Transactions, SMiRT 16, Washington DC, August 2001 *Paper # 0000*

ASSESSMENT, REPAIR AND MONITORING OF THE GENTILLY-1 CONCRETE CONTAINMENT STRUCTURE

A.A. Khan, M. Gray, B. Shenton, D. Panesar and M. Elgohary
Atomic Energy of Canada Limited, Mississauga, Ontario, Canada

ABSTRACT

The Gentilly-1 CANDU-250 MWe Nuclear Power Plant in Quebec, Canada, has been decommissioned. The spent fuel has been removed and the building serves only as storage for some of the used reactor components and low-level radioactive materials. The structure, about 30 years old, is showing signs of aging. Hence, studies were undertaken to determine if any remedial measures were needed. This is required to ensure that the prestressed concrete containment structure would fulfill its functional requirement for the next 50 years or more. This paper summarizes the results of the evaluation of the structure. The investigation showed that the structural concrete forming the dome and the wall could be expected to service for the required period. However, portions of the ring-beam needed repair. Different designs for the repair of the ring beam were considered. The design of the remedial work and the monitoring system that has been installed to ensure satisfactory long-term performance of the repaired ring beam are described.

INTRODUCTION

The Gentilly-1 nuclear power plant was designed by Atomic Energy of Canada Limited (AECL) in the 1960's and has been decommissioned. AECL, as the owner of the facility, is required to maintain the facility in a "static state". In general, the decommissioning strategy is to provide interim storage for all conventional and radiological hazards until the facility is finally decommissioned and demolished. The concrete reactor building structure is an essential part of the interim storage scheme.

In its current state, many of the loads including severe accidental and environmental loads for which the prestressed concrete containment structure has been originally designed for will not be experienced by the structure. However, the building is required to function for more than fifty years beyond the original design expectation and during this period of extended life, the building will be used to contain low-level radioactive materials and therefore must remain structurally sound. In addition, the appearance of the building must show that the structure is meeting the prime safety requirement. Poor appearance can strongly and detrimentally influence the perceptions of safety and, hence, satisfactory functioning of the containment structure. In early 1980's, it was found that some of the ring beam concrete that forms the junction between the perimeter wall and the domed roof, has shown signs of deterioration. The ring beam was repaired immediately but the repair was ineffective and signs of continuing deterioration quickly became apparent. Figure 1 shows the exterior view of G1-containment building and deterioration of ring beam.

More recently, a detailed study was undertaken to determine the condition of the structure and the actions necessary to ensure satisfactory performance of the structure over the remaining period of required service. In this context it is noted that the original design life for the concrete structure was 30 years. Structural condition assessment studies have been completed and it has been concluded that subject to completion of durable repairs to the ring-beam the concrete containment structure has the potential to be serviceable for a long time exceeding the 50 or more years as required by AECL.

The original design of the containment structure required the building to meet functional, safety and structural design load requirements. To meet all of these requirements the structure was designed and built using prestressed concrete. For its current application as a waste storage facility, many of the functions and loads for which the structure was designed will never be required or imposed. All high-level radioactive materials, such as spent fuel, have been removed from the facility to special storage facilities and the structure is not in operation. There is no risk of an accident. Accordingly, the structure is over-designed for its current function. Despite the foregoing, the structure is being required to function more than at least fifty years beyond its originally expected design life. Some parts of the structure are visibly aging and evidence was required to establish the following:

- the nature of the important aging and degrading mechanisms;
- the extent to which the aging mechanisms may have affected the structure;
- the extent to which aging mechanisms can be expected to influence the building for the remainder of its life;
- what, if any, measures are required to mitigate against the detrimental effects of aging.

In addition to these technical requirements, the appearance of the structure was poor. Particularly, some of the ring-beam concrete had deteriorated. While it remained to be determined whether this deterioration had adversely influenced the integrity of the structure, the poor appearance was influencing perceptions of safety. Due to the poor perception, the structure was not meeting one of the basic requirements of a structure. Recently, a detailed investigation has been carried out to assess the structural behaviour and safe performance of the reactor building. In situ measurements, laboratory tests and analyses were carried out to examine the condition of the structure.

