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EVALUATION AND REPAIR OF SPENT FUEL DRY STORAGE STRUCTURES

Julia Tcherner[1] and David Tanner[2]

[1] Senior Civil Engineer, Candu Energy Inc. Mississauga ON Canada (Julia.Tcherner@candu.com)
[2] Acting Facilities Manager, Atomic Energy of Canada Limited, Chalk River ON Canada (tannerd@aecl.ca)

ABSTRACT

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

Pattern cracking was observed during inspection at one of the sites that house these canisters. Thorough evaluation of the canisters to determine the cause and extent of cracking was undertaken including non-destructive tests and laboratory analysis of recovered core samples.

Based on the results of the evaluation, it was concluded that the nature and extent of cracking did not compromise structural integrity of the canisters and their ability to satisfy functional requirements. However, since existing cracks might jeopardize the long-term integrity of canisters, it was recommended to protect the canisters from further deterioration by preventing moisture from penetrating them.

A repair scheme was designed and implemented to waterproof the canisters to ensure their long term durability. This paper describes the investigation of the cracks, causes and extent of deterioration as well as the repair and its performance.

1 INTRODUCTION

The Spent Fuel Dry Storage Facilities were designed to provide safe, economical, reliable, and retrievable interim storage for spent fuel. The facility consists of reinforced concrete canisters containing steel cylinders supported on reinforced concrete slabs.

Pattern cracking was observed during inspection of the concrete canisters at one of the sites (Figure 1). An investigation of the canisters to determine the cause and extent of cracking to develop a repair scheme was undertaken.

2 EVALUATION OF CANISTERS

An investigation of the canisters to determine the cause and extent of cracking included the following activities:

- A condition survey of canisters;
- Non-destructive tests: Impact Echo, Ground Penetrating Radar (GPR), impact hammer, and half-cell potential; and
- Laboratory testing of extracted cores, including compressive strength and density tests, as well as petrographic analysis.

2.1 Impact Echo and GPR

The impact echo survey was conducted at forty-two locations evenly spaced around the canister and along its length. All impact echo tests showed similar results. Figure 2 shows an example of the type of signal obtained. Invariably there was a very large peak around 7 kHz. In addition, some tests showed very minor peaks around 15 kHz and at 1 to 1.5 kHz. To analyse the probable location of these reflected signals, calculations were made of the expected frequencies from known design details within the canisters.

The wave speed assumed based on the testing of cores extracted from the canisters did not provide a good fit for the data. It appeared that the surface cracking observed in some of the core tests have propagated to the outer reinforcing steel. Cracking of the concrete cover re-directs the stress wave, significantly reducing their speed and, combined with the large diameter and tightly spaced reinforcing steel that absorb the majority of the wave energy, has the effect of slowing the impact echo stress waves in that region. Thus, analysis was performed considering attenuation of signal waves due to the observed cracking in the outer layer of the concrete.

Based on the analysis, the 7 to 7.5 kHz peak was from the outer reinforcing steel, while minor peaks at 1 to 1.5 kHz were reflections from the inside steel cylinder or inside reinforcing cage. The minor peaks around 15 kHz were from the cracks in the concrete cover. There were no significant peaks noted between 7 kHz and 1.5 kHz, which indicated the absence of internal defects or flaws beyond the level of the outer reinforcing steel.

Another possible interpretation of the dominant peak frequency result of 7.5 kHz, which was considered, is that there is a crack at approximately 230 mm inside the concrete. This interpretation was considered improbable since it is unlikely for the crack to be present at exactly the same location in each of the tested canisters. However, it was prudent to include alternative technique (i.e. GPR scans) to rule out the existence of anomaly at that location. A limited number of GPR scans were conducted. The GPR survey showed a very tight pattern of reinforcing steel in the outer reinforcing cage, but did not show any indication of deterioration in the main body of the concrete (see Figure 3).

2.2 Field Investigation and Coring

In order to avoid cutting of the reinforcement while extracting core samples, a PROCEQ Profometer 5 rebar locater was used to scan the reinforcement. It was determined that the concrete cover as well as the spacing of the reinforcing bars was not uniform. Concrete core samples measuring 76 mm in diameter and 200 mm in length were recovered for testing. A few samples of smaller length were recovered to provide access to the reinforcement to perform half-cell potential survey.

