AGING OF CONCRETE STRUCTURES IN NUCLEAR POWER PLANTS*

D. J. Naus, † C. B. Oland † and E. G. Arndt ‡

‡Oak Ridge National Laboratory, Oak Ridge, TN 37831-8056
‡U.S. Nuclear Regulatory Commission, Washington, DC 20555

SUMMARY

The Structural Aging (SAG) Program, sponsored by the U.S. Nuclear Regulatory Commission (USNRC) and conducted by the Oak Ridge National Laboratory (ORNL), has the overall objective of providing the USNRC with an improved basis for evaluating nuclear power plant structures for continued service. The program consists of three technical tasks: materials property data base, structural component assessment/repair technology, and quantitative methodology for continued service determinations. Major accomplishments under the SAG Program during the first two years of its planned five-year duration have included: development of a Structural Materials Information Center and formulation of a Structural Aging Assessment Methodology for Concrete Structures in Nuclear Power Plants.

INTRODUCTION

As of May 31, 1990, there were 121 nuclear generating units in the U.S., in all stages of construction or operation, that have an aggregate design capacity of 113 gigawatts. Nuclear power continues to provide an increasing proportion of the electricity produced in the U.S., presently accounting for about 20% of the requirement. Since 1978, however, no nuclear power plants (NPPs) have been planned. The trend has been toward cancellation or deferral with 116 of the 249 plant orders placed between 1953 and 1978 having been cancelled. Furthermore, during the next 15 to 20 years, the operating licenses of several plants are scheduled to expire which, assuming no life extension of present facilities, could potentially result in loss of electrical generating capacity in excess of 75 GW during the time period 2006 to 2020. A potential timely and cost-effective solution to meeting future electricity requirements is to continue the service of existing facilities. Any continued-service considerations, however, need to include an in-depth assessment of the effects of aging on the safety-related concrete structures in these facilities.

STRUCTURAL AGING PROGRAM

Results of a study [1] conducted under the NRC Nuclear Plant Aging Research (NPAR) Program were utilized to help formulate the Structural Aging Program [2], which was initiated in 1988. The program has the overall objective of providing an improved basis for the NRC staff to permit...
continued operation of nuclear power plants near, at, or beyond the nominal 40 years for which they were granted an operating license. To accomplish this objective, the Structural Aging Program is addressing the concrete structures with respect to three technical tasks: materials property data base, structural component assessment/repair technology, and quantitative methodology for continued service determinations.

Materials Property Data Base

The objective of the materials property data base task is to develop the Structural Materials Information Center (SMIC), which contains data and information on the time variation of structural material properties. The need for such a data base was established in Ref. [1]. A review of data bases [3] revealed that no data bases existed that meet the needs of the SAG Program. Reference [4] presents the plan utilized in the development of SMIC which consists of the Structural Materials Handbook and the Structural Materials Electronic Data Base.

The Structural Materials Handbook is an expandable, hard-copy reference document that contains complete sets of data and information for each material in the Center and serves as the information source for the Structural Materials Electronic Data Base. The handbook consists of four volumes and is provided in a loose-leaf format so that each volume can be easily revised and updated. Volume 1 contains design and analysis information useful for structural assessments and safety margins evaluations. Volume 2 provides supporting data for the design values presented in Volume 1. Volume 3 consists of material data sheets that contain general information, as well as material composition and constituent material properties, for each material system in the handbook. Volume 4 contains appendices describing the handbook organization as well as updating and revision procedures. Reference [5] provides a detailed description of the handbook.

The Structural Materials Electronic Data Base is an electronically accessible version of the handbook. The data base was developed on an IBM-compatible personal computer using a data base management system [6,7]. Each material record in the data base may contain up to nine categories of data and information which can be sifted (sorted) using comparison indicators. Due to software limitations, all the data and information reported in the handbook are not included in the data base. The data base, however, provides an efficient means for searching the various data base files.

Each material system is presented as a separate chapter in the Structural Materials Handbook and as a separate data file in the Structural Materials Electronic Data Base. A unique seven-character material code, consistent in both the handbook and data base, is assigned to each material system. The material code consists of four identifying parameters, each of which can be utilized to sift information in the data base, i.e., the chapter index (selector for a particular material system), group index (enables materials with same chapter index to be arranged into subsets of materials having distinguishing qualities such as common compositional traits), class index (arrange groups of materials with common compositional traits into subsets having similar compositional makeup or chemistry), and identifier (differentiates material systems having same chapter, group, and class indexes according to a specific designation or specification). Currently, the SMIC contains data and information on concrete, mild steel reinforcement, steel prestressing, and structural steel materials.

Structural Component Assessment/Repair Technology

The structural component assessment/repair task has objectives of: developing a systematic methodology which can be used to make quantitative assessments of the presence, magnitude, and significance of any environmental stressors or aging factors which can adversely impact the durability of safety-related concrete structures in NPPs; and providing recommended inservice inspection or sampling procedures which can be used to develop the data required both for evaluating the
current condition of concrete structures as well as trending the performance of these components. Under this task, a structural aging assessment methodology for concrete structures in NPPs has been developed.

The structural aging assessment methodology is founded on several criteria: relationship of subelements to overall importance of the parent safety-related concrete structures, safety significance of the structure as a whole, influence of applied environment, and probability of occurrence as well as end result of degradation. Basic components of the methodology include: identification of all safety-related concrete structures and their subelements, assignment of values ranging from 1 to 10 to each of the above criteria for each subelement, and entering the values assigned into a formula which combines the values using weighting factors to prioritize aging importance. The end result is a listing of safety-related concrete structures and subelements, ranked in order of importance to aging and longevity of the NPP. Reference [8] presents more details on the methodology.

Quantitative Methodology for Continued Service Determinations

The quantitative methodology for continued-service-determinations task has the objective of developing a procedure that can be used for performing current condition assessments and making reliability-based life predictions of safety-related concrete structures in NPPs. That is, the methodology will integrate information on degradation and damage accumulation, environmental factors, and load history into a decision tool that will enable a quantitative measure of structural reliability and performance under projected future service conditions based on an assessment of the existing structure.

Probabilistic models have been developed to evaluate time-dependent reliability and deterioration of concrete structures subjected to stochastic loads. The changes in engineering properties of steel and concrete materials over an extended service life are taken into account. Degradation mechanisms related to corrosion of reinforcing steel and detensioning of prestressing tendons potentially impact numerous concrete structures in NPPs.

Degradation models and load process statistics necessary to illustrate the methodology have been identified. Reliability functions also have been developed to illustrate the evolution in structural reliability over time. Such functions can be used as a basis for selecting appropriate plant license extension periods or to determine required intervals of inspection and maintenance necessary to maintain reliability at an acceptable level. More details on these results are available in Ref. [9].

APPLICATION OF RESULTS

Potential regulatory applications of this work include: improved predictions of long-term material and structural performance and available safety margins at future times, establishment of limits on exposure to environmental stressors, reduction in total reliance by licensing on inspection and surveillance through development of a methodology that will enable the integrity of structures to be assessed, informed review and approval of plant continued-service requests, and improvements in damage-assessment procedures.

ACKNOWLEDGEMENTS

Mr. C. J. Hookham of Multiple Dynamics Corporation, Southfield, MI, developed the structural aging assessment methodology for concrete structures in nuclear power plants. Dr. B. Ellingwood and Mr. Y. Mori of Johns Hopkins University, Baltimore, MD, are developing the methodologies for current condition assessments and reliability-based life predictions for concrete structures.
Mr. T. M. Brown, Structural Engineer, Bartlett, IL, provides continuing assistance in program planning and implementation.

REFERENCES


DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.