OBJECTIVES

To satisfy the design and functional requirements, the following activities were undertaken:

1. Past assessment studies were reviewed and the results of previous approaches to repairs were examined.
2. The structure was visually inspected, areas of unsound materials were identified and any unexpected structural features were characterized. Reinforcing steel was exposed and examined for the possible effects of corrosion.
3. Samples of the concrete were cored from the wall, the dome and the ring-beam and subjected to laboratory investigations for physical and chemical tests. The laboratory tests and examinations provided information on the general condition of the structure and allowed for identification and evaluation of any ongoing detrimental aging processes.
4. The *in-situ* stress conditions in the concrete structure were measured at several locations on the wall and the dome. These measurements were compared with expected design values to ensure that the building conformed to design expectations.

RESULTS OF CONDITION ASSESSMENT

Past repairs

During the early investigation of the containment structure, it was found that the fill-concrete near the ends of post-tensioned anchorages regions had deteriorated and needed repair. Investigations carried out in the past and observations made during site inspections indicate that it is likely that a number of factors combined to cause the deterioration of some parts of the ring beam. These factors include the presence of alkali-aggregate reactions (AAR) in the concrete, the effects of wetting and drying and freezing and thawing and inadequate quality of workmanship.

In the past, the original fill concrete in the pockets of the ring-beam was removed and replaced with a sanded mortar. This repair was not durable. With the risk of the new mortar infill falling off the structure and causing injury, all loose materials were removed from the ring-beam in 1993. From this time onwards, the end caps of the pre-stressing strands had been left exposed.

Visual Inspection

Visual inspection and sounding in 1998 indicated that the exposed end plates of the pre-stressing strands were generally in good condition and appeared to have been well protected against corrosion by paint. Sounding also indicated that generally, the structural concrete of the walls, dome, buttresses and ring-beam were not spalling, nor badly affected by environmental factors or AAR. It was likely that if the areas of fill-concrete could be successfully repaired then the building should be durable and provide safe storage facility for the required period. It was necessary to test this experience-based judgement by measuring the quality of the concrete by sampling and carrying out laboratory-based tests and by measuring the *in situ* stresses in the wall and the dome. As a part of condition assessment program, testing were performed to measure the physical and chemical properties of structural concrete of containment structure.

Materials Testing

Fourteen 100 mm diameter cores were taken from the wall, ring beam and dome of structural concrete. A summary of the tests carried out to measure the properties are presented.

Petrographic Examination

The structural concrete is variously cracked at a microscopic scale. There is evidence of the effects of AAR and it is likely that this is related to the presence of reactive coarse aggregates in the concrete. The quality and compaction of the concrete is seen to be in good condition. Minor carbonation effect was also observed. The maximum depth of 3 mm after about 30 years confirms that the quality of concrete with regard to its permeability to air is excellent. Time to corrosion for reinforcement at 50 mm cover could exceed 100 years.

Chloride Ion Content

The chloride ion content is a variable that influences the corrosion of reinforcing steel. For the samples tested, it was found that even for the upper 10 mm cover concrete of the upper dome after 30 years, the values are well below the threshold level.

Water Soluble Alkali Content

The water soluble alkali content is a measure of one of the components that, given appropriate reaction conditions, can lead to AAR. Water soluble alkalis are present in the structural concrete at Gentilly-1. Combined with the presence of alkali reactive coarse aggregate AAR can occur if the pores in the concrete are filled with and have access to moisture. If the internal humidity of the concrete is below 80%, further deterioration can be prevented. It was recommended to use protective coating as an additional safeguard for the future repair work.

Air Voids and Water Absorption

The air void content, pore size distribution and water absorption properties of a concrete control its ability to resist the effects caused by freezing and thawing. Observations and results from the tested specimens indicate that water absorption values are very low (about 4-5%) for the cores tested. Concrete is able to resist adverse effects of freezing and thawing.