A half-cell potential survey was conducted in accordance with ASTM C876. A total of 42 measurement points were used to produce the equipotential maps. Areas where potential is less negative than –0.1V are shown as shaded. However, according to test method ASTM C876, values that are less negative than –0.20V have a greater than 90% probability that no corrosion is present. It is not until the readings are more negative than –0.35V, that corrosion is likely. Thus, the results of the half-cell potential testing showed that corrosion was not occurring in any of the canisters tested. However, it is interesting to point out that although corrosion is of no concern currently, the probability of corrosion was higher in the tested canister that does not contain spent fuel. The heat from the fuel in the canisters most likely helps reduce the moisture content in the concrete, which has the effect of limiting one of the principal factors controlling the potential for corrosion.

An impact hammer survey indicated that there was no significant difference in the quality of the concrete cover as variability of results was low. The rebound numbers were very high exceeding the normal range for the instrument.

2.3 Laboratory Analysis of Cores

Typical cracking on the surface of the concrete ranged in width from 0.1 to 0.25 mm and extended through the cores in most cases to approximately 50 percent of the core length. In some cases, deposition of secondary mineralization on the surface of the canisters at crack locations was observed. Efflorescence was observed in many cases below the crack. Although the pattern of cracking and leaching deposits often associated with Alkali Aggregate Reaction (AAR) were observed on most canisters, petrographic examination did not reveal features typically associated with AAR.

Visual inspection of cores revealed uneven gradation of the coarse aggregate in the concrete cover. The values for compressive strength and density of the cores averaged at about 77 MPa and 2513 kg/m^3 respectively. An air void system analysis was performed in accordance with ASTM C 457. Results showed that for a few of the tested canisters, the air void system of the outer concrete did not satisfy the requirements for minimum air content and maximum spacing factor of voids as was stated in the CSA A23.1. However, based on the construction records, adequate air content was present in the concrete when delivered to the site. Petrographic examination of cores revealed varying degrees of segregation of the coarse aggregate in the outer layer.

Based on these observations, it is likely that placement / consolidation techniques used to place the concrete between the outer ring of reinforcing steel and the exterior forms, combined with large size of the coarse aggregate and dense reinforcement layout resulted in significant disruption of the proportioning of the concrete. As a result, an outer layer of concrete was depleted with respect to coarse aggregate and did not have a proper air void system. However, this did not appear to have negatively impacted the field performance of the concrete, as widespread signs of degradation associated with the freeze-thaw failure were not present.

2.4 Results of the Investigation

Based on results of the investigation, it was concluded that the nature and extent of cracking did not compromise the structural integrity of the canisters. Cracks were mostly shallow and strength and density of the tested cores exceeded design values of 28 MPa and 2368 kg/m^3 respectively.

The distribution and character of the cracking suggests they are principally the result of factors such as restrained drying shrinkage and thermal effects, enhanced by the geometry of the structures and construction practices used. Although efforts were taken to reduce the effects of thermal stresses developed during the hydration of such large masses of concrete mostly by using low heat of hydration cement, the impact of temperature differentials on the concrete canisters is important when considering that canisters were constructed in cold weather conditions.

Although cracking has had little effect on the performance of the canisters and quality of concrete, the long term integrity of the structures might be jeopardized as the existing crack network acts as conduits for moisture movement into the interior of the concrete, which is evident by the widespread occurrence of leaching on the exterior of the canisters. Thus, it was recommended to protect the canisters from further deterioration by preventing the moisture from penetrating the canisters.

3. WEATHERPROOFING

Weatherproofing work was undertaken in 2010 and consisted of the following components:

- Weatherproofing of the canisters;
- Weatherproofing of the base slabs;

- Replacing the joint sealants in the joints between the base slabs; and
- Repainting the weather caps on the canisters.

The amount and nature of cracking in the canisters' surfaces was such that it was not feasible to repair them individually. Therefore the approach for surface treatment of the canisters was considered.

The original concept to weatherproof the canisters involved the use of the crystalline material (Xypex) that was supposed to create a crystalline structure deep within the pores and capillary tracts of the concrete mass to prevent penetration of water and aggressive chemicals.

This concept was considered superior to the coating or membrane solution as crystalline material supposedly becomes an integral part of the structures, thus not requiring reapplication. However, issues were encountered with this approach and were attributed to a variety of factors including surface preparation and curing of the material.

