Carbonation and Chlorides Testing – a client's approach to Condition Assessment Techniques

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Introduction

It has often been suggested that owning a 'Crystal Ball' would be a useful thing to have for predicting asset management problems that may arise in projects before they occur.

Many treated water storage tanks in Australia are made from steel reinforced concrete, and several factors, both structural and environmental, come into play when determining the actual design life of these tanks (60 to 80 years), as opposed to the estimated design life (100 years plus). Two such factors are:

- The steel reinforcement fabric does not have sufficient concrete coverage to avoid corrosion from occurring due to the surrounding environment - ***Carbonation***.
- The concrete itself has 'inbuilt chemical components' that cause the steel fabric to corrode – ***the presence of Chlorides***.

Luckily, there are several procedures available that can be used to predict whether carbonation may occur and whether chlorides are present.

This paper details how Aqualift worked with a client, SA Water, to identify the signs of carbonation and the presence of chlorides.

Assessing carbonation

Carbonation is a common problem in concrete structures exposed to the natural, external environment; it is less of a problem in concrete which is 'climate controlled', such as the inside areas of buildings or surfaces submerged in water. Carbonation slowly reduces the alkalinity of concrete, and it is the alkalinity factor which slows down the corrosion process of the reinforcing fabric within the concrete.

Carbonation happens naturally and leads to an exponential deterioration process related to the age of the concrete; in most cases the older the concrete, the more the carbonation depth increases.

This is why a minimum steel cover of between 60 to 80mm is specified when building with reinforced concrete; this should ensure that the predicted design life is achieved, without the threat of premature failure.

Carbonation testing is generally carried out on two separate areas of a tank, to ensure that weathering factors are considered. The sides of the tanks that face east and west should be the main focus for initial carbonation testing, as they are more exposed to the sun, unless trees or other shade factors are present.

If results indicate a high carbonation percentage, then additional tests in other representative areas around the tank should be done whilst onsite. The military-based ‘clock face’ positions of 3, 6, 9, and 12 O’clock can be used on the documentation to record the test results, with 6 O’clock being located at the main entry hatch area.

The testing involves two separate procedures: steel cover depth assessment (Figure 1) and a carbonation deterioration depth (Figure 2).

For the steel cover depth assessment, a re-bar detector is run vertically in a side-to-side pattern down the test area and readings of steel depths (4 to 6 readings is an ideal number) are taken and the results recorded on the test result sheet.

Figure 1: using a re-bar meter to conduct a steel cover depth assessment

These readings are then averaged out, with the shallowest reading recorded as a ‘wild card’ factor.

A 5mm impact drill bit is then used to check carbonation deterioration depth.

