Inspection of Concrete Behind Steel Liners Using Ultrasonic Methods

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Abstract

Concrete structures found in nuclear power plants (such as sumps, containments, and pipes) are many times covered by a steel liner or include a steel liner within the thickness of the element. Nondestructive evaluation methods for metals and concrete have been focused and used on their specific material obviating the need for techniques to detect defects in concrete behind steel liners.

This paper presents information from published research and results from testing, performed using a commercially-available nondestructive evaluation (NDE) test methods, on different structures that contain liners of different thickness.

Results from testing indicate that the level of success of inspecting the concrete behind a liner, or concrete with an embedded liner, depends on the bond between the liner and the concrete, and the thickness of the liner. A higher level of success has been achieved when a good bond exists between the concrete and the liner and the thickness of the liner is less than 6 mm.

Keywords: concrete, embedded steel liner, steel liner, ultrasonic methods,

1. Introduction

Steel lined concrete structures are found in nuclear power plant facilities. While nondestructive evaluation methods have focused on the inspection of concrete or steel independently there is limited documentation of test results of concrete found behind steel liners.

This paper summarizes testing results and results from literature that focus on the inspection of concrete behind liners and of concrete that contain embedded liners. The paper presents test results on concrete behind liners thicker than 20 mm, concrete behind 6mm liners, and structures with embedded liners. Testing was performed with commercially available NDE methods. For brevity, the name of the method will be presented and details about the techniques used can be found in external references [1].

2. Testing of concrete behind liners thicker than 20 mm

The Electric Power Research Institute has commissioned several projects related to the inspection of concrete behind liners thicker than 20 mm. The first effort, published in 2013, was related to testing a steel-concrete-steel construction mockup with embedded foam balls that represented voids within the concrete [2]. During this study a commercially available ultrasonic
shear wave (USW) array and an USW pulse echo with a scanner were used for testing. The USW array used was a 12 x 4 array. The USW array and USW pulse echo were operated at a center frequency of 50 kHz and the data analysis was performed using a research level tomography software. While preliminary results performed in the laboratory indicated promising results, subsequent testing performed on two large-scale mockups indicated that the USW techniques were not capable to detect defects in the concrete while performing testing on the surface of the 20 mm steel liner.

The need from the industry to continue searching for a NDE technique that would allow evaluation of concrete behind liners thicker than 20 mm, motivated the research team to continue investigating other available methods. In this second study it has been found that while some methods, such as sounding and impulse response, provide information on the bond between the concrete and the steel, other methods, such as direct transmission ultrasonic pulse velocity (UPV), impact echo, and direct transmission shear wave have not been successful in locating 30 cm diameter honeycombs embedded in the mockups. The research team is evaluating the use of high energy x-rays for characterization of defects in the concrete behind the 20-mm liner.

3. Testing of concrete behind a 6-mm liner

More recently a testing campaign on mockups that include a 6-mm liner and 0.5 m of reinforced concrete have shown successful results. For this study, sounding, a 12 x 4 USW array, and an impact echo system were used. For this paper the sounding and USW array results are reported.

With the use of sounding it was possible to locate areas of the plate that had poor or no contact with the concrete. This information is particularly important as the lack of contact between the concrete and the steel plate will not allow ultrasound to travel into the concrete.

Data collected with the USW array was collected at 10 cm on center in the horizontal and vertical directions. Figure 1 presents B-scans across different regions of the mockup.

![Figure 1. B-scans collected from a location with a honeycomb (left) and from an area with poor contact between the steel plate and the concrete that also includes a small shallow delamination (right). Spacing between bars and backwall reflection correspond well with design drawings.](image)

The B-scan on the left was collected from a region where the bond between the concrete and the steel plate is good and contains a reflection from an embedded honeycomb. The round reflections near the top of the image are steel bars located perpendicular to the direction of the scan. The spacing between the bars corresponds well with the design drawings and the strong
backwall reflection can be distinguished at approximately 0.5 m. A faint reflection from the honeycomb is observed within thickness of the concrete and a lack of backwall reflection also provides an indication of the presence of the defect.

The figure on the right presents an area with lack of backwall reflection and an indication of an embedded shallow delamination. The region with the lack of backwall reflection corresponds to an area in which the steel plate was noted to have poor contact with the steel plate and the concrete by means of hammer sounding. The small delamination is represented by a reflection on top of the 4th piece of rebar, from left to right, near the testing surface.

