Dependent	3

Note 1: Property values at various temperatures are reported. Design curves reflect results obtained from specimens tested at ambient temperature.
Note 2: Property values at various times are reported. Design curves reflect results obtained from specimens tested at ambient temperature.
Note 3: Property values for different environmental exposure conditions are reported. Design curves reflect results obtained from control specimens.

3.3 Materials

3.3.1 Portland Cement Concretes

Compressive strength versus time (Property Code 3621) design curves and other time-dependent properties are developed by fitting ambient-temperature test results with fourth-order polynomials. The time range of interest begins when the concrete is 28-days old and extends until the last specimen is tested. Fourth-order polynomials were selected as the standard because these equations can be used to represent nonlinear material performance that increases or decreases with time and because ambient-temperature, time-dependent properties for different concretes can be compared by simply equating the constant terms in the equations.

Table 5. Environment-dependent metallic material properties in the Structural Materials Information Center.

Property Code	Property Description	Property Type	Notes
3701	Engineering Stress-Strain Diagram	Ambient Conditions	1
3702	Engineering Stress-Strain Diagram	Temperature Dependent	2
3711	Tensile Yield Strength vs Temperature	Temperature Dependent	2
3712	Ultimate Tensile Strength vs Temperature	Temperature Dependent	2
3721	Ultimate Tensile Elongation vs Temperature	Temperature Dependent	2
3731	S-N Diagram	Environment Dependent	3

Note 1: Engineering stress-strain diagrams for different forms, sizes, thicknesses, etc. are reported. Design curves reflect results obtained from specimens tested at ambient temperature.
Note 2: Temperature-dependent engineering stress-strain diagrams for different forms, sizes, thicknesses, etc. are reported. Design curves reflect results obtained from specimens tested at ambient temperature.
Note 3: Fatigue property values for different environmental exposure conditions are reported. Design curves reflect results obtained from specimens tested at ambient temperature.

For concretes older than 10 years, two fourth-order polynomials are used to represent the design curve. One equation represents material performance from 28 days to 10 years and the other equation represents material performance after 10 years. Due to software limitations, the development of two-part design curves requires assistance from the preparer because EnPlot does not have features for combining equations or for ensuring continuity.

Temperature-dependent modulus of elasticity versus time (Property Code 3612) and temperature-dependent compressive strength versus time (Property Code 3622) test results are tabulated and plotted on graphs presented in Volume 2. Also included with the graphical and tabulated results are the ambient-temperature design curves which are developed from control specimen test results. Unfortunately, design curves cannot be developed for the temperature-dependent results because exposure conditions and testing methods are typically unique.

Bond stress versus slip properties (Property Code 3651) are developed using fourth-order polynomials and control specimen test results. These results are used so that the bond between concretes and reinforcing steels can be easily compared. Fourth-order polynomials were selected as the standard because these equations can be used to represent nonlinear bond-slip behavior. Test results obtained from specimens exposed to other environmental conditions are presented in

Volume 2. Design curves for these conditions are not developed because exposure conditions and testing methods are typically unique.

3.3.2 Metallic Materials

Engineering stress-strain diagrams (Property Codes 3701 and 3702) are developed for metallic reinforcement, prestressing tendon, and structural steel materials. Each diagram includes a design curve that is synthesized from minimum specified tensile strength or elongation values and reported modulus of elasticity values. These design curves, which are only valid under ambient-temperature conditions, are used to establish material property values and to compare one metallic material to another. Test results obtained at various temperatures for different material forms, sizes, and thicknesses are tabulated and plotted in Volume 2. Design curves for these conditions are not developed because exposure conditions and testing methods are typically unique.

Various temperature-dependent properties including tensile yield strength (Property Code 3711), ultimate tensile strength (Property Code 3712), and ultimate tensile elongation (Property Code 3721) are developed for metallic reinforcement, prestressing tendon, and structural steel materials. Each graph includes a design curve that was synthesized from minimum specified tensile strength or elongation values and reported modulus of elasticity values. These design curves, which are only valid under ambient-temperature conditions, are used to establish material property values and to compare one metallic material to another. Test results obtained at various temperatures for different material forms, sizes, and thicknesses are tabulated and plotted in Volume 2. Design curves for these conditions are not developed because exposure conditions and testing methods are typically unique.

Fatigue properties of metallic reinforcements are also developed. One of these properties is presented as an S-N diagram (Property Code 3731) in which the stress range is plotted against the number of cycles. Each S-N diagram includes a design curve that reflects a lower bound to fatigue test results. Each design curve is also represented by mathematical equations that can be used to compute the number of cycle that correspond to a specific stress range.

3.3.3 Rubbers

Temperature-dependent hardness versus time (Property Code 3662) test results are tabulated and plotted on graphs presented in Volume 2. Also included with the graphical and tabulated results are the ambient-temperature design curves which are developed from control specimen test results. Unfortunately, design curves cannot be developed for the temperature-dependent results because exposure conditions and testing methods are typically unique.

4. MATERIAL PROPERTIES USING A COMPARATIVE APPROACH

4.1 Introduction

The structural integrity of a concrete structure in a nuclear power plant can be evaluated using either a load test or an analytical approach. However, uncertainties in the physical characteristics of the structure, doubts concerning its exposure conditions and service history, and incomplete knowledge about the current properties of the structural materials in the structure can complicate the evaluation process (Ref. 9). A load test method and an analytical approach for conducting a strength evaluation of existing concrete buildings have been established by ACI Committee 437 (Ref. 10).

A load or proof test can be conducted on all or only part of an existing concrete structure. These tests are particularly applicable to structures and components such as cranes and lifting devices that must resist prescribed loads. Normally, a load test is not considered unless an analytical approach is impractical or unsatisfactory. However, for certain critical structures such as concrete containment vessels in nuclear power plants, a structural integrity test (SIT) must be performed before the vessel can be placed in service (Ref. 11). In this particular test, the entire containment vessel is pressurized.

The structural integrity of an existing concrete structure can also be evaluated using an analytical approach which involves a theoretical stress analysis. This analysis must take into account the physical characteristics of the structural members and their connection details, material properties, the quality of construction, and the present condition of the structure. For this analysis to be reliable, properties of the materials in their current condition within the structure must be obtained and used in the analysis. Typically, two methods are used to obtain these properties. One method relies on nondestructive testing techniques. When test instruments are calibrated or certified using standardized procedures, this method can provide the needed properties. The other method requires that material samples be removed from the structure for testing. Visual examinations combined with destructive and nondestructive testing can also be used to characterize the overall condition of the materials in a structure. Inspections, sampling, and nondestructive testing are not feasible, however, unless the materials are accessible. Generally, a comparative approach must be used to obtain the properties that are needed.