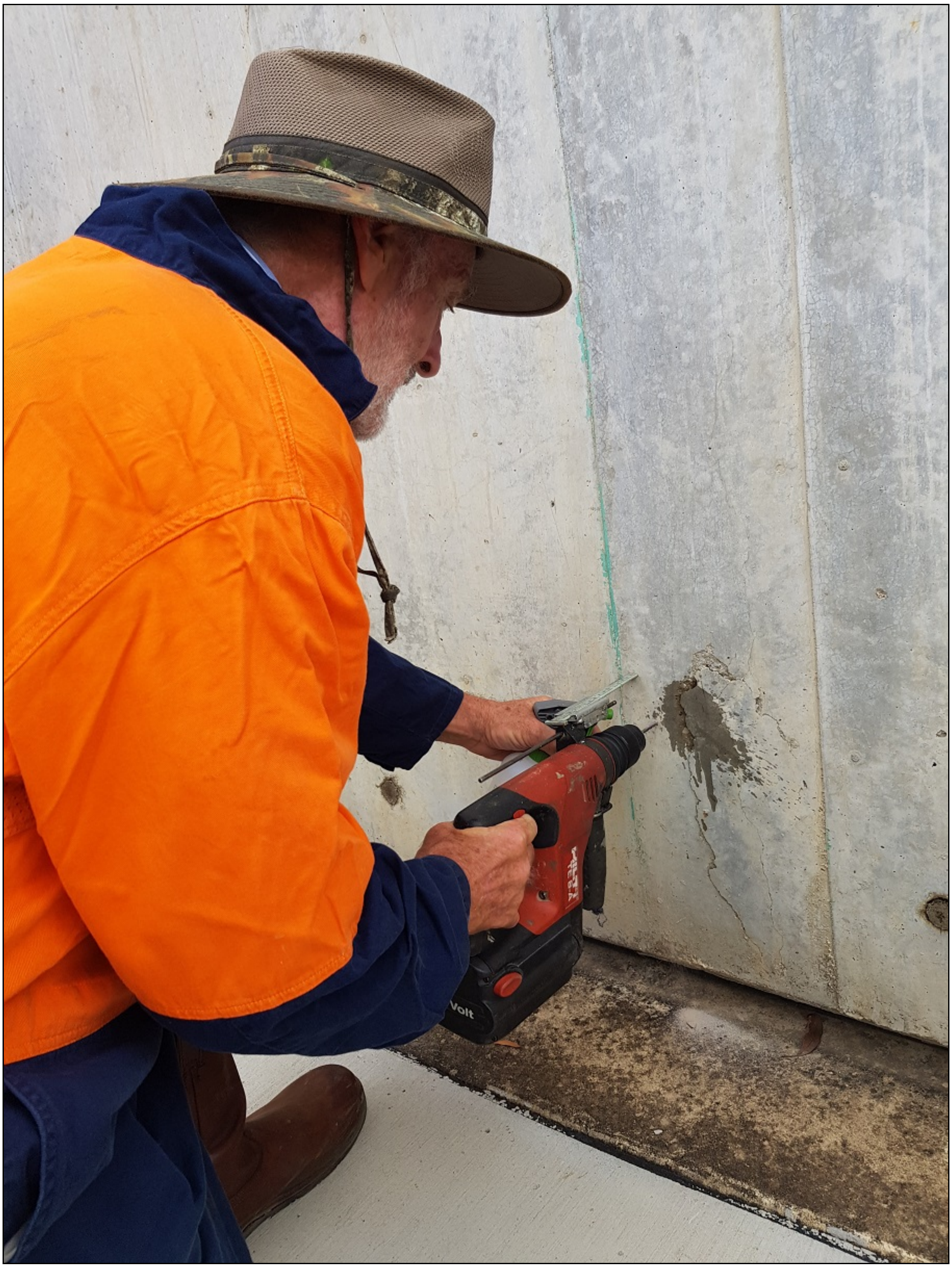

Figure 2: drilling holes in order to conduct carbonation deterioration depth

An indicator solution of 50% distilled water, 50% methylated spirits, mixed with half a teaspoon of phenolphthalein powder per litre of solution, is sprayed onto the drill tailings to show when good alkaline concrete is reached – the tailings turn purple when alkaline concrete has been detected (Figure 3).

Figure 3 - purple tailings indicating that alkaline concrete has been detected

Again, 4 to 6 readings should be taken, with the results recorded on the test result sheet, averaged out and the deepest reading being recorded as a 'wild card' result.

A carbonation factor percentage is calculated by placing the carbonation depth over the steel cover depth. An example calculation would be: a carbonation depth of 25mm, with a steel cover average of 50mm, would give a carbonation factor of 50% (25/50 = 0.5, or 50%).

If the tank being assessed is between 40 and 60 years old, this would be an acceptable percentage, as carbonation occurs in concrete at an exponential rate.

If the carbonation factor percentage is higher (that is, >50%), particularly in newer structures, then remedial actions (such as a waterproof external coating) will need to be considered to achieve the expected design life target.

Measuring for the presence of chlorides

Chlorides attacking the steel fabric of concrete tanks is another source of deterioration that can affect the life of the tank. If the concrete structure has the added pressure of stored water behind it, then the consequence of failure (COF) can be significant.

The chlorides found within concrete is commonly present because it occurs naturally in the raw materials used in the concrete batching process – that is, by being present in the gravels and sands that have been extracted from salty rivers and quarries, or from the water used in the mixing process; they can all contribute to a sort of 'inbuilt failure mode' of the finished concrete structure.

To test for the presence of chlorides, concrete dust samples are collected in sterile jars and sent to a laboratory for analysis (Figure 4).