4. Testing of concrete with embedded liners

Two studies with cases of steel liners embedded in concrete are documented in this section. The first study is related to the inspection of pre-stressed concrete cylinder pipe (PCCP) which is documented in detail a research report [3]. The structure is a network of individual pipes connected along a length of approximately 5 km. Each individual PCCP is approximately 3.5 m in diameter with an approximate length of 4.9 m and an approximately full thickness of 25 cm. The pipe contains a 1.5 mm thick embedded steel cylinder within the concrete at an approximate depth of 50 mm from the interior surface of the pipe. A representative cross section of the PCCP is presented in figure 2.

![Figure 2](image)

Figure 2 Representative cross section of the 25-cm thick PCCP with a 1.5 mm embedded liner at an approximate depth of 50 mm from the interior of the pipe.

Testing was performed with an impact echo system, an USW array, and an USW pulse echo system on sections of pipe with and without defects [3]. The results presented in this paper only include testing with the USW array. The USW array was a 12 x 4 transducer configuration at a center frequency of 50 kHz. Data was collected on the surface of the pipe at an approximate spacing of 30 cm along the length of the pipe (x) and 30 cm along the circumference of the pipe (Y). Figure 3 presents a C-scan and a B-scan of approximately ¼ of the circumference of the pipe along its entire length.
Figure 3 C-scan showing the areas of delamination (top) and B-scan showing a reconstruction of the cross section of the pipe at a clock position of 6:20 (bottom)

The top of Figure 3 presents the areas of delamination detected within the pipe. Data were gated to only display reflections within the thickness of the pipe. The bottom portion of Figure 3 includes a B-scan along the 6:20 o’clock position of the pipe. In this figure the reflection within the thickness of the pipe is located at an approximate depth of 50 mm. The identified depth of delamination corresponds well with the approximate location of the steel cylinder and therefore it was concluded that the delamination is occurring at the depth of the cylinder. Note that when the cylinder is in good contact with the concrete, the ultrasonic waves are capable to penetrate through the cylinder and it is possible to obtain a full thickness reflection of the pipe.

The second case study is from a containment structure with a full thickness of approximately 1.0 m with an embedded liner at an approximate depth of 75 cm from the outer diameter of the wall [4]. Testing was performed with a USW pulse echo mounted on a scanner with datasets at a center frequency of 30 and 60 kHz. Results from the study indicate that a reflection from the liner and the full thickness reflection can be distinguished from the data collected from the shear wave array.

5. Discussion

The information obtained from the compilation of studies presented in sections 2 – 4 indicate that the thickness between the plate and the bond between the concrete and the steel plate are the primary factors that affect the propagation of waves through a concrete structure lined with concrete.
If the liner is thicker than 20 mm, ultrasonic methods have not been capable to penetrate through the steel plate and provide information regarding the condition of the concrete behind the plate. In contrast, when concrete is located behind a 6-mm liner, ultrasonic methods have been successful in identifying features behind the steel liner. Similarly, in cases in which a liner is thinner than 6 mm, embedded, and in good contact with the concrete, ultrasonic methods have the capability to identify full thickness reflections and potentially defects located behind the embedded liner.

Adequate contact between the concrete and the steel liner is important to allow the waves to penetrate through the steel and into concrete. In the case where concrete is located directly behind the liner, good contact is necessary to identify features within the concrete and a full thickness of the concrete element. If there is not sufficient contact between the concrete and the liner, the waves will not be able to penetrate through and no information related to the condition of the concrete can be obtained. In the case of an embedded liner, a lack of bond between the liner and the concrete will be identified as a delamination and it will not be possible to obtain information of what is behind the delamination.

6. Conclusion

This paper presented a summary of test results from structures with concrete behind liner and concrete structures with an imbedded liner. Test results were primarily obtained from USW methods and sounding.

The compilation of case studies indicates that the thickness of the steel plate and the bond between the steel and the concrete play a fundamental role in allowing ultrasonic methods to successfully test concrete behind steel liners.

A good bond between the steel plate and the concrete and a liner thickness of 6 mm or less were noted to be the conditions that would allow for the identification of features behind a steel liner. In the case where testing was performed on a 20-mm plate or where poor contact existed between the concrete and steel, the ultrasonic waves were not capable to penetrate beyond the steel plate. However, this feature may be beneficial when trying to identify delaminations or lack of contact between the concrete and the embedded steel liner.

7. References