4.2 Comparative Approach

A third way to obtain the properties needed for a theoretical stress analysis uses a comparative approach. In this approach, the performance characteristics of other materials that have been exposed to similar service or environmental conditions are used to establish properties for materials in an existing structure. This approach can be used for almost any structure because it does not require removal of material samples or access for nondestructive testing. In nuclear power plants where access to structural concrete components is restricted or removal of material samples is prohibited, this approach may be the only feasible way to establish the properties needed for a theoretical stress analysis. This approach has been used successfully in conjunction with material sampling and nondestructive testing to obtain mechanical properties for use in evaluating the structural integrity of fire-damaged reinforced concrete walls in a nuclear power plant (Ref. 12). This approach has also been used to develop a standard test method for comparing concretes on the basis of the bond developed with the reinforcing steel (Ref. 13).

Establishing material properties using the comparative approach requires a large knowledge base of long-term and environment-dependent material behavior such as the one being developed at the Structural Materials Information Center. The data and information in this structural materials property data base have been formatted so that materials with similar compositions and similar baseline or reference properties can be easily identified for comparison. Procedures for using the data base to establish current property values for materials in existing concrete structures and for estimating the future performance of these materials are described below.

4.3 Establishing Current Property Values

A step-by-step procedure for establishing current property values for materials in an existing concrete structure is listed below. This procedure should only be used as a guide, however, because each concrete structure has unique characteristics and features, and each theoretical stress analysis must be performed on a case-by-case basis.

1. Collect background information so that the structural materials in the existing structure can be uniquely identified.
2. Establish the service history for each structural material.
3. Identify the types of material properties needed for the theoretical stress analysis.
4. Search the data base to identify materials with compositions, characteristics, and exposure conditions similar to the structural materials in the structure.
5. From the properties reported for these materials, select properties that adequately reflect the service history of the structural materials in the existing structure.
6. Using the design curves in Volume 1 and the supporting documentation in Volume 2 of the *Structural Materials Handbook* reported for these properties, establish numerical values for each property needed for the theoretical stress analysis.

Details of each step in this procedure are described below.

4.3.1 Background Information

Construction specifications, structural drawings, quality assurance records, laboratory test reports, mill certificates, batch tickets, inspection reports, and other historical reference documents developed when the structure was being built, modified, or repaired are usually good sources of background information.

4.3.2 Service History

Information that describes normal plant operations, environmental exposure conditions, and abnormal occurrences can be used to establish the service history for each structural material in an existing concrete structure. This type of information can often be obtained from logbooks, inspection reports, inservice test records, and other documents such as repair manuals and maintenance procedures.

4.3.3 Properties Needed for a Theoretical Stress Analysis

After the structural materials in an existing concrete structure have been identified and their service histories established, the types of properties needed for a theoretical stress analysis can be identified. Mechanical, thermal, physical, and other properties are some of the types of material properties that may be needed. Although these properties must be established on a case-by-case basis, a theoretical stress analysis intended to verify the structural adequacy of an existing concrete structure usually requires mechanical properties such as the compressive strength and modulus of elasticity of the concrete, yield strength of the metallic reinforcements, ultimate tensile strength of prestressing tendon materials, and yield strength and modulus of elasticity of embedded structural steels.

4.3.4 Data Base Search Procedure

In order to screen materials from the data base that have compositions, characteristics, and exposure conditions similar to the structural materials in an existing structure, data base search parameters must be established. These parameters need to reflect the compositional makeup of the material as well as baseline or reference property values derived from background information.

The data base has been set up so that materials can be screened using either material codes or property codes as search parameters. Each material in the data base has been assigned a unique seven-character material code such as the one shown in Fig. 1, and each property in the data base has been assigned a unique four-digit property code as shown in Table 1.

After search parameters have been established and material properties needed for the theoretical stress analysis have been identified, the data base screening process can be initiated. One way to search the data base is to examine the appropriate chapter in Volumes 1, 2, and 3 of the *Structural Materials Handbook.* A second way is to use the menu-driven software features in Mat.DB (Ref. 4) to "sift" the appropriate *Structural Materials Electronic Data Base* file. The types of structural materials that are currently available from the Structural Materials Information Center, and the formats in which data and information are presented are listed in Table 6.

Table 6. Types of materials available from the Structural Materials Information Center.

Material Type	Presentation Format	
	Structural Materials Handbook Volumes 1, 2, and 3	*Structural Materials Electronic Data Base* File Name
Portland Cement Concrete	Chapter 01	CONCRETE.DB
Metallic Reinforcement	Chapter 02	REBAR.DB
Prestressing Tendon	Chapter 03	TENDON.DB
Structural Steel	Chapter 04	STEEL.DB
Rubber	Chapter 05	RUBBER.DB

Specific rules and recommended guidelines for screening the handbook and the electronic data base cannot be firmly established because, for certain structural materials in the existing structure, many types of search parameters may be involved and numerous searches may be required to yield materials that are considered similar. Each material that is identified by the search will be represented by a unique seven-character material code. These codes are used consistently in the *Structural Materials Handbook* and the *Structural Materials Electronic Data Base* to distinguish one material from another.

4.3.5 Appropriate Properties

The long-term and environment-dependent properties reported for each material identified by the search must now be examined. Properties which are not needed for the theoretical stress analysis and properties which do not adequately reflect the service history for the corresponding material in the existing structure can be eliminated from further consideration. For each property that remains, a numerical property value can now be determined.

4.3.6 Numerical Property Values

A convenient way to establish numerical values for these properties is to use the mathematical equations for the design curves presented in Volume 1 of the *Structural Materials Handbook.* These equations are valid over specified limits, and use of these equations beyond these limits is not recommended. Another way to establish property values is to use the engineering graphs and the tabulated data or values presented in Volume 2 of the *Structural Materials Handbook.* The equations and supporting documentation are presented in both the International System of Units (SI) and customary units. Each numerical property value can be determined using either type of units.

4.4 Estimating Future Properties

A step-by-step procedure for estimating future properties of materials is listed below. This procedure is applicable to structural materials in existing concrete structures that are required to remain in service for a specified period of time.

1. Establish current properties for the structural materials in the existing structure using the procedure described above.
2. Establish the continued service period, and predict the service conditions for each structural material during this continued service period.
3. From the properties reported in the data base for these materials, select properties that adequately reflect the continued service period and the predicted service conditions for the structural materials in the existing structure.
4. Using the design curves in Volume 1 and the supporting documentation in Volume 2 of the *Structural Materials Handbook* reported for these properties, establish numerical values for each property at the end of the continued service period.

Details of each step in this procedure are described below.

4.4.1 Current Properties

A procedure for establishing current material properties is presented in Section 4.3. This procedure should be used to establish numerical property values for the structural materials in an existing concrete structure.

4.4.2 Future Service Conditions

In order to estimate changes in properties of structural materials in an existing concrete structure due to continued service, two parameters must be identified and quantified. The time period the structure is to remain in service must be established, and the future service conditions for each structural material must be predicted.