The coating system for waterproofing of the canisters consisted of a primer and two coats of Thorolastic by BASF. Such a system, when properly applied, has a proven field record (i.e., has been performing well in a similar application for the period of over 10 years). Improvements for the surface preparation (pressure washing using higher water pressure or sand blasting) were implemented. Large voids in the concrete were repaired with a compatible material (Gel Patch by BASF) prior to application of the coating system.

Quality control / quality assurance activities were implemented for this application. A few test patches were prepared to confirm surface preparation and application method (Figure 4). Measurements of the wet film thickness during application of the coating are shown in Figure 5. X-cut test was performed following requirements of ASTM D3359 to confirm adhesion thus qualifying surface preparation and curing (Figure 6).

Deterioration at the bottom of the canisters shown in Figure 7 was repaired using Gel Patch by BASF and sealed with a "cant-bead" of NP1 by BASF (single component polyurethane sealant). Flexible joint sealant SL2 by BASF was installed between the base slabs treated with Enviroseal 40 to provide waterproofing (Figure 8). Repaired canisters shown in Figure 9 are performing well after nearly three years since weatherproofing.

4. CONCLUSIONS

It proved useful to combine a few methods to perform evaluation of the spent fuel dry storage structures. This was necessary when establishing the base line condition of the existing structure. Subsequent periodic examinations will then be performed by means of visual inspection, if the structure is accessible. Non-destructive testing and laboratory analysis of extracted samples may be performed if warranted based on results of visual inspection.

Laboratory analyses of the cores extracted from the structures provided very valuable information as to the composition of concrete, quality of the air-void system, indications of the chemical reactions, and propagation and characterization of cracks. However, this information is limited mostly to the outer layer of concrete. Also, it might not always be practical to extract samples if radiation doses are high.

To investigate thick walled concrete structures with dense reinforcement, it may be beneficial to map the reinforcement using a GPR survey. Based on this information, the impact echo test can be carefully positioned to avoid as many layers of the reinforcement as possible in order to increase the impact energy beyond the level of the outer reinforcing steel. Optimum spacing for the impact echo tests should be chosen to provide reliable information related to the internal condition of the structure.

For repair, it is beneficial to use materials with long lasting field records in similar applications. Test patches should be used to measure wet film thickness and adhesion in order to qualify surface preparation and application method to ensure long lasting repair.

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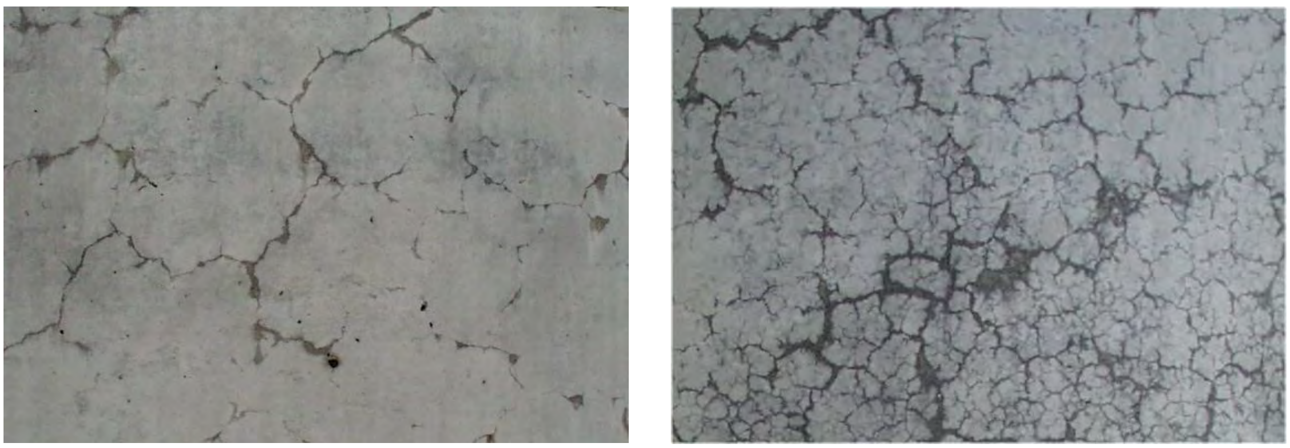

