Assessing and Managing Aging of Nuclear Safety-Related Concrete Structures – Recent AECL Experiences

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ABSTRACT

Many CANDU®[1] Nuclear Generating Stations are nearing the end of their original design life and life extension is being considered. It is important to confirm the integrity of the safety-related civil structures and equipment to continue successful operation of the station.

To provide an initial health prognosis of a structure, Condition Assessment (CA) is performed. The assessment of current condition of a structure is based on the history of operation and maintenance assessed against the design basis and the functional, safety, and operational requirements. The health prognosis for extended life is then based on both this current condition and a systematic identification and assessment of Aging Related Degradation Mechanisms (ARDMs) and their impact on the functional requirements of the structure.

AECL has recently assessed condition of safety-related concrete structures of CANDU® plants, Nuclear Research Universal (NRU) facility, and waste storage facilities. The assessment included the following structures: containment (including prestressing system and liner), Reactor Building internal structures, spent fuel bays, spent fuel dry storage facility, spent resin tanks, underground waste storage structures, etc. The paper presents the methodology used to perform condition assessment, typical techniques and limitations.

Understanding and monitoring of aging of civil safety related structures by implementation of the Aging Management Program (AMP) enables controlling and mitigating effects of aging related degradation, supporting licensing renewals and making prognosis for future performance.

Recently, a comprehensive AMP was developed and implemented for three decommissioning facilities to maintain their integrity. The paper highlights the main components of the AMP and provides examples of its implementation.

CONDITION ASSESSMENT

The integrity of civil structures is essential for continued operation of Nuclear Power Plants and nuclear facilities. As structures age, changes in material properties arise from continuing microstructural changes and environmental influences. In addition, deviation from design specifications during construction or changes in anticipated environmental conditions can sometimes lead to unpredicted effects, which may jeopardize the integrity of the structures.

In consideration of the life extension of the plant or a waste management facility, structures that are safety-related and/or important to power production are typically selected for condition assessment.

Condition assessment is a systematic and rigorous evaluation of design, construction, operation and maintenance data in order to assess the effect of aging degradation on structures, establish their current condition, and provide a prognosis for future performance with associated recommendations. The condition assessment will identify changes, which are necessary and sufficient in order to address issues related to aging effects, and may include economic opportunities for improvement.

The typical approach to performing a condition assessment is summarized in the following steps:

- Gather and review design, construction, operation, inspection, and maintenance history and any other relevant documentation in order to define the design basis and identify any changes to the structure during construction and operation;
- Establish physical and functional boundaries of the structure and associated components;
- Perform screening to identify specific structures or components that do not require further aging assessment;
- Undertake an aging assessment of the selected structures or components remaining after screening (including ARDM assessment, aging evaluation and establishing structure's health prognosis);

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- Provide recommendations for each structure in terms of repair and monitoring, as well as Plant Life Management (PLiM) related maintenance activities to assure plant safety and production goals over the life of the plant or the waste management facility.

AECL Experiences in Condition Assessment of Civil Structures

A number of condition assessments of nuclear safety related structures of CANDU® 6 plants (Wolsong 1, Gentilly-2, Point Lepreau), NRU facility, and waste management facilities were performed. Assessments included containment structures (concrete, prestressing system, and liner), Calandria vault structures, fuel transfer structures, spent fuel bays, spent resin tanks, underground liquid waste storage structures, dry waste storage structures, etc.

The depth of condition assessment is dependent upon the quality of gathered information. Besides review of documents and drawings, interviews with site personnel helped in identifying the information, which was not formally documented. Walkdowns have proven to be a valuable source of information as they helped in identifying location of areas of distress and possible deterioration of a structure.

Based on review of available information, design and operational exposure conditions of structure were compared. An engineering judgement was used to understand all potential aging mechanisms that might influence performance of a structure under assessment and an ARDM matrix was created. An example of an ARDM matrix is shown in Table 1. Susceptibility of a structure to each ARDM was evaluated as high, medium, or low, based on the following criteria:

- **High** means the degradation mechanism is occurring or has occurred, either in this structure or in a similar structure under similar conditions, and that steps have not been taken, or it is unclear if any such steps are adequate, to mitigate the degradation for the target life, or to prevent forced outages, etc.
- **Medium** means the degradation mechanism is known for this system or component, either at this facility or a similar one, and is being managed or mitigated.
- **Low** means the mechanism is plausible for the structure, but is easily managed with the current programs or has no impact on achieving the target life.