The remaining service life for many existing concrete structures cannot be accurately defined because long-term plans have never been endorsed. For other structures, such as the concrete structures in an operating nuclear power plant, service life is clearly defined by the terms and conditions of the plant operating license issued by the U. S. Nuclear Regulatory Commission.

When operating procedures are not expected to change during the continued service period, the previous service history for the structural materials can be used to estimate future service conditions. However, when operating procedures are expected to change during the continued service period, future service conditions must be predicted. These predictions need to reflect service history factors, facility modifications, revised loading conditions, and short-term and long-term exposure conditions that may occur during the continued service period.

4.4.3 Appropriate Properties

The long-term and environment-dependent properties reported in the data base for each of the structural materials in the existing structure must now be examined. Properties which do not adequately reflect the predicted service conditions must be eliminated from further consideration. For each property that remains, numerical property values which correspond to prescribed times in the future can now be determined.

4.4.4 Numerical Property Value Changes

In order to estimate the change in a material property due to continued service, two property values must be established. The first value must reflect the current condition of the material. This value can be the one that was established based on the service history of the material, or it can be one that reflects the predicted service conditions. The second value must reflect the predicted service conditions at the end of the service life. The difference between these two numerical property values represents the change due to continued service.

A convenient way to establish numerical value changes for these properties is to use the mathematical equations for the design curves presented in Volume 1 of the *Structural Materials Handbook*. These equations are valid over specified limits, and use of these equations beyond these limits is not recommended. Another way to establish property values is to use the engineering graphs and the tabulated data or values presented in Volume 2 of the *Structural Materials Handbook*. The equations and supporting documentation are presented in both the International System of Units (SI) and customary units. Each numerical property value can be determined using either type of units.

5. EXAMPLE USES FOR THE STRUCTURAL MATERIALS PROPERTY DATA BASE

5.1 Potential Applications

The structural materials property data base is useful for establishing numerical property values for use in theoretical stress analyses of reinforced concrete structures in nuclear power plants. These analyses are required when structural modifications or repairs are being considered or when the effects of changes in operating conditions on structural performance are being assessed. The data base could also be used to predict the future performance of structural materials that are to remain in service. The following sections contain examples of how the data base could be used to establish material property values for use in theoretical stress analyses.

5.2 Plant Modification Example

In this example, a utility is considering alternatives for increasing the capacity of an overhead crane in one of its nuclear power plants. This crane is supported by reinforced concrete beams and columns which are part of a safety-related structure.

In order to assess the current structural capacity of the reinforced concrete beams and columns, the compressive strength of the concrete and the tensile yield strength of the reinforcing bars are needed. One method that could be used to establish these properties is to obtain material samples for destructive testing. However, in this case, this method is not feasible because the beams and columns are very heavily reinforced, and removal of concrete cores and reinforcing bar samples would degrade the structure.

An alternative way to obtain these properties is to use the comparative approach described in Sect. 4.2. The following paragraphs describe how this approach could be used to establish property values for the concrete and the metallic reinforcements that were used to construct the reinforced concrete beams and columns that support the crane.

5.2.1 Concrete Properties

The first step in the comparative approach process begins with the collection of background information about the concrete from historical records and plant data files. Based on original construction documents, these beams and columns were cast in 1962 using a normal-weight, portland cement concrete. Documents showing the mix design, baseline properties, and plastic concrete properties for this concrete are available. A review of plant records and operating logs revealed that the concrete in these beams and columns has never been exposed to freezing and thawing conditions, to elevated temperatures, or to moist or harsh chemical environments. A recent visual inspection of the beams and columns was performed, and the inspection report indicates that the surface of the concrete was in excellent condition.

Before a theoretical stress analysis of the reinforced concrete beams and columns can be performed, the current compressive strength of the concrete must be determined. Other mechanical properties such as the modulus of elasticity, shear strength, tensile strength, and flexural strength of the concrete may also be required, but these particular properties can be estimated using the compressive strength value.

The next step in the comparative approach process is to identify other concretes in the data base that have compositions which are similar to the concrete that was used to construct the beams and columns. Using the mix proportions and the baseline information, an electronic search of the data base reveals that several normal-weight, portland cement concretes with compositions, characteristics, and exposure conditions similar to the concrete in the beams and columns are included in the data base. Each of these concretes includes time-dependent compressive strength versus time design curves and mathematical equations that reflect at least 30 years of behavior.

The final step in the comparative approach process is to establish the current, 30-year compressive strength of the concrete used to construct the beams and columns. This is accomplished by first computing the 28-day and the 30-year compressive strength values for similar concretes in the data base. Then, by using either the average difference between these values, or the average percent change in these values, the 28-day compressive strength of the concrete used to construct the beams and columns is estimated.

5.2.2 Metallic Reinforcement Properties

The metallic reinforcements that were used in the reinforced concrete beams and columns that support the crane conformed to ASTM A 15 requirements for intermediate grade plain and deformed reinforcing bars. Construction drawings indicate that No. 10 deformed bars were used as the primary flexural and axial reinforcement, and 12 mm (1/2 in.) diameter plain bars were used for the column stirrups and the shear reinforcement.

The material properties that are needed for a theoretical stress analysis include the modulus of elasticity and the tensile yield strength of the steel. Although the construction records did not include engineering stress-strain diagrams, these records indicate that the yield strength of these bars was at least equal to the minimum value specified in ASTM A 15 which is 276 MPa (40 ksi).

Data and information for uncoated plain and deformed reinforcing bars that conform to ASTM A 15 requirements for intermediate grade steel have been collected at the Structural Materials Information Center. Based on baseline information and design curves reported for these materials, the following properties are considered suitable for use in a theoretical stress analysis of the reinforced concrete beams and columns that support the crane. These property values include a modulus of elasticity of 200 GPa (29,000 ksi), a tensile yield strength of 276 MPa (40 ksi), and engineering stress-strain diagrams that reflect elastic-plastic material behavior at ambient temperatures.

5.3 Continued Service Performance Example

This example is a continuation of the plant modification example described in Sect. 5.2. In this case, the future compressive strength of the concrete will be estimated so that the structural capacity of the reinforced concrete beams and columns after 40 years of service can be determined. During this 10-year continued service period, the environmental conditions around the beams and columns are not expected to change significantly.

5.3.1 Concrete Properties

Before the 40-year compressive strength of the concrete can be estimated, the current compressive strength of the concrete must be established. Using the procedure described in Sect. 5.2.1 and the compressive strength versus time design curves presented in the data base, the estimated average 30-year compressive strength of the concrete in the beams and columns is established.

