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Nuclear Power Plant Structural Monitoring Program

Programme de contrôle structural dans une centrale nucléaire

Bauliches Überwachungsprogramm in einem Kernkraftwerk

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SUMMARY

This paper discusses the key features of a structural monitoring program in place at one American nuclear power plant located on the Pacific coast. The program has several purposes including defining the condition of the civil structures, identifying problems at an early stage that require corrective or preventive maintenance, and developing "baseline" reference information on the structural conditions for future reference. The monitoring program is expected to yield benefits to the utility in extending the useful life of the plant, reducing repair and maintenance costs, planning and budgeting capital and operations/ maintenance expenditures, and addressing license renewal issues.

RÉSUMÉ

Cet article souligne les points essentiels du programme de surveillance de la structure porteuse d'une centrale nucléaire nord-américaine. Les objectifs sont d'esquisser le développement de l'état structural de l'ouvrage, d'ordonner en temps voulu des mesures de réparation et d'entretien et d'établir un état de référence de la structure permettant des évaluations futures. Les avantages d'un tel programme devraient se traduire par une prolongation de la durée d'utilisation de l'installation, une réduction des coûts de réparation et d'entretien, une amélioration de planification et de budgétisation des dépenses ainsi qu'un renouvellement de l'autorisation d'exploitation.

ZUSAMMENFASSUNG

Der Beitrag erörtert die Hauptteile eines Ueberwachungsprogrammes des Tragwerks in einem Kernkraftwerk an der US-Pazifikküste. Ziele sind die Aufzeichnung der Entwicklung des baulichen Zustands, eine frühzeitige Veranlassung von Reparatur- und Unterhaltsmassnahmen und die Erstellung eines Referenzzustandes des Tragwerks für zukünftigen Beurteilungen. Als Vorteile verspricht man sich eine Verlängerung der Nutzungsdauer der Anlage, eine Reduktion der Reparatur- und Unterhaltskosten, verbesserte Planung und Budgetierung der betreffenden Aufwendungen sowie die Erneuerung der Betriebserlaubnis.

1. BACKGROUND

Existing nuclear power plants in the United States were designed and built, and are operated under rigorous regulatory scrutiny of the U.S. Nuclear Regulatory Commission and its predecessor the U.S. Atomic Energy Commission. The principal goal of this regulatory scrutiny was, and still is, to assure the performance of safety functions of these plants under extreme, and often highly unlikely conditions such as earthquake, tsunami, tornado and high-energy pipe breaks, in order to protect the public from an uncontrolled release of radioactive material.

Most U.S. nuclear power plants were issued Construction Permits (regulatory approval to begin construction) during the 1960s and 1970s. The civil structures of these plants were, thus, mostly built during the period 1965 to 1975 and are from twenty to thirty years old. The design life for these plants was intended to be forty years of operating life. As the plants approach or exceed the half way point in their design lives, regulatory and engineering attention have shifted from design and construction to operation and maintenance. Plants sited on both the east and west coasts are exposed to a marine environment and the increased likelihood of corrosion of steel structures and reinforcing steel in concrete structures. New regulatory guidelines are being prepared and issued regarding maintenance of nuclear power plants for example, the U.S. NRC's Maintenance Rule (10 CFR 50.65) specifies that all nuclear power plant owners must develop a maintenance program for plant systems, structures and components determined to be sensitive to aging. Concerns for the environment and the financial risks associated with building large, new generating plants mean that many utilities will want to use the full design life and in some cases consider life extension of their nuclear power plants.

Much of the focus by regulators and operators has been on the active systems (electro-mechanical systems) which must operate and perform safety functions during or following an extreme event. While this is appropriate, attention must also begin to be given to the passive civil engineering features. Most plant operating organizations are made up of electrical and mechanical engineering staff and few have civil/structural engineering expertise on staff. These skills are generally obtained from in-house central engineering groups or from outside consultants. Many operating organizations are looking to add or have added civil engineering expertise into the operating group or have provided an on-site civil engineering presence.

Many utility power facilities such as dams and their power waterways are required by regulatory agencies, such as the Federal Energy Regulatory Commission, to be inspected on a regular basis. Other power plant facilities such as chimneys and chimney liners are also subject to regular inspection although not a regulatory requirement. Although safety is a primary consideration, concern for economic loss associated with outages and massive repair costs are also part of the decision to inspect and monitor.

Utilities have recognized aging management as an activity vital to the long-term safety, reliability, and economic operation of a nuclear power plant. Because of the extreme expense associated with testing of civil structures, a structural monitoring program is an attractive and relatively inexpensive way of assuring performance.