The ARDMs not included in the table, or those having no marks against them in the table, are considered implausible for the structure given the environmental conditions or materials, or a combination thereof, and are not considered further.

Conclusions and health prognosis were then provided based on the thorough review of available information with particular attention to and focus on aging related degradation. Where sufficient information to provide a health prognosis was not available, activities to support results of the assessment were recommended in addition to recommendations for plant program enhancements to verify and ensure continuing health of the structure. A general recommendation to effectively manage aging was to periodically examine structures at regular intervals within the framework of an aging management program.

AGING MANAGEMENT PROGRAM (AMP)

Aging of nuclear plant structures, if unmitigated, may reduce the integrity and functional capability margins provided in the design and thus increase risks, and can impact on power production capabilities.

Understanding and monitoring the aging process of nuclear safety related structures by implementation of AMP enables controlling and mitigating effects of aging related deterioration before a degraded condition can cause a loss of integrity or interference with operations. Thereby, implementation of AMP helps supporting licensing renewals and making prognosis for future performance of structures.

An AMP provides appropriate procedures for evaluating performance of structures by means of periodic examinations. Canadian and American codes related to in-service examination of nuclear safety related structures including containment [1], [2] require examinations to be performed at regular intervals. Periodic examinations provide an effective aging management tool, i.e. when deterioration is detected, a maintenance activity can be implemented to prevent it from becoming a defect that would require a major repair.

A comprehensive AMP defines the scope and frequency of periodic examinations, qualifications of the evaluation team, examination methods, examination criteria, repair and monitoring options and materials, and documentation requirements. As examination of all structures with an established frequency might not always be feasible, it is important to examine representative areas most likely to experience deterioration, as well as to examine areas critical to the structural integrity of the safety-related structure. Ranking system can be utilized to prioritize structures and their sub-elements based on safety significance, environmental exposure, and anticipated tolerances to degradation.

Implementation of AMP for AECL Waste Management Facilities

AECL manages three shutdown prototype reactors: NPD (Nuclear Power Demonstration), Douglas Point, and Gentilly-1. These facilities were permanently shutdown over 20 years ago and are currently in a safe sustainable shutdown state, which is referred to as the Storage With Surveillance (SWS) phase. The purpose of this phase is to maintain integrity of buildings and structures to allow for decay of the radioactive material. These facilities contain radioactive materials and are licensed by the Canadian Nuclear Safety Commission (CNSC) as waste management facilities. Some ancillary buildings that have very low radiation hazards or were decontaminated during the initial decommissioning activities are used for alternative purposes, which keeps an interest in maintaining these buildings in good condition during the SWS phase.

To meet the goal of the SWS phase, an AMP was prepared for each of the three facilities. The chart in Figure 1 outlines main steps in development of an AMP. Ranking system proposed in Reference [3] was utilized with some modifications to address the fact that plants are no longer in operation. The chart in Figure 2 shows main steps to create a list of critical structures starting with the most important one as far as structural integrity is concerned.

Aging Management Programs were implemented for waste management facilities. Few examples of repair and inspection activities recently performed to effectively manage the structures are described below.

Evaluation of Dry Storage Spent Fuel Canisters

The Spent Fuel Dry Storage Facilities were designed to provide safe, economical, reliable, and retrievable interim storage for the spent fuel. Reinforced concrete canisters with inside steel cylinder are supported on reinforced concrete slabs.

Fine pattern cracking was observed during inspection at one of the sites. Evaluation of canisters to determine the cause and extent of cracking was undertaken including the following activities:

- Condition survey of canisters;
- Non-destructive tests: Impact Echo, Ground Penetrating Radar (GPR), impact hammer, cover meter, and half-cell potential;
- Laboratory evaluation of extracted cores, including compressive strength and density test, petrographic analysis, and testing the depth of carbonation.