A review of data and information reported in the data base for similar concretes having up to 50 years of inservice performance test results indicates that the compressive strength of concretes exposed to inside environments would be expected to increase only about 3 percent between ages of 30 and 40 year. Therefore, the compressive strength of the concrete used to construct the beams and columns can be assumed to increase by approximately 3 percent over the next 10 years.

5.3.2 Metallic Reinforcement Properties

Since the environmental conditions around the beams and columns are not expected to change significantly during the 10-year continued service period, the reinforcing bars should not experience degradation, and the 40-year properties of the reinforcing bars should be the same as the 30-year properties reported in Sect. 5.2.2.

5.4 Reactor Pressure Vessel Annealing Example

In this example, an electrical utility is investigating the possibility of annealing the reactor pressure vessel at its nuclear power plant. Annealing is being considered because it is a feasible way to increase the toughness of the pressure vessel steel and thereby extend the service life of the plant. In order to properly anneal this particular steel, the temperature of affected parts of the vessel must be maintained at 482°C (900 °F) for at least 24 hours. Results of a thermal analysis indicate that during the annealing operation certain reinforced concrete components located adjacent to the reactor vessel to provide support and shielding functions could be exposed to temperatures as high as 177°C (350°F) for up to 7 days.

Before annealing can be considered feasible, the effects of elevated temperature on structural performance of the reinforced concrete must be assessed and evaluated using results from theoretical stress analyses. These analyses must reflect the current properties of the materials used to construct the affected structural components as well as the properties of these materials after the annealing has been completed. The following paragraphs describe a way in which the comparative approach could be used to establish current and future property values for the concrete, metallic reinforcements, and structural steel used to construct the walls and floors adjacent to the reactor pressure vessel.

5.4.1 Concrete Properties

Construction drawings indicate that a normal-weight, portland cement concrete was used to construct the walls and floors adjacent to the reactor pressure vessel. The mix design, baseline properties, and plastic concrete properties for this concrete are available. Based on construction records, this concrete was cast in 1972. Since then, these walls and floors have not been exposed to freezing and thawing conditions, to significant elevated temperatures, to abnormal or severe loading conditions, or to harsh chemical environments.

In order to estimate the performance of these structural components before, during, and after the annealing operation, theoretical stress analyses must be performed using the current compressive strength of the concrete and the compressive strength of the concrete after exposure to 177°C (350°F) for 7 days. Because the area adjacent to the reactor pressure vessel is not accessible for routine inspection or remote sample removal, these properties cannot be developed using standard destructive or nondestructive testing techniques. Other indirect methods, such as the comparative approach described in Sect. 4.2, must be used. The following paragraphs describe how the data and information in the structural materials property data base could be used to establish these property values.

Using the mix proportions and baseline information, an electronic search of the data base reveals that several normal-weight, portland cement concretes with compositions, characteristics, and exposure conditions similar to the concrete in the beams and columns are included in the structural materials property data base. Each of these concretes includes time-dependent compressive strength design curves and mathematical equations that reflect at least 30 years of behavior. The data base search also identified other concretes with similar compositions and characteristics that have been exposed to elevated temperatures for selected periods of time. Each of these concretes includes compressive strength design curves, mathematical equations, and supporting documentation that reflect time-dependent, elevated-temperature behavior.

The current compressive strength of the concrete used to construct the walls and floors adjacent to the reactor pressure vessel can be established by first computing the 28-day and the 20-year compressive strength values for similar concretes identified in the data base. Then, by using either the average difference between these values, or the average percent change in these values, the 28-day compressive strength of the concrete used to construct the walls and floors is appropriately adjusted.

The compressive strength of this concrete after 7 days of exposure to 177°C (350°F) can be estimated using compressive strength versus time design curves and supporting documentation presented in the data base for the concretes that were tested at elevated temperatures. This is accomplished by locating similar concretes in the data base that have been exposed to elevated temperatures and determining the average relative change in compressive strength values for these concretes due to exposure to 177°C (350°F) for 7-days. Then, the current 20-year compressive strength of the affected concrete is appropriately adjusted using this average relative change value. Using this procedure, the estimated average compressive strength of the concrete in the walls and floors after exposure to 177°C (350°F) for 7 days is 59 percent of the current 20-year compressive strength of the concrete. Due to conservatism in the original design, however, the compressive strength of this concrete after exposure to 177°C (350°F) for 7 days is still above the specified compressive strength design value.

5.4.2 Metallic Reinforcement Properties

The construction drawings indicate that various sizes of plain and deformed reinforcing bars were used to construct the reinforced concrete walls and floors adjacent to the reactor pressure vessel. Quality assurance files and construction records indicate that these bars conformed to ASTM A 615, Grade 60 requirements and that the yield strength of these bars was at least equal to the minimum specified value of 414 MPa (60 ksi).

Like the concrete, these bars will be exposed to elevated temperatures during the vessel annealing operation. The material properties that are needed for theoretical stress analyses include modulus of elasticity, tensile yield strength, ultimate tensile strength, ultimate tensile elongation, and thermal coefficient of expansion of these metallic reinforcements.

Data and information for uncoated plain and deformed reinforcing bars that conform to ASTM A 615, Grade 60 requirements have been collected at the Structural Materials Information Center. Using this data and information, property values at ambient temperature and at 177°C (350°F) can be determined.

5.4.3 Structural Steel Properties

The construction drawings also indicate that the reinforced concrete walls and floors adjacent to the reactor pressure vessel contain hot-rolled structural steel shapes embedded in the concrete. These structural steel members, which were fabricated from ASTM A 36 structural steel, were included in the design to distribute concentrated loads to the foundation.

Like the concrete and the reinforcing bars, these structural steel members will also be exposed to elevated temperatures resulting from the annealing operations. The material properties that are needed for theoretical stress analyses include modulus of elasticity, tensile yield strength, ultimate tensile strength, ultimate tensile elongation, and thermal coefficient of expansion of this structural steel.

Data and information for ASTM A 36 have been collected at the Structural Materials Information Center. Using this data and information, property values at ambient temperature and at 177°C (350°F) can be determined.

6. SUMMARY

The Structural Materials Information Center was established at the ORNL as part of the SAG Program to serve as a collection point for long-term and environment-dependent material properties and to prepare and distribute these data and information for use by the NRC in evaluating nuclear power plant structures for continued service. The data and information that are collected are being presented in two complementary formats. The *Structural Materials Handbook* is an expandable, hard-copy reference document that contains the complete data base for each material. The *Structural Materials Electronic Data Base* is accessible using an IBM-compatible personal computer and contains data and information taken from the handbook.

Research activities at the Structural Materials Information Center have focused on five main categories of materials including portland cement concretes, metallic reinforcements, prestressing tendons, structural steels, and rubbers. Proposed activities will focus on collection, assembly, and formatting of data and information for these materials as well as for other nonstructural materials that are often embedded in concrete.