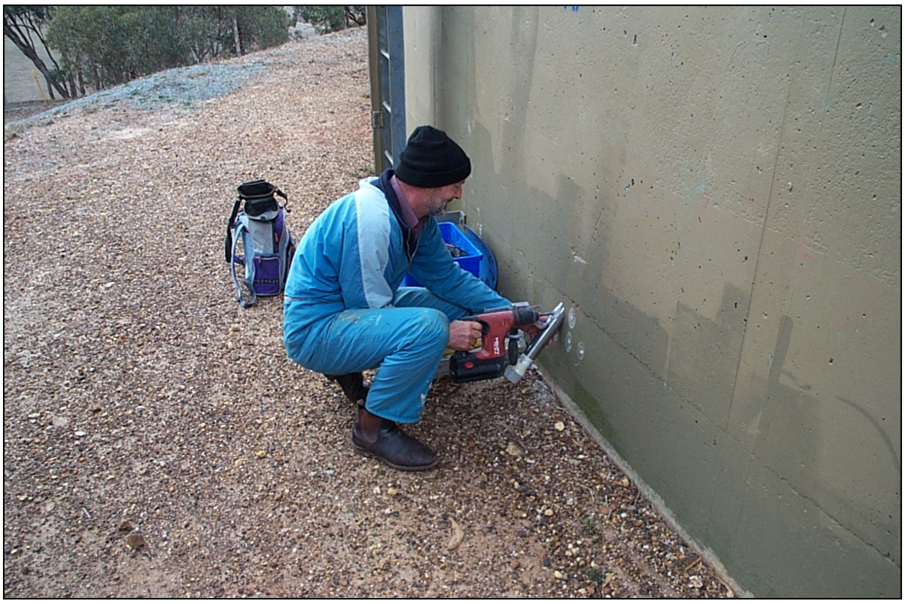

Figure 4: collecting a concrete dust sample for chlorides analysis

This test is generally conducted in one location and consists of drilling a series of 6 holes over a 300mm x 300mm sample area, using a 12mm impact bit. The drill is initially 'spudded' in to around 5mm in depth to remove any surface contaminants, and then the holes are drilled into a depth of 25mm, with the dust being directed through a SS drilling tube, which in turn is connected to the sample jar.

Once the 25mm samples are collected and the jars labelled, the drilling tube is 'blown' clean and the same holes are re-drilled to a depth of 50mm, with the same dust collection method being employed.

The holes are then filled and repaired using a good quality mastic material and the collected samples are sent off to a laboratory for analysis.

The results were compared against the following criteria for the risk of chlorides-induced corrosion of steel reinforcement:

- Less than 0.4% chlorides: Corrosion unlikely
- 0.4% - 1.0% chlorides: Corrosion probable
- 1.0% and greater chlorides: Significant corrosion probable

The Project

SA Water, a significant water industry client, believes in a long-term approach to the management of their tank assets, and has developed testing procedures to detect both carbonation and the presence of chlorides that results in deterioration of concrete. They use these procedures to assess the state of the concrete within their 488 plus rural storage tanks (Figure 5) that are spread across a wide and diverse geographical area.

Figure 5 – SA Water's Stokes WS119 tank

There are many different types of tanks within this number, in all shapes and sizes, some made from steel, but with the majority constructed from concrete, like the one shown in Figure 5.

SA Water had limited 'in-house' resources to regularly assess all of these tanks, so it was decided to train a suitable contractor in the testing procedures and let them conduct a 'wide ranging' condition assessment program, over a three-year period.

Aqualift had been cleaning and inspecting some of these tanks over previous years, so we were asked to carry out the task. It involved spending a week at SA Water's Adelaide technical services section to learn about the procedures and also to spend days out in the field with their personnel, putting the new skills into practise.

The next phase was to enter all the tanks into our Aqualift System Asset Management (ASAM) software system and to give each tank a standardised name and a unique, but simple, Water Storage (WS) number, beginning with WS 001.This included a lot of static data from their existing spreadsheets, including locations, age, dimensions and construction materials (Table 1).

The ASAM software was also updated to include the Carbonation Factor percentages and the percentages of chlorides for samples collected at depths of 25mm and 50mm. The inspection information and images were loaded at the end of each day, allowing the clients based back in Adelaide to follow the progress and use the program's search functionality to track important issues as they were uncovered.