Based on results of evaluation, it was concluded that the nature and extent of cracking did not compromise structural integrity of the canisters. Cracks were mostly shallow and strength and density of canisters exceeded design values. The cause of cracking was drying shrinkage and thermal effects enhanced by geometry and inadequate construction practices. However, since existing cracks might jeopardize the long-term integrity of canisters, it was recommended to protect canisters from further deterioration by preventing the moisture from penetrating the canisters. Various repair options are currently being investigated.

Exploratory Investigation of the Underground Structure for Radioactive Waste Storage

The function of the underground concrete structure is to house stainless steel tanks for storage of radioactive spent resin. Recently, exploratory investigation was performed to supplement condition assessment of the normally inaccessible structure. The investigation included the following activities:

- Excavating to gain access to the top slab and top of one of the outside walls;
- Performing field tests, i.e. impact hammer, Ground Penetrating Radar (GPR), and half-cell potential test;
- Performing laboratory evaluation of extracted cores including compressive strength and density tests, petrographic analysis, carbonation depth and chloride content measurements;
- Drilling the hole through the top slab and performing camera inspection inside the vault.

Waterproofing membrane appeared to perform its functions, as the concrete was found dry when membrane was removed. Although the concrete of the top slab slightly differed from the concrete of the wall in mix proportion, both of them exhibited similar field service characteristics. Fine micro cracking and presence of ettringite within the voids was noted in both elements. Overall, both concretes were considered to be in good condition. Camera inspection inside the vault did not reveal presence of any significant deterioration.

Repair and Monitoring of the Ring Beam

During visual inspection of the Gentilly-1 containment structure, deterioration in form of cracking, spalling and delamination of concrete was observed predominantly in the ring beam and buttresses. An evaluation of the structure to determine the cause and extent of deterioration and to assess the condition of prestressing system consisted of the following activities:

- Non-destructive tests and laboratory analysis of concrete cores;
- Overcore concrete stress measurements;
- In-situ stress measurement (Figure 3) and inspection of post tensioned cables for signs of corrosion (Figure 4).

In the areas of post-tensioning anchorages, concrete serves mainly a secondary function of protecting anchorage heads from corrosion. Despite the very poor concrete quality of the concrete in the post-tensioned recesses (Figure 5), the anchorage heads were in a reasonably good condition. Exposed rebar and post-tensioned tendons in the wall did not reveal any significant signs of corrosion. Deterioration was mainly due to Alkali Aggregate Reaction (AAR). All measured stresses were compressive as expected, generally in the design range.

To minimize future expansion due to AAR and to protect reinforcing and prestressing steel from corrosion, the water ingress had to be prevented. Deteriorated concrete of the ring beam was replaced using cement based grout material. Subsequently, Glass Fiber Reinforced Polymer (GFRP) sheets were applied. Prequalifying work was carried out to test the repair method prior to application. Figure 6 shows the ring beam after repair.

To monitor the ring beam in order to provide assurance of structural integrity and to investigate suitability of instruments for long-term monitoring, instrumentation was installed inside and outside of the repair. The instrumentation consisted of the Vibrating Wire Strain Gauges (VWSG) and Fiber Optic Sensors (FOS). Readings were taken during concrete pouring and hydration. Currently, monitoring is performed by assessing data collected semi-annually using VWSG. Strain is small and is mostly due to temperature variations throughout the year.

Repair of Turbine Building Walls

Vertical cracks have been observed in the Turbine Building (T/B) concrete perimeter walls during inspection at Gentilly 1. These walls connect the piers above the spread footing and provide stability of the building against wind and seismic loads.

Repair work was conducted. Cracks in concrete walls were repaired using epoxy injection (Figure 7). The quality of repair was assured based on the inspection of extracted cores over a few repaired cracks. The penetration of epoxy into the crack was examined using measurement microscope. Subsequently, the core was broken by hitting with the hammer in vertical direction to ensure that it would not brake along the line of repaired crack. One joint in the concrete wall, where a leakage was suspected, was repaired using polyurethane injection.

Areas of delaminated mortar on the block wall were removed using saw cut and repaired using repair mortar (Figure 8). After repair of delaminations was completed, joints between the block wall and concrete wall were redefined and filled with polyurethane sealant.