Compressive Strength, Modulus of Elasticity and Poisson's Ratio

Core samples obtained from containment structural elements were tested to measure the mechanical properties of concrete. It was found that the average measured values exceeded the specified designed values of compressive strength (i.e., 35 MPa at 28 days). A summary of tests performed on concrete core samples resulted in the following range :

Compressive Strength: 54.8 to 66.4 MPa

Modulus of Elasticity: 28.9 to 31.2 GPa

Poisson's Ratio: 0.11 to 0.20

In-Situ Stress Measurements

As a part of condition assessment program, in-situ stresses were determined for the perimeter wall, ring beam and dome of the concrete containment structure at varying depths. The main purpose of these measurements were to produce a plan for the repair / remediation work needed to ensure the structural integrity. Overcoring stress measurements in the concrete were performed using doorstopper cells in conjunction with a compact self-contained data acquisition system, the Intelligent Acquisition Module (IAM). Testing was done in 70-mm diameter diamond drill holes. Over-core stress measurements were taken both in circumferential and meridonial directions at each location. Figure 2 shows a typical diamond drill set up for doorstopper gauge overcoring.

As expected, all of the measured stresses in the containment concrete structural members were compressive. Generally, the values measured were within the range as predicted from stress calculations. It is likely that the stresses have changed since construction. However, with the competing effects of AAR, creep of the concrete and relaxation of the pre-stressing tendons, the exact changes cannot be determined and isolated.

For the present purpose, it is considered sufficient that the structural concrete is still under enough compression that it can be judged to be expected that, as a whole, the structure should maintain its integrity and meet its function as a storage facility.

STRUCTURAL ASSESSMENT SUMMARY

Alkali aggregate reaction has occurred in the structural concrete that forms the ring-beam, wall, dome and buttresses of the Gentilly-1 containment structure. The chemicals needed for the continuing reaction are present, however, the reaction is proceeding very slowly, if at all. The reasons for this slow reaction are due to the low permeability of the concrete to water and, hence, low humidity in the voids of the concrete. This situation is not likely to change. If effects of AAR are observed then preventing the ingress of water into the concrete by, for example, coating the concrete with a siloxane sealer, should be sufficient to reduce the reaction. There are insufficient chloride ions in the concrete to induce excessive and adverse corrosion of the reinforcing or prestressing steel.

It was concluded that the containment structure was in good structural condition and that the building could be expected to remain serviceable as required and for the next 50 or more years. Assuming that the humidity in the concrete is below 80%, or that the post-tensioning system can restrain any further expansion, the service life of the structure will depend on the ring beam repair design and the quality of the repair execution.

REPAIR OF THE RING BEAM

Based on the findings of structural condition assessment, it was determined that portions of the ring-beam needed repair. The design of the remedial work and the monitoring system that has been installed to ensure satisfactory long-term performance of the repaired ring beam are described. As can be seen from Figure 1, the deterioration has mainly occurred in the secondary concrete and around the cut-outs of the post-tensioning anchorage system

Different design alternatives were studied to provide a durable repair technique for the ring beam. The repair method used included the removal of all deteriorated concrete from the sound structural substrate of ring beam. The voids so generated were filled with a modified repair concrete which bonds well with the original structural concrete. Glass Fibre Reinforced Plastic (GFRP) will be bonded to the exterior surfaces of the repaired ring beam. This scheme will restore the concrete of the ring beam, protects prestressing anchorages system from corrosion, and provides a durable solution that meets concerns arising from poor appearance and adverse condition of the ring beam.

Figure 3 shows the installation of scaffolding to perform the repair of ring beam. All the unsound and unbonded fill-concrete was removed using saw cut for shallow depths (50 mm or less) and jack hammer was used for deeper areas. All the fractured concrete were removed prior to the surface preparation. High pressure washing was employed to remove the dirt or other debris material. Figure 4 shows a typical surface preparation of a ring beam patch using high-pressure water washing. For the apparent non-damaged concrete area, a hammer test was used to examine the concrete surface for delamination. 15 mm diameter steel L-shaped dowels spaced at a maximum of about 500 mm was used to anchor 10 mm diameter reinforcing steel bars. For shallow repair, a steel wire mesh with a spacing of 200 mm in each direction was used. Figure 5 shows the L-shaped dowel installed prior to the placement of concrete.

Sika 225 mortar and Sika 212 concrete with maximum aggregate size of 10 mm were used as a fill-concrete repair materials for depths equal or less than 50 mm and for depths greater than 50 mm, respectively. Properties tests including concrete compressive strength, pull out, and tensile strength on the repaired materials were carried out to ensure that the desired strength and quality assurance criteria is met.

