Aging of concrete components and its significance relative to life extension of nuclear power plants*

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1 INTRODUCTION

Nuclear power currently supplies about 16% of the U.S. electricity requirements, with the percentage expected to rise to 20% by 1990. Despite the increasing role of nuclear power in energy production, cessation of orders for new nuclear plants in combination with expiration of operating licenses for several plants in the next 15 to 20 years results in a potential loss of electrical generating capacity of 50—60 gigawatts during the time period 2005 to 2020. A potential timely and cost-effective solution to the problem of meeting future energy demand is available through extension of the service life of existing nuclear plants. Any consideration of plant life extension, however, must consider the concrete components in these plants since they play a vital safety role.

Under the USNRC Nuclear Plant Aging Research (NPAR) Program, a study was conducted to review operating experience and to provide background that will lead to subsequent development of a methodology for assessing and predicting the effects of aging on the performance of concrete-based structures. The approach followed was in conformance with the NPAR strategy (Morris and Vora 1985).

2 DESCRIPTION OF SAFETY-RELATED CONCRETE COMPONENTS IN LWRS

A myriad of concrete-based structures are contained as a part of an LWR system. Although the particular components may vary somewhat according to the selection of nuclear steam supply system and containment concept, the seismic Category I structures generally fall into four primary categories: reactor containment buildings, containment base mats, biological shield walls and buildings, and auxiliary buildings.

From a safety standpoint the containment building is probably the most important structure of a nuclear power plant since it serves as the final barrier against the release of radioactive fission products to the environment under postulated design basis accident conditions. The

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first concrete containments were built in the mid-1960s and typically consisted of a cylindrical reinforced concrete wall with a hemispherical dome and flat base slab. Leak tightness was provided by a steel liner. Fully prestressed concrete containments (PCCs) were first built in the late 1960s. Current generation PCCs have evolved through efforts to increase the efficiency of the prestressing systems which is reflected through changes in containment geometry, prestressing tendon layouts, and increased capacity of the prestressing systems.

Base mats for reactor containment vessels can be either reinforced, prestressed, or a combination of reinforced and prestressed. Thickness requirements of the base mats are controlled by the concrete shear capacity, maximum allowable compressive stress of concrete, maximum allowable steel area and allowable soil-bearing pressure.

Biological shield walls for commercial reactors are fabricated from standard weight reinforced concrete, and the walls can either support all or part of the reactor pressure vessel weight. A shield building, or secondary containment, is a medium leakage reinforced concrete structure that surrounds the steel containment vessel.

Auxiliary buildings include functional units such as diesel generator building, control room/building, etc. These structures are generally box-shaped, shear-wall buildings constructed of reinforced concrete.

3 TRENDING OBSERVATIONS ON CONCRETE COMPONENT PERFORMANCE

Reviews of the performance of concrete materials (Naus 1981) and components (Ashar and Naus 1982, Fraczek 1979, Hauser 1979) enable some general observations to be made on concrete aging and component performance. When fabricated with close attention to the factors related to the production of good concrete, the concrete will have infinite durability unless subjected to extreme external influences. Under normal environmental conditions aging of concrete does not have a detrimental effect on its strength for concrete ages to at least 50 years (limit for which well-documented data has been identified). Review of the performance of concrete components in general civil engineering structures indicates that few structures actually fail in use and that the errors that do occur are predominately detected during construction. The source of these errors is generally the result of either construction or design detail mistakes. The overall performance of concrete components in nuclear applications has been very good. With the exception of anchor head failures at Farley 2, errors detected during the construction phase or early in the structure's life were generally of no structural significance or "easily" repaired and were nonaging related.