In addition to reference properties and baseline information, at least one long-term or one environment-dependent property is reported for each material in the Structural Materials Information Center. These properties are presented in the *Structural Materials Handbook* and the *Structural*

Materials Electronic Data Base as design curves. Each design curve indicates either changes in material performance over a prescribed period of time due to an ambient-temperature aging factor such as exposure to inside atmospheric conditions or variations in material performance due to a specific environmental condition such as elevated temperature.

The data and information presented in the structural materials property data base are potentially useful for establishing numerical property values for use in theoretical stress analyses of reinforced concrete structures in nuclear power plants. These analyses are required when structural modifications or repairs are being considered or when the effects of changes in operating conditions on structural performance are being assessed. The data base could also be used to predict the future performance of structural materials that are to remain in service.

In this report, a method for establishing material property values for use in theoretical stress analyses of existing reinforced concrete structures using a comparative approach has been presented. In this approach, the performance characteristics of other materials that have been exposed to similar service or environmental conditions are used to establish properties for materials in an existing structure. This approach can be used for almost any structure because it does not require removal of material samples or access for nondestructive testing. In nuclear power plants where access to structural concrete components is restricted or removal of material samples is prohibited, this approach may be the only feasible way to establish the properties needed for a theoretical stress analysis.

Examples of how the comparative approach could be used to establish current and future material property values are provided. In one example, the current compressive strength of a 30-year-old portland cement concrete is established and the change in compressive strength of the concrete after 10 years of continued service is estimated. In another example, changes in portland cement concrete, metallic reinforcement, and structural steel properties due to thermal exposure resulting from annealing of the reactor pressure vessel are established. These properties are required so that the effects of elevated temperature on structural performance can be assessed.

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DATA BASE ON STRUCTURAL MATERIALS AGING PROPERTIES

BARRY OLAND

OAK RIDGE NATIONAL LABORATORY

OAK RIDGE, TENNESSEE

NRC AGING RESEARCH CONFERENCE

TECHNICAL SESSION 6B

STRUCTURES, STRUCTURAL COMPONENTS, AND CAST STAINLESS STEEL

MARCH 26, 1992

WASHINGTON, DC

*Research sponsored by the Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission under Interagency Agreement 1886-8084-5B with the U.S. Department of Energy under Contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

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MARCH 26, 1992
WASHINGTON, DC

A STRUCTURAL AGING PROGRAM HAS BEEN INITIATED AT THE OAK RIDGE NATIONAL LABORATORY

- SPONSOR
  - U. S. NUCLEAR REGULATORY COMMISSION.
- PURPOSE
  - IDENTIFY POTENTIAL STRUCTURAL SAFETY ISSUES RELATED TO CONTINUED SERVICE OF NUCLEAR POWER PLANTS.
- SCOPE AND OBJECTIVES
  - IDENTIFY DEGRADATION PROCESSES THAT AFFECT CONCRETE.
  - IDENTIFY ISSUES TO BE CONSIDERED DURING THE REVIEW OF NUCLEAR POWER PLANTS FOR CONTINUED SERVICE.
  - EVALUATE INSERVICE INSPECTION AND STRUCTURAL ASSESSMENT PROGRAMS.
  - IDENTIFY ISSUES THAT REQUIRE ADDITIONAL RESEARCH.

ONE TASK FOCUSES ON DEVELOPMENT OF A STRUCTURAL MATERIALS INFORMATION CENTER

- LONG-TERM AND ENVIRONMENT-DEPENDENT PROPERTIES FOR VARIOUS MATERIALS ARE BEING COLLECTED.
  - PORTLAND CEMENT CONCRETES
  - METALLIC REINFORCEMENTS
  - PRESTRESSING STEELS
  - STRUCTURAL STEELS
  - RUBBERS
- THESE PROPERTIES ARE THEN ORGANIZED AND ASSEMBLED INTO A STRUCTURAL MATERIALS PROPERTY DATA BASE.
- THE DATA BASE WILL BE USED TO:
  - ESTIMATE CURRENT PROPERTY VALUES FOR MATERIALS IN EXISTING STRUCTURES
  - PREDICT FUTURE MATERIAL PERFORMANCE

THE DATA BASE IS PARTICULARLY APPLICABLE TO STRUCTURAL EVALUATIONS THAT ARE BASED ON THEORETICAL STRESS ANALYSES

- ANALYSES ARE REQUIRED WHEN:
  - THE ULTIMATE CAPACITY OF A STRUCTURAL CONCRETE COMPONENT IS BEING VERIFIED
  - CHANGES IN OPERATING CONDITIONS ARE BEING CONSIDERED
  - EFFECTS OF ELEVATED TEMPERATURE EXPOSURE ON STRUCTURAL PERFORMANCE ARE BEING ASSESSED
  - STRUCTURAL MODIFICATIONS OR REPAIRS ARE BEING PLANNED
- ANALYSES ARE PERFORMED WHEN LOAD TEST ARE IMPRACTICAL OR UNSATISFACTORY.

THE DATA BASE IS PRESENTED IN TWO COMPLEMENTARY FORMATS

STRUCTURAL MATERIALS HANDBOOK

STRUCTURAL MATERIALS ELECTRONIC DATA BASE

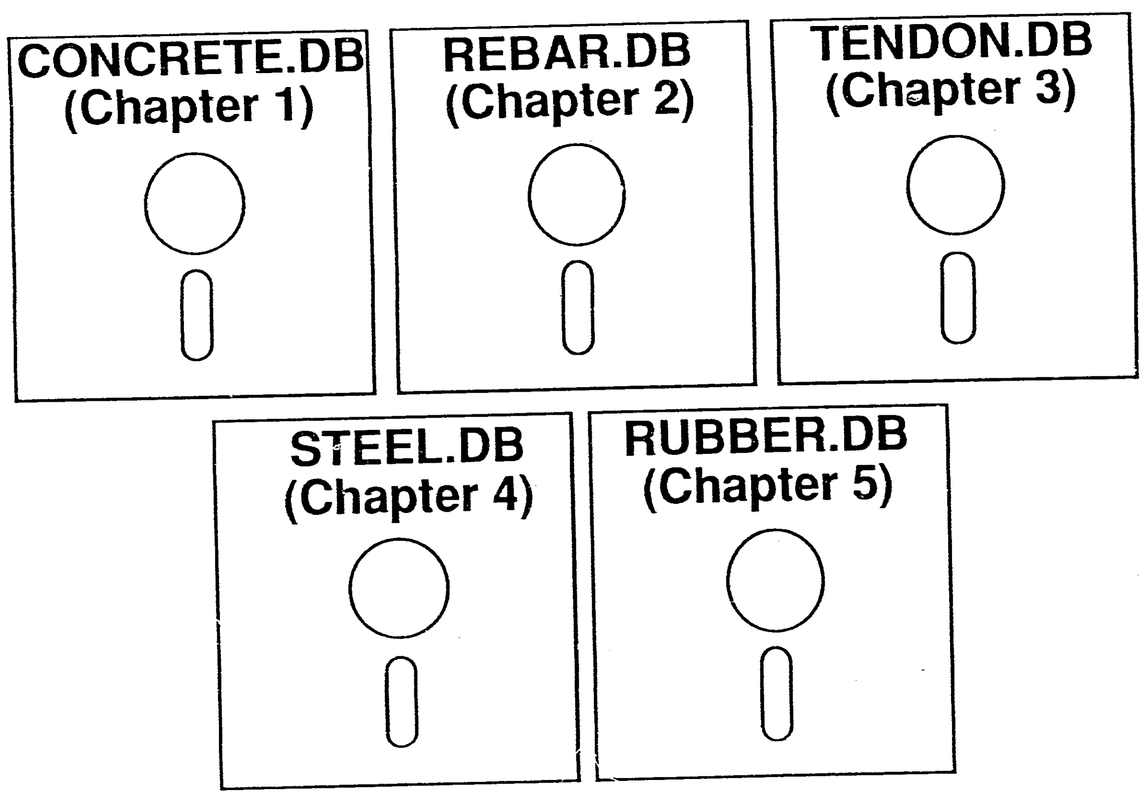
THE STRUCTURAL MATERIALS HANDBOOK IS A HARD-COPY REFERENCE DOCUMENT THAT IS PRESENTED IN FOUR VOLUMES

