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CONDITION ASSESSMENT OF EXISTING WATER RETAINING STRUCTURES

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Abstract: Corrosion of reinforcement is the most significant cause of premature deterioration of reinforced concrete structures. Many of the concrete structures, which have been exposed to aggressive environments, suffer from durability problems and fail to fulfill their design service life requirements. Chloride induced corrosion is considered to be one of the major deterioration mechanism in reducing the service life of reinforced concrete structure which is subjected to aggressive environment. Therefore condition assessment of structures over a period of time is mandatory with routine monitoring.
The majority of water supply systems have some form of water storage tanks, most often constructed from reinforced concrete. These tanks are an integral part of the potable water distribution network but are often taken for granted from a maintenance and condition assessment point of view. To ensure the durability and sustainability they should be carefully monitor and maintained, a condition assessment system must be used.
The objective of this study was to propose a system to perform a condition assessment of existing reinforced concrete water retaining structures. To achieve the objective visual inspection and Non-destructive tests were conducted for water retaining structures identified at southern province of Sri Lanka. Analytical Hierarchy Process was mainly used to evaluate the collected data to determine the condition state of the water retaining structures.

Keywords: Aggressive environments; Chloride induced corrosion; Condition assessment; Non-destructive test; Visual inspections; Analytical hierarchy process

1. Introduction

The quality control measures during construction generally consist of workability tests on fresh concrete and cube compressive strength of concrete samples after some specified days of curing. But the results of the above tests do not reflect the true quality of the concrete prevailing in the structure because the quality of concrete in the structure depends on many factors such as the method of mixing, transporting, placing, compacting, and curing. While concrete members with a certain amount of imperfections can satisfy the requirements relating to strength and serviceability, such concrete may not satisfy durability requirements.

In addition to that, the reinforced concrete structures can be deteriorated due to some other factors such as aging, exposure to aggressive environments, and excessive loads.

Corrosion-induced damages, such as concrete cracking, spalling, delamination, and cross-sectional reduction of the reinforcement, may dramatically affect the long-term performance of reinforced concrete structures; decrease the load-bearing capacity of a structure, and in the worst-case lead to fatal structural consequences, such as failure.

National Water Supply & Drainage Board in Sri Lanka has many water retaining structures close to the coastal belt. Some of them have more than 30 year service period. Generally, these structures are continuously operating without adequate maintenance or any restoration. During the investigation, it is clearly recognized that these water tanks are seriously subjected to vegetation on the concrete elements, spalling, cracks, and water leakages apart from serious chloride induced corrosion damages. Hence, they may not be achieved the design service life of the structure. However, the National Water Supply & Drainage Board still does not have a proper condition assessment system to monitor such reinforced concrete structures.

The rate of deterioration of reinforced concrete water tanks can be reduced by using possible restoration methods with continuous monitoring of the structures using a suitable condition assessment system based on a visual inspection and non-destructive tests.

Further, to ensure safe durable service and to select the most appropriate repair strategy for reinforced concrete water retaining structures, the follow up of a suitable condition assessment system may provide more successful results. The objective of the study is to introduce a mechanism to evaluate the current structural condition of reinforced concrete water retaining structures based on a condition assessment system with visual inspection and non-destructive testing.

This paper discusses the condition assessment of three reinforced concrete water tanks that have been used for the service for more than 30 years and a recently build tank as a case study.

2. Methodology

The condition assessment of reinforced concrete water retaining structures is mainly based on the data collected from visual inspection and non-destructive testing.

2.1. Data collection from visual inspection

The reinforced concrete structures should be carefully scrutinized element by element to identify visual defects and failures. Generally, the information about cracks, vegetation cover, spalling, reinforcement exposure, water leakages, honeycombs, and distance from the sea is collected as visual inspection data. In addition to that, extra important information about the structure such as age, dimension, capacity, maintenance records, and utilization is collected.

The information collected by visual inspection of the structure provides first guidance to plan subsequent testing program with non-destructive tests.

2.2 Analysis of visual inspection data

An appropriate analytical method should be select to analyze visual inspection data to build up a smooth decision-making system. The analytical procedure introduced by Rashidi and Gibson in 2011 for the condition assessment of reinforced concrete bridges is referred for the study. Accordingly, Visual Inspection Factor (VIF), Crack Details factor (CDF), Casual Factors (CF) are calculated with following Analytical Hierarchy Process (AHP), which was developed by Saaty (1980). [3], [4] and [5]. The Element Significant Factor (ESF) and Element Construction Type Factor (ECTF) are determined based on the literature review.

2.3 Data collected from Non – Destructive tests

Rebound hammer test, cover meter survey, corrosion resistivity test, and crack gauge were used to investigate the structural condition of the reinforced concrete tanks as non-destructive tests. The rebound hammer is a surface hardness test that indicates the quality and soundness of the concrete surface. The cover meter is used to investigate the precise concrete cover depth and to pinpoint the exact location of the rebars in the reinforced concrete **elements**. The resistivity meter is used to assess the rate of corrosion in embedded reinforcing **steel. Based** on the importance of corrosion rate, rebound number, and concrete cover, the priority weights were determined. By using the priority weights, the Non-destructive Test Factor (NDF) was calculated. [1]