Repair of Sealant in Reactor Building Bottom Joint

During the spring of 2005, the leakage of water had been noticed at the bottom of the Gentilly 1 Reactor Building perimeter wall adjacent to the top slab of the North tunnel. The condition of the joint on the outside of the R/B was inspected. Although the sealant did not seem to become brittle, the bond between the sealant and the concrete had deteriorated (Figure 9).

Repair work to replace the joint was carried out (Figure 10). Prior to repair of the joint around the R/B wall, the old joint material was removed and the joint was cleaned and then sealed using urethane based joint sealant material.

REFERENCES

[1] CAN/CSA N287.7-96 (R2005), In-Service Examination and Testing Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants, 1996 (R2005).

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Table 1 Example of Aging Related Degradation Mechanism Matrix

ARDM	Concrete	Reinforcing Steel	Steel Components	Sealing Compound
Chemical Attack	L	-	-	-
Fatigue / Vibration	-	-	L	-
Abrasion / Erosion / Cavitation	-	-	-	-
Thermal Exposure / Cycling	M	-	-	M
Irradiation	L	L	L	M
Corrosion	-	M	M	-

H – high

M – medium

L - low

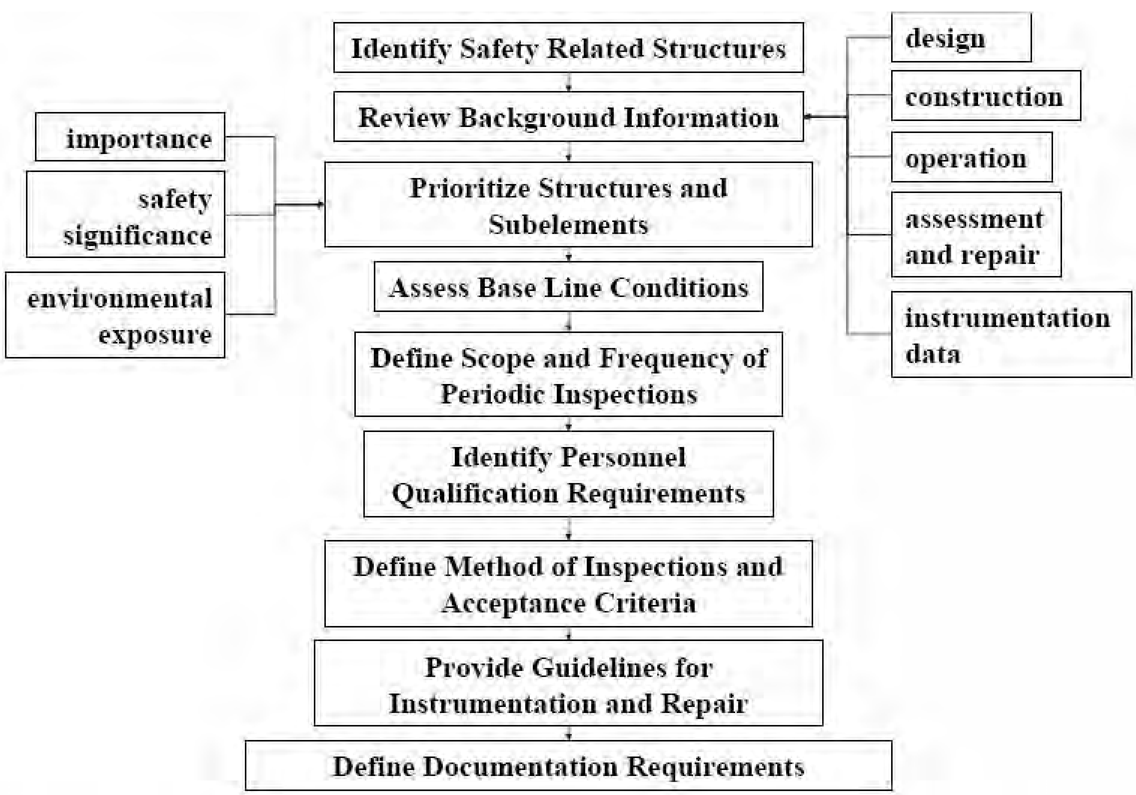

Figure 1 Main Steps in Development of an AMP

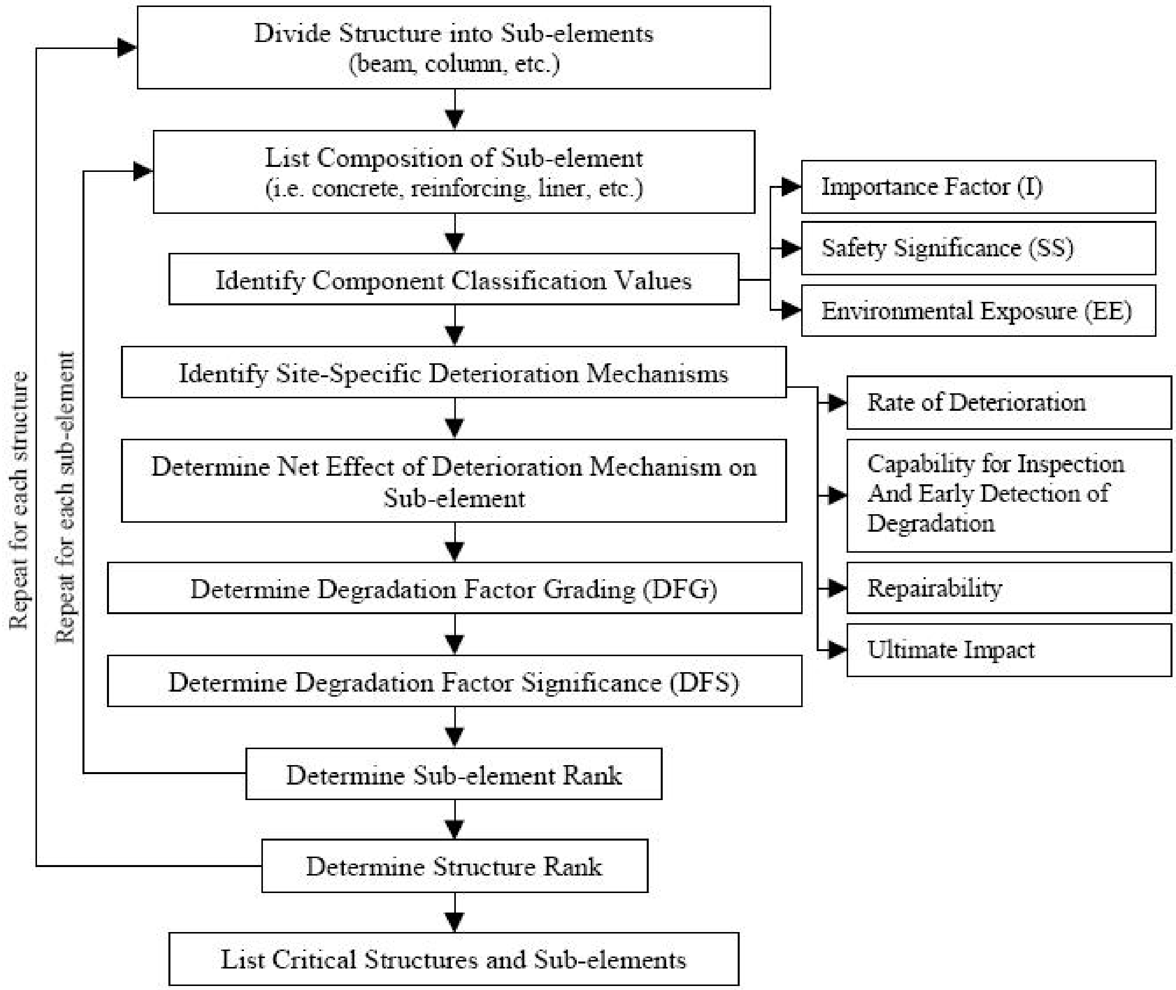

Figure 2 Prioritization of Structures and Sub-elements

Figure 3 In-situ Stress Measurements

Figure 4 Inspection of Prestressing Cables

Figure 5 Condition of the Ring Beam Before Repair

Figure 6 Condition of the Ring Beam After Repair

Figure 7 Epoxy Injection of Cracks in T/B Walls

Figure 8 Repaired T/B Walls

Figure 9 Deterioration of Sealant at the Bottom of R/B

Figure 10 R/B Bottom Joint Sealant Repair