In order to ensure the long-term performance of the repair and to meet the design life criteria of 100 year, sensors such as Vibrating Wire Gauges and Fibre Optic Sensors are embedded both inside and close to the surface of the repaired sections at the North, South, East and West faces. Temperatures and strain measurements are taken from very early period of hydration. It is planned to install Fibre Optic Sensors in the GFRP to monitor the strains and thermal effects occurring in the GFRP. The data from these instruments will enable to assess the adequacy of the repair and to confirm that, in time, the structure is performing in a safe and satisfactory condition.

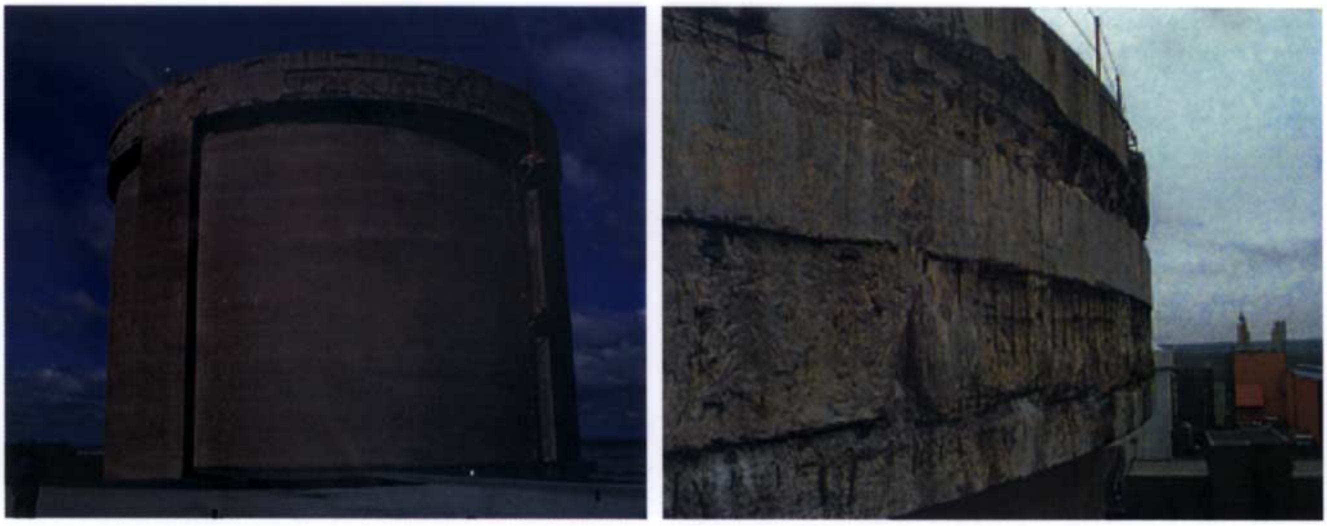
CONCLUSIONS

Based on the condition assessment studies, it is concluded that:

1. After about 30 years since construction, the structural concrete is still in a good condition and the structure is satisfying current functional and design requirements.
2. The *in-situ* stresses measured in the concrete containment structure are all compressive and are well within the range of predicted designed values. The concrete has been subjected to alkali-aggregate reactions. Assuming that the internal humidity of concrete is below 80 %, deterioration will not be of any significant amount.
3. The damage to the infill-concrete is not of structural significance. The repair that was undertaken of the ring beam and the future maintenance program will ensure many more years of service of Gentilly-1 structure.

ACKNOWLEDGEMENTS

The work reported was carried out by a large team with members from G-1 Station, Consultants, Contractors and AECL. The endeavours of all of the participants are gratefully acknowledged. The authors would like to extend special thanks to Professor Sami H. Rizkalla, Professor Kenneth W. Neale, Dr. Gamil Tadros of Network of Centres of Excellence of Intelligent Sensing for Innovative Structures (ISIS Canada), and Mr. John A. Bickley for their technical support and expert opinion on the project. The technical contribution for the overcore stress measurements made by Mr. Paul Thompson and his team from AECL's Underground Research Laboratory is particularly worthy of thanks.



a) Gentilly-1 Containment Structure

b) A Close-up view of ring beam

Figure 1: An exterior view of containment structure

Figure 2: A typical diamond drill set up used for overcore stress measurements

Figure 3: Installation of scaffolding in-progress

Figure 4: Water washing used for surface preparation

Figure 5: L-shaped dowel installed for reinforcement bars