4 POTENTIAL ENVIRONMENTAL STRESSORS AND AGING FACTORS TO WHICH LWR SAFETY-RELATED CONCRETE COMPONENTS MAY BE SUBJECTED

Reactors are generally designed for a plant life of about 40 years. Over this period of time, changes in concrete's material or reinforcing steel properties in all likelihood will occur. Concrete in many structures can suffer undesirable degrees of change with time, but these changes do not have to be detrimental to the point that the structure has deteriorated and is unable to meet its functional and performance requirements. Mechanisms (factors) that, under unfavorable conditions, can produce premature concrete deterioration include (1) freezing and thawing, (2) aggressive chemical exposure, (3) abrasion, (4) corrosion of steel and other embedded material, (5) chemical reactions of aggregates, and (6) miscellaneous (unsound cement and shrinkage cracking). For concrete components utilized in nuclear-safety-related structures, an additional factor can be added, extreme environmental exposure (e.g., elevated temperature and irradiation).

5 DETECTION OF CONCRETE AGING PHENOMENA

Murphy (1984) notes that tests are conducted on concrete to assess future performance of a structure as a result of: (1) noncompliance of strength tests; (2) inadequacies in standards for placing, compacting, or curing of concrete in the structure; (3) damage resulting from overload, fatigue, frost, abrasion, chemical attack, fire, explosion, or weathering; and (4) concern about the capacity of a structure to withstand design, actual, or projected loadings. For nuclear applications prolonged exposure to elevated temperature and irradiation conditions should be added to this list. Questions concerning whether the concrete in a structure was cast using the specified mix composition can be answered through examination of core samples. Discontinuities in concrete structures (cracking, voids, delamination) can be detected by visual inspection, nondestructive testing, or examination of cores. Insitu concrete strength determinations can be made using either direct (testing of core samples) or indirect techniques (surface hardness, rebound methods, penetration methods, pullout resistance methods, breakoff resistance methods, ultrasonic pulse velocity methods). The primary source of distress to which mild steel reinforcing materials could be subjected would be corrosive attack. Techniques available for corrosion monitoring and inspection of steel in concrete include (1) visual inspection, (2) mechanical and ultrasonic tests, (3) core sampling and chemical and physical tests, (4) potential mapping, and (5) rate of corrosion probes. The ability of a PCC to withstand the loadings that would develop as a result of a LOCA depends on the continued integrity of the prestressing tendons. In the U.S. the condition and functional capability of unbonded posttensioning systems must be periodically assessed. The present basis for conducting tendon inspections is contained in the USNRC Regulatory Guide 1.35," Inservice Inspections of Ungrouted Tendons in Prestressed Concrete Containment Structures," and covers items such as sample selection, anchorage hardware, tendon stress levels, tendon wire or strand condition, and grease evaluation.

6 REMEDIAL MEASURES FOR REPAIR OR REPLACEMENT OF DEGRADED CONCRETE COMPONENTS

Types of distress requiring repair that could occur in LWR safety-related concrete components include: cracking, spalling or delamination, nonvisible voids, and fracturing or shattering. Established remedial measures generally involve the use of one or more of the following materials: epoxy resins, shotcrete, preplaced aggregate concrete, wedge anchors and additional reinforcement, and miscellaneous sealant materials (Warner 1977, ACI Committee 224 1984). Selection of the technique for repair of a concrete structure depends to a large degree on the size, depth, and area of repair required. Existing structural elements can also become inadequate due to either a change in performance requirements or occurrence of an overload condition. Under those conditions retrofitting may be required to reestablish serviceability. Retrofitting can be accomplished by either strengthening of existing elements, addition of new force-resisting elements, a combination of element strengthening and addition, or use of supplemental connecting devices (Warner 1977). A review of the effectiveness of repairs to concrete structural elements (Naus 1986) indicates that remedial measures for repair of degraded concrete components are capable of completely restoring structural integrity when proper materials and techniques are utilized.