Concrete Carbonation & Cover Averages

DATE:			JOB NUMBER:			ASSET NO:	
CLIENT:			ASSET NAME:				
AVG. CARBONATION:	12		AVERAGE COVER:	48		CF:	25%
MAX. CARBONATION:	16		MINIMUM COVER:	43		AGE:	32
6 o'clock		9 o'clock		12 o'clock		3 o'clock	
Carbonation	Cover	Carbonation	Cover	Carbonation	Cover	Carbonation	Cover
		15	43			15	53
		8	44			16	50
		10	47			8	51
			46				52
			45				51
			43				
Average	Average	Average	Average	Average	Average	Average	Average
		11	45			13	51
Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
		15	43			16	50

Table 1: example test result sheet

At the time of the project, there were five regional management areas, and each one had a slightly different way of doing things, depending on logistics and funding. Our job was to carry out a consistent 'fresh eyes' approach, so that all tanks could be graded to the same standard, so that funds could be allocated where most required.

Seeing as all the tank sites were to be visited, it was necessary to fully document, GPS locate and photograph each asset as part of our ASAM Level 1 inspection process. This concentrated on Security, Safety, Contamination and Structural issues. A ‘Drop camera’ was also used to gain limited internal images of the sediment, ladder condition and any pipework that lay close to the entry hatch area. It can be likened to a ‘Zen approach’, whereby no one issue was focussed upon, but rather everything was looked at whilst onsite and compared to all the other tanks. As the inspection process developed, some earlier information was adjusted to define the best- and worst-case scenarios.

We developed our own testing equipment and documentation (based on similar projects) to speed things up and then proceeded to travel around the different regions in turn. The local area management would assign an operator to take us around to their sites and make sure we did not become lost, an easy thing to do in some of the remote areas. We also learned a lot of useful local knowledge, such as the best bakeries to visit in each town.

Project Results

A lot of interesting facts emerged from the project, which allowed ‘the crystal ball approach’ to be quantified and used with confidence.

Tanks in certain areas had higher levels of chlorides, possibly due to the local building materials that were used in their construction. The surrounding ground also determined the uptake of chlorides by the concrete tank structure, particularly where the tanks were either inground or semi inground.

The oldest tanks, when compared to newer tanks, had less carbonation present, as a higher cement ratio was used and less performance additives were available for inclusion in the concrete mix. Design specifications were also more conservative pre-1970’s, when a majority of the tanks were constructed, and a lot of experience was obviously lost in the later years.

Certain years produced better (or worse) building results, possibly due to weather conditions and the availability of both contractors and an experienced labour force. Boom years always deplete available experienced personnel and tanks built in those years were generally of poorer quality. Where two or more tanks were built on the same site, it was easy to pick the order in which they were constructed. The first tank would have minor defects, but, presumably as the building crews ‘came together’ and bonded, the last tank to be built would be close to perfect, if such a thing is possible when working with concrete, in remote areas, out in the elements and with changes in staff along the way.

The asset management group we worked with estimated that most of their tanks had been built within a 40-to-50-year period, and that they could all fail within a similar time period, unless repairs were undertaken early enough to be both effective and cost efficient. Fortunately, concrete structures can be ‘saved’ and their original design life maintained and often exceeded if some of the main problems are identified within a suitable time period. This enables rehabilitation procedures to be carried out before too much damage occurs. A renovation solution can be as simple as installing a protective coating to reduce any further exposure to the external weather or backfill soil elements.

Unfortunately, some of the tanks inspected were found to be ‘too far gone’ to be rehabilitated, so these would be allowed to continue operating for a more limited period of time and then be removed from service.

One other important issue was discovered. Tanks that had already been taken out of service and abandoned were often left unsecured. This would allow travellers to access the sites, maybe climb up onto the tank for a photographic opportunity and then become injured by either falling in or off the structure.

SA Water, being the owner of the site and the tank, would face potential legal compensation issues by allowing persons to access an unsafe structure; the same as leaving an open hole in the ground during a project, that someone may fall into and injure themselves.

Most of these structures were not allowed to be climbed by staff, but being rope access technicians, as well as divers, we cautiously went where others dared not to, and assessed each situation accordingly.

Our recommendations in these cases were to either better secure the site and conduct regular visits, or to remove the abandoned structure completely.