Figure 1 Close up View of Typical Cracking Pattern on the Outside Surface of Concrete Canisters

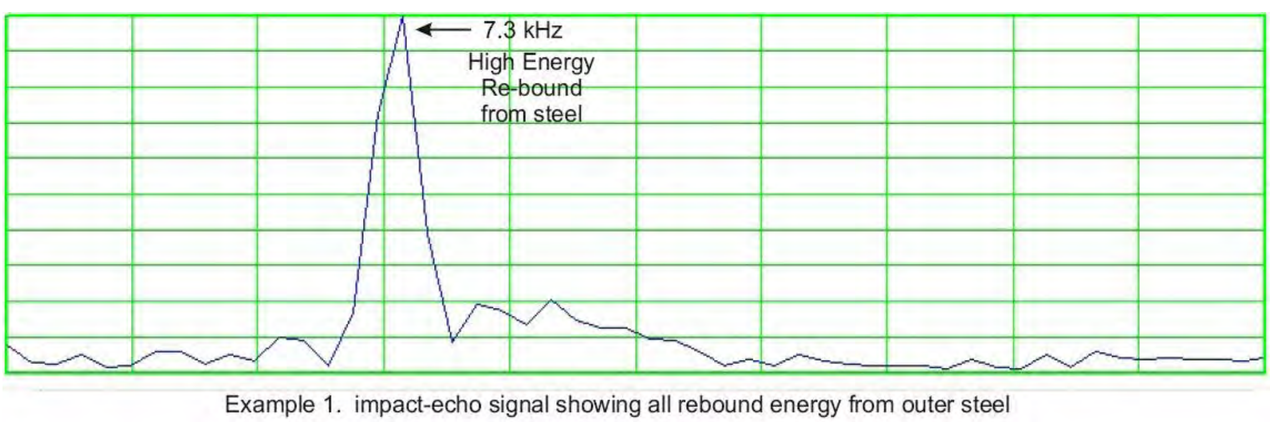

Figure 2 Example of Impact Echo Signal in Canister

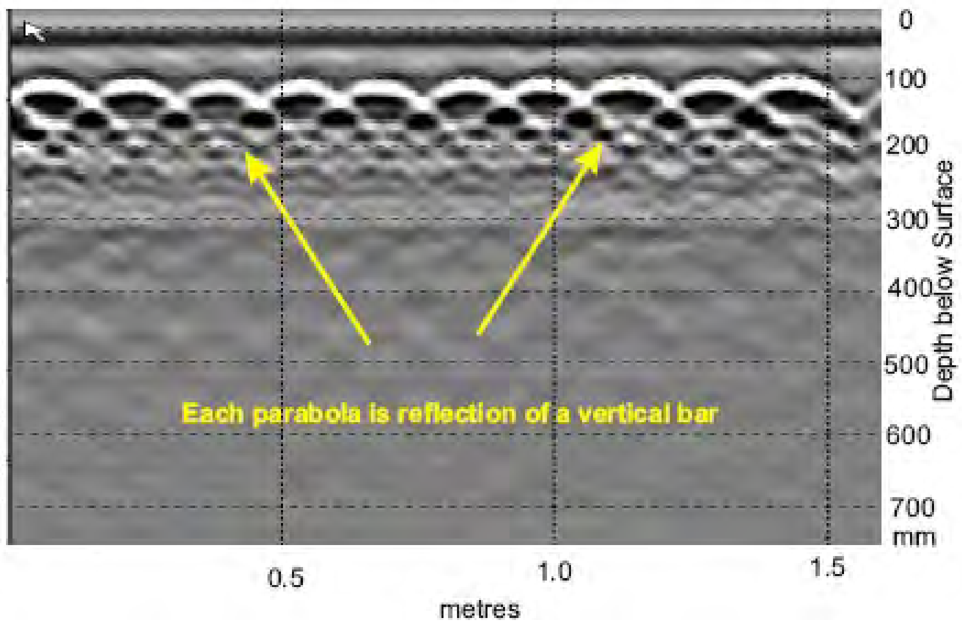

Figure 3 Horizontal GPR Scan of Canister

Figure 4 Test Patch

Figure 5 Measuring Wet Film Thickness

Figure 6 X-cut Test

Figure 7 Deterioration at the Bottom of the Canister

Figure 8 Base Slab (before and after repair)

Figure 9 Repaired Canisters