2. OBJECTIVES OF THE STRUCTURAL MONITORING PROGRAM (SMP)

The overarching goal of the Structural Monitoring Program (SMP) is to provide additional assurance that the passive functions of the civil structures are performed to the relevant specifications. There are a number of supporting objectives outlined below:

- To provide for systematic and periodic inspection of the structures and features and ensure that licensing and design basis requirements are satisfied with acceptable margins;
- To provide a baseline of the current condition of important structures and features and a regular comparison of these conditions with the baseline conditions;
- To provide for the inclusion and prioritization of the appropriate civil structures and structural features into the program;
- To provide a mechanism by which operating experience and lessons learned can be shared and applied;
- To integrate the above information into the plant maintenance program so that preventive and corrective maintenance can be planned and carried out as needed to prolong useful life.

3. SCOPE

The SMP focuses mainly on plant civil structures that are safety related, important to nuclear safety, and/or involve a large risk of economic loss. At one nuclear plant located on the Pacific Coast, the structures currently included in the program are the containments (exterior reinforced concrete shell with steel lining, interior concrete and steel structures), auxiliary and fuel handling buildings (reinforced concrete and structural steel) turbine building and turbine pedestal (reinforced concrete and structural steel), intake structure (reinforced concrete structure and circulating water tunnels), and outdoor water storage tanks (steel tanks, some with concrete exterior).

These structures include both reinforced concrete (structural walls and floor slabs, columns, beams, and other special elements) and steel structures (floor beams, columns, bracing, trusses, and connection elements). Since most of these structures are constructed of reinforced concrete, they receive the most attention. The marine environment, through direct seawater contact or coastal fog, provides two of the three ingredients needed for corrosion activity (moisture, oxygen, and salts). Degradation of reinforced concrete structures due to chloride intrusion and reinforcing steel corrosion also may not be evident until significant damage has already occurred. Typical symptoms of problems include surface discoloration, spalling, cracking, and in advanced stages, delamination. Such areas often exhibit a hollow sound when struck by a hammer. Slowly developing damage in the early stages is typically followed by rapid deterioration, increasing the importance of early detection.

Reinforced concrete applications in nuclear power plant structures also differ somewhat from other industrial and commercial structures. Because of the massive proportions of nuclear power plant equipment, and unique requirements such as shielding and severe design conditions (e.g., pipe break, seismic, tornado wind and wind-driven missile), reinforced concrete structures tend to have thick, heavily reinforced walls and slabs, massive basemats, and unusual configurations. Strengthening modifications such as thickening of walls after the original construction was completed also create a condition where two layers of concrete with different ages may be placed in contact. High thermal loads due to operating characteristics of equipment and systems may also occur in structures. These characteristics may cause more significant cracking than in ordinary concrete structures. While such cracking usually has no effect on structural integrity, it does increase the potential for reinforcing steel corrosion.

Degradation or damage to steel structures is generally more evident and noticeable than in concrete structures. Evidence of a problem such as corrosion, damaged coatings, and deformation is also more apparent because steel structures are more often exposed and accessible to inspectors.

In addition to important structural elements noted above, secondary features or elements such as architectural siding and equipment supports are also given a cursory review by the program. Inappropriate modifications and changes to configuration might also be discovered through the walk down. However, this coverage is not the primary emphasis of the walk down or inspection team.

4. IMPLEMENTATION OF THE PROGRAM

The key program steps include preparatory work, walk down implementation, and follow-up actions. Preparatory work includes data gathering and planning for the walk downs. In addition to gathering information on the configuration of each of the structures, design criteria, design and as-built drawings, and material and construction specifications are collected and reviewed. Lists of system problems and current projects or modifications are also compiled and placed in a central location.

The purposes of walk down planning are to identify the important elements to be covered in walk downs, develop an efficient walk down path or sequence, checklists, and other practical tools. In order to provide the most cost-effective walk downs, the key structural elements or features are selected during the planning phase. These elements or features are primarily chosen based on their importance to the structural system of the building or plant safety systems. In addition, structures subjected to harsh environmental or operating conditions, for example, exposure to seawater or differential displacements caused by pressurization during integrated leak rate testing (ILRT) of the containments are included in the walk downs.

Limitations on access to the identified structural elements also deserve consideration. Physical barriers, hazardous conditions, operating temperatures, radioactive contamination or attempts to keep radiation dose rates to walk down team members "as low as reasonably achievable" may impede access to the structures requiring monitoring. In addition, the timing for walk downs should be considered. In some cases, parts of structures are accessible only during a plant outage (e.g., inside containments). However, the scheduling of walk downs during refueling outages may also hinder access in other cases. Materials staging and disassembled equipment may prevent inspection of parts of the structure. Walk down planning, of course, should be a living process in which improvements and lessons learned are continuously incorporated into the plan for subsequent walk downs. A written monitoring plan also provides a road map for future users, and provides guidance in the event that the designated personnel are unavailable.