- VOLUMES 1, 2, AND 3 ARE SUBDIVIDED INTO CHAPTERS. EACH CHAPTER CORRESPONDS TO A SPECIFIC TYPE OR CATEGORY OF MATERIAL.
- VOLUME 4 CONTAINS ORGANIZATION AND REVISION CONTROL PROCEDURES.
- EACH VOLUME IS PUBLISHED IN A LOOSE-LEAF BINDER.

STRUCTURAL MATERIALS HANDBOOK	STRUCTURAL MATERIALS HANDBOOK	STRUCTURAL MATERIALS HANDBOOK	STRUCTURAL MATERIALS HANDBOOK
Volume 1	Volume 2	Volume 3	Volume 4
Design Values	Supporting Documen-tation	Material Data Sheets	Revision Control Procedures

THE STRUCTURAL MATERIALS ELECTRONIC DATA BASE IS AN ELECTRONICALLY ACCESSIBLE VERSION OF THE HANDBOOK

- Mat.DB — ASM INTERNATIONAL
- EACH ELECTRONIC DATA BASE FILE CORRESPONDS TO A CHAPTER IN THE HANDBOOK.



DATA AND INFORMATION FOR 61 MATERIALS ARE CURRENTLY REPORTED IN THE DATA BASE

- PORTLAND CEMENT CONCRETES
  - MODULUS OF ELASTICITY VERSUS TIME
  - COMPRESSIVE STRENGTH VERSUS TIME
  - BOND STRESS VERSUS SLIP
- METALLIC MATERIALS
  - ENGINEERING STRESS-STRAIN DIAGRAMS
  - YIELD STRENGTH VERSUS TEMPERATURE
  - TENSILE STRENGTH VERSUS TEMPERATURE
  - TENSILE ELONGATION VERSUS TEMPERATURE
  - S-N DIAGRAMS
- RUBBERS
  - HARDNESS VERSUS TIME

EACH MATERIAL IS REPRESENTED BY A SEVEN-CHARACTER MATERIAL CODE

MATERIAL CODE ARRANGEMENT

01	C	A	001
CHAPTER INDEX (01 - 99)	GROUP INDEX (A - Z)	CLASS INDEX (A - Z)	IDENTIFIER INDEX (001 - 999)

- CHAPTERS REPRESENT MATERIAL TYPE.
- GROUPS SUBDIVIDE MATERIALS HAVING SIMILAR DISTINGUISHING QUALITIES.
- CLASSES ARRANGE GROUPS OF MATERIALS WITH SIMILAR COMPOSITIONAL TRAITS.
- IDENTIFIERS DIFFERENTIATE BETWEEN MATERIALS FROM THE SAME CHAPTER, GROUP, AND CLASS.

THE DATA BASE INCLUDES PROPERTIES FOR PORTLAND CEMENT CONCRETES

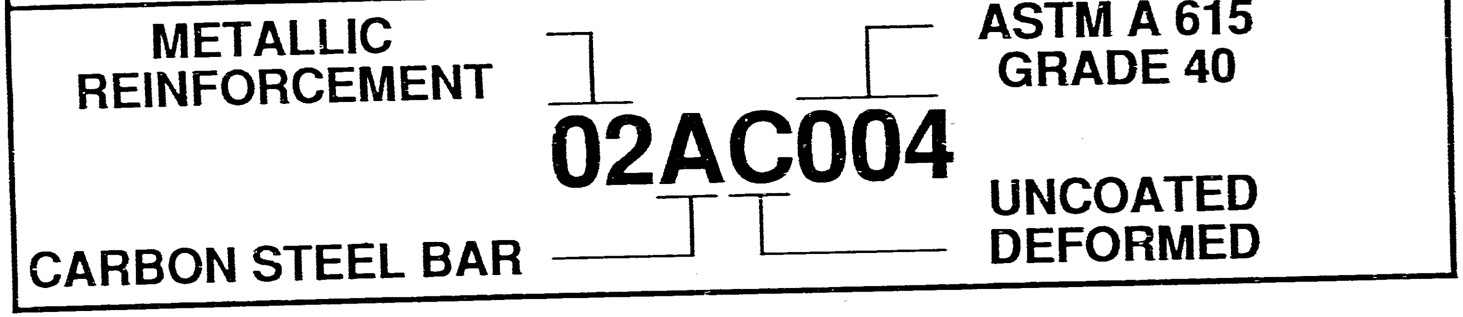
CHAPTER 1		CONCRETE.DB	
GROUP	DESCRIPTION	CLASS	DESCRIPTION
A	INSULATING	A	STONE
B	STRUCTURAL LIGHTWEIGHT	B	GRAVEL
C	NORMAL-WEIGHT	C	MANUFACTURED OR BY-PRODUCT
D	HEAVYWEIGHT		