7 TOWARDS FORMULATION OF A METHODOLOGY TO PROVIDE A QUANTITATIVE MEASURE OF STRUCTURAL RELIABILITY AND RESIDUAL LIFE

When concrete structures have been fabricated with close attention to the factors related to the production of good concrete (material selection, production control, desirable properties, economy), the concrete will exhibit infinite durability; however, where there has been a breakdown in one of these factors or the component was subjected to an extreme environmental stressor, distress can occur. It has also been established that various techniques are available for identifying regions in structures subjected to deteriorating influences and that remedial measures exist for providing a satisfactory repair. Where the system breaks down, however, is that a damage methodology to provide a quantitative measure of the ability of a structure to meet potential future requirements does not presently exist. Three areas, however, that would provide significant input toward qualifying the ability of a LWR safety-related concrete component to meet its functional and performance requirements at some future time, based on its performance history or present status, can be addressed: (1) development of a representative material property data base, (2) establishment and evaluation of an accelerated aging methodology for concrete materials, and (3) formulation of a methodology to provide a quantitative measure of structural reliability and residual life.

Under normal operating conditions a high level of confidence can be placed in traditional material performance based on past experience. However, for concrete material systems used in LWR applications where operating conditions are not necessarily considered normal because of potential elevated temperature and irradiation exposure over a protracted period of time, the confidence level will not be as high. This is not the result of obvious deteriorating influences operating on these structures, but rather from the lack of a historical material property data base that can be used to form the basis for life extension considerations. Three plants in the U.S. that are currently shutdown (Dresden 1, Humbolt Bay and Shippingport), however, provide an opportunity for making major contributions to the material property data base relative to aging effects. By obtaining concrete core samples from pertinent locations and conducting petrographic examinations and load-to-failure tests, an indication of the significance of aging can be obtained. Also, prestressing tendon in-service surveillance reports and containment integrated leak-rate test reports would provide significant information useful in trending material performance (concrete materials, prestressing materials, corrosion inhibitors, seals and gaskets, etc.).

Prediction of the service life of a building component or material is dependent on there being either sufficient available data on performance of the component or material under representative conditions for the period of interest, or accelerated testing methods can be used to develop the required data. Since the amount of long-term data on the performance of concrete material systems under conditions representative of an LWR environment are extremely limited, and the data which can be derived from plants which are shut down in all likelihood will be somewhat plant specific and probably not representative for either all safety-related concrete components or potential environmental stressors, additional data must be developed. A possible approach to the development of supplemental data is to use accelerated aging techniques. It is envisaged that the required accelerated aging program would involve three major phases: (1) problem definition (material and component characterization, degradation factor identification and simulation, test performance requirement definition), (2) design and performance of predictive service life tests, and (3) mathematical model development. Results obtained from such a program will aid in describing and understanding the phenomena of potential deterioration with the passage of time, assist in determining the residual service life of materials and components in conjunction with actual degradation conditions, and help in establishing maintenance or remedial measure programs that will assist in either prolonging a component's service life or improving the probability of the components surviving an extreme event.

Assessment of functional/performance characteristics of concrete components is an important consideration in the extension of the operating life of nuclear facilities. Given the complex nature of the various environmental stressors that can exert deteriorating influences on the concrete components, a systems approach is probably best in addressing the evaluation of a structure for life extension considerations. Basic components of such an approach would encompass development of: (1) a classification scheme for structures, elements, and deterioration causes/effects; (2) a methodology for conducting a quantitative assessment of the presence of active deteriorating influences; and (3) the structural reliability techniques to estimate the ability of a structure (component) to meet potential future requirements.

8 CONCLUSIONS

Conclusions derived from the scoping study are that: (1) performance of concrete-based components has generally been very good with the few problems identified being attributable to either design or construction errors, (2) techniques for detecting the effects of environmental stressors provide qualitative data, but quantitative interpretation can be difficult; (3) remedial measures are capable of restoring structural integrity of degraded concrete members; (4) durability of concrete constructions is well established, but documented data on concrete longevity for use in life extension considerations is limited; (5) primary effects which could lead to loss of component serviceability have been identified (cracking and loss of strength due to environmental stressors), however, severity criteria (e.g., tolerable crack widths) for degradation of these components need to be established; and (6) a damage methodology needs to be developed for assessing concrete component reliability at some future point in time.

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