Walk downs are generally performed by two civil engineers, one serving as a back-up or alternate for the other. In addition, engineers from other disciplines, or maintenance or operations personnel may be included. The need for additional personnel is considered case-by-case. Data collection forms which have been developed in advance are usually used on the walk downs. Besides personnel safety equipment, other tools brought along on the walk down may include general area drawings, flashlight, tape rule, pens and markers, crack measuring device such as a thickness gage, camera, and hammer for sounding concrete. In areas where potential for radioactive contamination is significant, tools, papers, and the like are kept to a minimum.

The collection of baseline data for various structures or elements is also included. In this program, baseline information is defined as the data collected on the physical condition of the structure or element being inspected, in the initial walk down under the SMP. This information is then used for tracking and trending to monitor changes. For example, for structural concrete this information may take the form of crack maps, records of widths and length or areas that are spalled or delaminated, or some measures of settlement or alignment. In order to select the appropriate features for monitoring and to gather and maintain this data in a cost-effective manner, consideration is given to factors such as importance of the structural elements, redundancy in the structural system, seismic margin possessed by the particular element, exposure to harsh environments, and structural configuration. The set of baseline features is not intended to be static. Instead, if important changes or events occur, additional information or additional elements would be added to the data set.

Following the completion of the walk down, a concise report of observations and findings is prepared. This report summarizes the events of the walk down, discusses follow-up or corrective actions, and identifies items that need to be done at the next walk down. Problems or corrective actions are handled according to an established procedure for dealing with plant problems. Follow-up actions may include engineering evaluation to ensure qualification or adequacy of margin, and additional testing or investigation by specialists or experts (e.g., corrosion rate testing, obtaining cores from damaged concrete, pulse velocity or other in-situ tests).

Repairs to the damaged area may be considered. Factors related to repairs include costs of repairs, consequences of deferral, corrective actions to the root cause of the degradation or damage, and the practicality and effectiveness of design changes and repair methods. Design changes or repairs might include increased concrete cover, different concrete mix designs for repairs or use of grouting for patch work, protective coatings to both concrete surfaces and rebars, and the addition of sacrificial zinc strips to reinforcing steel. The importance and function of damaged structural elements should also be considered (e.g., the effect that spalled or delaminated concrete may have on the shear capacity or compression zone of a reinforced concrete wall or beam). In a power plant, the accessibility of the structural elements requiring repair is often hindered by attachments such as electrical raceways, piping, and equipment. The temporary support, removal, or de-activation of such attachments is often necessary to facilitate the repairs. In some cases, it may be more economical to replace rather than refurbish commodities such as electrical raceways and heating and ventilation ducts. These factors will also influence the budget planning process, where repairs will compete with other projects for scarce funds in today's operating environment.

5. CONCLUSIONS

The SMP, properly implemented, provides additional assurance that civil engineering features at a nuclear power plant will meet performance objectives. In addition, there are benefits of an economic nature that accrue to the owner/operator by implementing an SMP. These are summarized below.

- Through regular inspection, significant degradation of structures important to safety or continued generation will likely be discovered in a timely manner. For many structures, degradation that is discovered only after it has progressed to a certain point can lead to an extended outage or be expensive to repair. The SMP also allows for planned, smaller, incremental investments in maintenance instead of a potentially large, and unplanned investment.
- The baseline which is established by the SMP, allows comparison of effects after an event, such as an earthquake, against the baseline. This can be useful in convincing regulators to allow production to begin more quickly, or, perhaps, at all. The baseline can also assist in validation of insurance and or warranty claims.
- The SMP allows for optimization of expenditures for maintenance and rehabilitation by providing information for more effective maintenance planning. Trend analysis allows evaluation of the need for expenditures and for acceleration or delay of expenditures.

- The SMP provides an effective tool in dealing with regulatory bodies in that it puts dealings on a more factual basis. This can prevent delay in receiving approvals and avoid problems that might lead to loss of production and revenue.
- The SMP provides an aid to investment decisions about life extension. Trending information, gathered over a relatively long period, is felt to be more useful than a one time study that cannot provide information as to whether effects are accelerating, stable or diminishing with time. The SMP can provide for a more intelligent decision.
- By integrating the SMP into the plant maintenance program, communication between the plant maintenance staff and the civil engineers will be enhanced. This communication should lead to improved understanding by both groups to the benefit of plant safety and economy. The team-building environment fosters networking (within the plant organization, other plants and coastal installations), development of knowledge about new products and techniques, and current research by universities and professional groups.

In conclusion, the SMP is believed to be a positive contribution to both plant safety and to the efficient operation of the plant for economic benefit.

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