01CA001

- 01 — PORTLAND CEMENT CONCRETE
- C — NORMAL-WEIGHT
- A — STONE AGGREGATE
- 001 — SERIES B, LANNON DOLOMITE

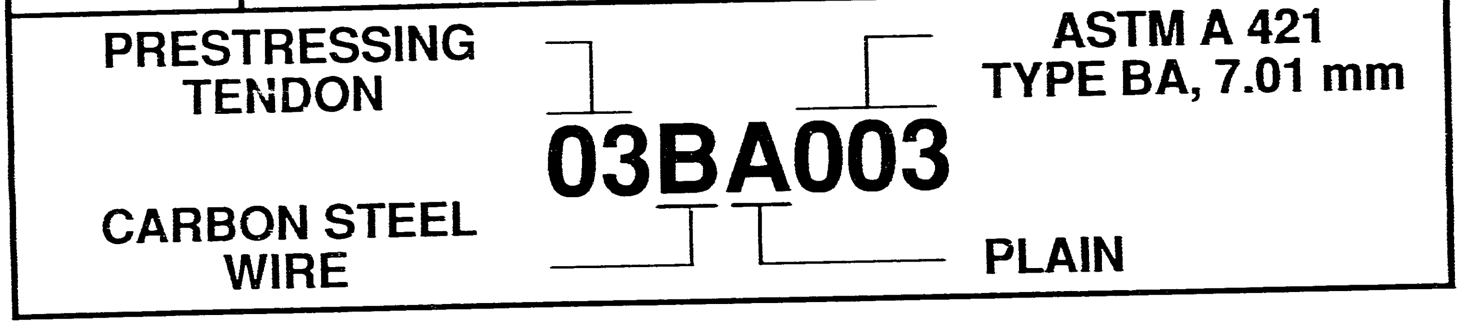
THE DATA BASE INCLUDES PROPERTIES FOR METALLIC REINFORCEMENTS

CHAPTER 2		REBAR.DB	
GROUP	DESCRIPTION	CLASS	DESCRIPTION
A	CARBON STEEL	A	UNCOATED PLAIN
B	STAINLESS STEEL	B	COATED PLAIN
C	STEEL WIRES	C	UNCOATED DEFORMED
D	MATS / FABRIC	D	COATED DEFORMED



THE DATA BASE INCLUDES PROPERTIES FOR PRESTRESSING TENDONS

CHAPTER 3		TENDON.DB	
GROUP	DESCRIPTION	CLASS	DESCRIPTION
A	CARBON STEEL BARS	A	PLAIN
B	CARBON STEEL WIRES	B	DEFORMED
C	STRAND		
D	NONMETALLIC		



THE DATA BASE INCLUDES PROPERTIES FOR STRUCTURAL STEELS

CHAPTER 1		CONCRETE.DB	
GROUP	DESCRIPTION	CLASS	DESCRIPTION
A	CARBON STEEL	A	HOT-ROLLED OR COLD-ROLLED
B	STAINLESS STEEL	B	BOLTS
		C	SPECIAL MATERIALS

STRUCTURAL STEEL
ASTM A 36

04AA002

CARBON STEEL
HOT-ROLLED

THE DATA BASE INCLUDES PROPERTIES FOR RUBBERS

CHAPTER 5		RUBBER.DB	
GROUP	DESCRIPTION	CLASS	DESCRIPTION
A	ASTM D 1418, CLASS M	A	POLYMETHYLENE TYPE
B	ASTM D 1418, CLASS N	B	NITROGEN TYPE
•		•	
I	OTHER TYPES	J	MIXTURES

RUBBER

SIS, EPDM, 75 IRHD

05AA001

ASTM D 1418, CLASS M

POLYMETHYLENE TYPE

EACH MATERIAL PROPERTY IS REPRESENTED BY A FOUR-DIGIT PROPERTY CODE

PROPERTY CODE RANGES	PROPERTY CODE RANGE DESCRIPTION
1000 - 1999	General Information
2000 - 2999	Constituent Material and Plastic Concrete Properties
3000 - 3999	Mechanical Properties
4000 - 4999	Thermal, Physical, and Other Properties
5000 - 9999	Available for Data Base Expansion

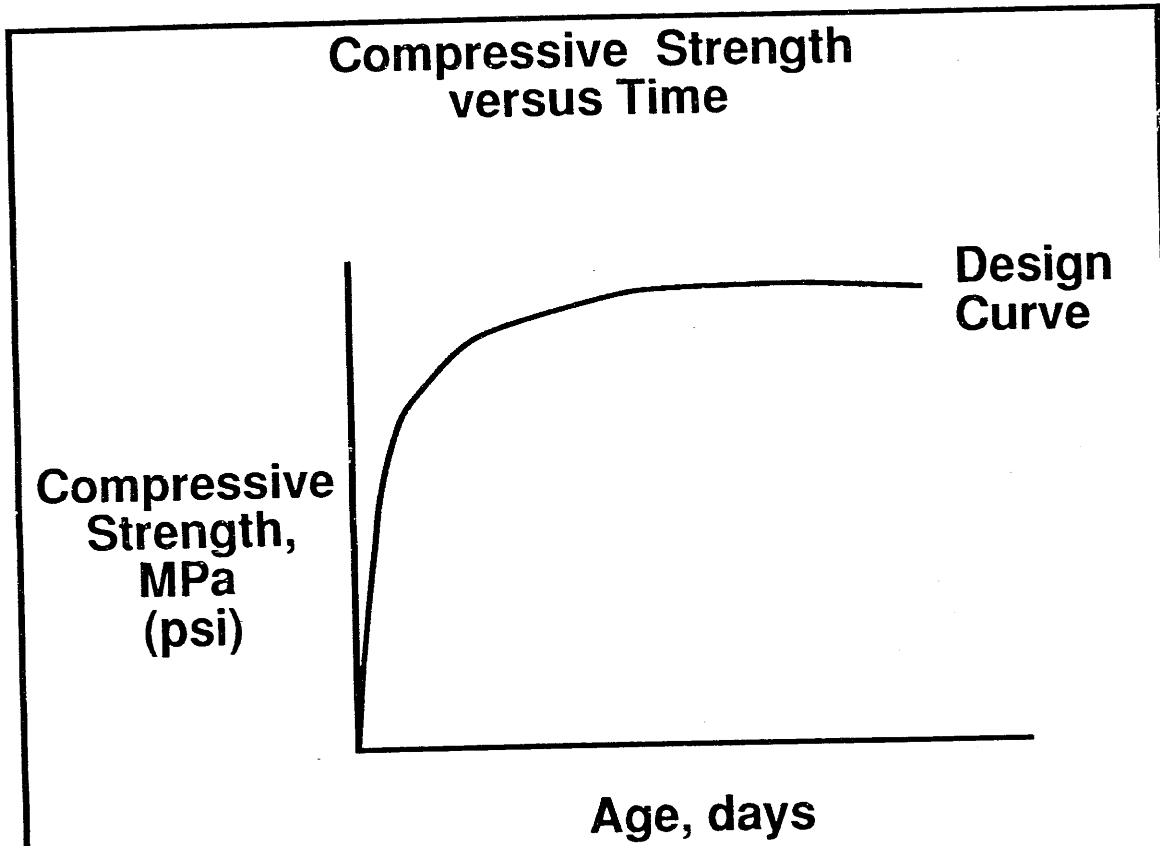
- PROPERTIES ARE REPORTED IN THE INTERNATIONAL SYSTEM (SI) OF UNITS AND IN CUSTOMARY UNITS WHENEVER POSSIBLE.

A LETTER DESIGNATION IS USED TO REFLECT THE RELATIVE QUALITY OF REPORTED PROPERTIES

QUALITY LEVEL	QUALITY LEVEL TERM DESCRIPTION	RELATIVE QUALITY LEVEL RATING
A	Recommended Property	Highest
B	Selected Property	.
C	Typical Property	.
D	Provisional Property	.
E	Interim Property	Lowest

- ELEVEN REQUIREMENTS ARE USED TO DETERMINE THE QUALITY OF DATA OR VALUES.
- CRITERIA HAVE BEEN ESTABLISHED FOR EACH QUALITY LEVEL.

VOLUME 1 OF THE STRUCTURAL MATERIALS HANDBOOK CONTAINS DESIGN VALUES



$$f'c = f_0 + A_1(t) + A_2(t)^2 + A_3(t)^3 + A_4(t)^4 \text{ MPa}$$

VOLUME 2 OF THE STRUCTURAL MATERIALS HANDBOOK CONTAINS SUPPORTING DOCUMENTATION

Average Compressive Strength Test Results		
Age, days	MPa	psi
28	19.1	2770
365	28.8	4180
1825	40.7	5900
3650	43.6	6320
9125	47.5	6895
18250	46.5	6750

Five cylindrical concrete specimens were tested at each age. Each specimen was stored outside and exposed to freezing and thawing conditions.

VOLUME 3 OF THE STRUCTURAL MATERIALS HANDBOOK CONTAINS MATERIAL DATA SHEETS

Material Composition		
Constituent Materials	kg/m^3	lb/yd^3
Cement	308	519
Sand	739	1246
Gravel	1207	2034
Water	166	280
Total	2420	4079

This material was cast at the University of Wisconsin in 1923 as part of a long-term study on the properties of concrete. Specimens were stored outside and tested at selected time intervals over a fifty-year period.

THE STRUCTURAL MATERIALS ELECTRONIC DATA BASE USES NINE INFORMATION FIELDS

INFORMATION FIELD	COMMENT
DESIGNATIONS	MATERIAL CODE (S)
SPECIFICATIONS	PROPERTY CODES (S)
COMPOSITION	MIX DESIGN (S)
NOTES	TEXT FORMAT
FORMS	USED FOR METALS (S)
GRAPHS	IMPORTED FROM EnPlot
PROPERTIES	SPREAD SHEET FORMAT
APPLICATION CLASSES	USED FOR METALS (S)
RANKINGS	USED FOR METALS (S)
(S) - ELECTRONICALLY SEARCHABLE	

AT LEAST ONE DESIGN CURVE IS REPORTED FOR EACH MATERIAL IN THE DATA BASE

- DESIGN CURVES REPRESENT TIME-DEPENDENT OR ENVIRONMENT-DEPENDENT BEHAVIOR.
- DESIGN CURVES ARE DEVELOPED FROM HIGH-QUALITY DATA AND TEST RESULTS.
- WHEN HIGH-QUALITY DATA ARE NOT AVAILABLE, DESIGN CURVES ARE SYNTHESIZED FROM REFERENCE VALUES AND BASELINE INFORMATION.
- DESIGN CURVES ARE:
  - PREPARED USING EnPlot SOFTWARE
  - PRESENTED AS TABLES, MATHEMATICAL EQUATIONS, AND ENGINEERING GRAPHS

DESIGN CURVES CAN BE USED TO ESTABLISH CURRENT PROPERTY VALUES FOR MATERIALS IN EXISTING STRUCTURES

- COLLECT BACKGROUND INFORMATION.
- ESTABLISH THE SERVICE HISTORY.
- IDENTIFY MATERIAL PROPERTIES THAT ARE NEEDED.
- SEARCH THE DATA BASE FOR MATERIALS THAT ARE SIMILAR.
- SELECT MATERIALS WITH PROPERTIES THAT REFLECT THE SERVICE HISTORY.
- USE THE DESIGN CURVES TO ESTABLISH NUMERICAL PROPERTY VALUES.

DESIGN CURVES CAN ALSO BE USED TO ESTIMATE FUTURE MATERIAL PERFORMANCE

- ESTABLISH CURRENT NUMERICAL PROPERTY VALUES.
- DETERMINE THE CONTINUED SERVICE PERIOD AND ENVIRONMENTAL EXPOSURE CONDITIONS.
- SELECT MATERIALS WITH PROPERTIES THAT REFLECT THE CONTINUED SERVICE PERIOD AND EXPOSURE CONDITIONS.
- USE THE DESIGN CURVES TO ESTABLISH NUMERICAL PROPERTY VALUES FOR THE CONTINUED SERVICE PERIOD.

MATERIAL PROPERTIES ARE BEING OBTAINED IN SEVERAL DIFFERENT WAYS

- TECHNOLOGY EXCHANGES ARE BEING USED.
  - CONTACTS WITH VARIOUS RESEARCH ORGANIZATIONS IN THE UNITED STATES, CANADA, JAPAN, GERMANY, SWITZERLAND, DENMARK, AND ENGLAND HAVE BEEN ESTABLISHED.
- PROTOTYPICAL MATERIAL SAMPLES ARE BEING PROCURED.
  - MATERIAL SAMPLES ARE BEING OBTAINED FROM EXISTING CONCRETE STRUCTURES AND SUBJECTED TO VARIOUS LABORATORY TESTS.
  - GOVERNMENTAL AGENCIES, ELECTRICAL UTILITIES, AND CONCRETE RESEARCH ORGANIZATIONS ARE COOPERATING IN THIS EFFORT.

IN SUMMARY, A STRUCTURAL MATERIALS PROPERTY DATA BASE IS BEING DEVELOPED AT THE OAK RIDGE NATIONAL LABORATORY

- DATA AND INFORMATION ON PORTLAND CEMENT CONCRETES, METALLIC REINFORCEMENTS, PRESTRESSING TENDONS, STRUCTURAL STEELS, AND RUBBERS ARE BEING COLLECTED.
  - TECHNOLOGY EXCHANGES
  - MATERIAL SAMPLE PROCUREMENT
- DATA AND INFORMATION FOR EACH MATERIAL ARE PRESENTED IN TWO COMPLEMENTARY FORMATS.
  - STRUCTURAL MATERIALS HANDBOOK
  - STRUCTURAL MATERIALS ELECTRONIC DATA BASE
- THE DATA BASE WILL BE USED TO ESTABLISH PROPERTY VALUES FOR MATERIALS IN EXISTING STRUCTURES AND TO PREDICT FUTURE MATERIAL PERFORMANCE.

END

DATE
FILMED
7/8/92