2.4 Structural safety condition assessment

Condition Index (CI) was calculated by using equation 1 for each and every element. Each calculated CI value is round off to nearest whole number ($CI \in 1,2,3,4$). [1]

$$CI = (0.5 \, x \, VIF) + (0.3 \, x \, CDF) + (0.2 \, x \, NDF) --------- (1)$$

Areas with equal CI valves are separately accumulated and element condition is calculated using equation 2 as Element Condition Index (ECI).

$$ECI = \frac{\sum(q_i \, x \, CI)}{\sum q_i} ------------------------ (2)$$

q_i is the area of an element reported in condition index (CI)
CI is the Condition Index of selected area (CI $\in 1,2,3,4$)
Overall condition of a water tank is calculated using equation 3 as Overall Tank Condition Index (OTCI). A higher OTCI value reflects the worst case of a reinforced concrete tank.

$$OTCI = \frac{CF \sum(ESF_i \, x \, ECTF_i \, x \, ECI_i)}{n} --------------- (3)$$

ESF_i is the Element Significant Factor of the i^{th} element
CF is the Casual Factor
$ECTF_i$ is the Element Construction Type Factor of the i^{th} element
ECI_i is the Element Condition Index of the i^{th} element
n is the number of elements
Tank Soundness Score (TSS) is calculated as a percentage (equation 4)
Lower TSS value reflects the worst case of a tank.

$$TSS = \frac{(HOTCI - OTCI)}{HOTCI} \, x \, 100 ----------------- (4)$$

HOTCI is the highest OTCI valve (i.e. worst case) of any tank which can be calculated by using equation 5.

$$HOTCI = \frac{16 \sum(ESF_i \, x \, ECTF_i)}{n} ----------------- (5)$$

Table 1 shows the TSS ranges and status relevant to physical description of tank proposed based on the values used to analyse the Bridge Soundness Score by Rashidi and Gibson (2011). [2]

Table 1: Tank Soundness Score (TSS) ranges and their physical description

TSS (%) range	Tank condition description	safety condition of RC tank
$75 < TSS \leq 100$	The tank shows no deterioration. There may be discoloration, efflorescence and/or superficial cracking but without effect on strength and/or serviceability.	Good condition
$50 < TSS \leq 75$	Minor cracks, spalls, bleeding marks and algae may be present with moderate to low level of corrosion of steel reinforcement and no deterioration of the system.	Satisfactory/ fair condition
$25 < TSS \leq 50$	Some delamination and/or spalls may be present. Corrosion of steel reinforcement may be present with loss of bar sections and the strength may be loss and need repairing and retrofitting of element or tank.	Poor condition
$0 \leq TSS \leq 25$	Delamination, spalls, herbs and algae and corrosion of steel reinforcement are prevalent. Element displacements and movements are present. Need to replacement of either element or the tank.	Serious/ failure condition

Figure 1 illustrates a flow diagram of a methodology for the proposed condition assessment of the reinforced concrete water retaining structures.

3. Case study

Reinforced concrete water tanks listed in Table 2 were selected for the case study.

Analytical Hierarchy Process was used to find the priority vector of the visual inspection data. [5]

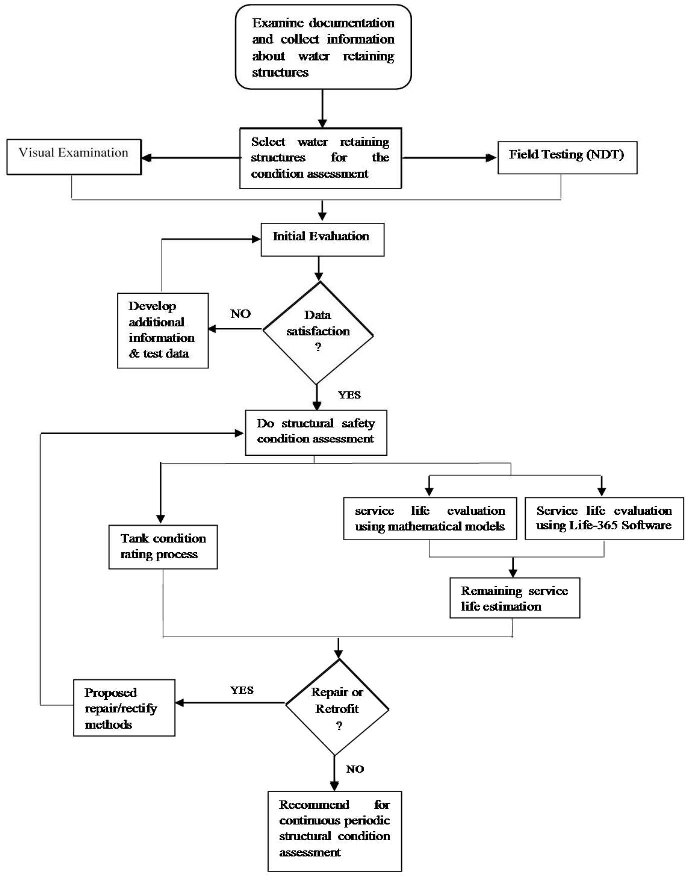

Figure 1: Flow Diagram for the condition assessment

Table 2: Details of selected reinforced concrete water tanks

Structure	District	Type of tank	Distance from sea (m)	Tank build year (No. of service year)
A	Matara	Ground Reservoir	420	1985 (35)
B	Matara	Ground Reservoir	420	1963 (57)
C	Hambantota	Elevated Tank	7460	2007 (13)
D	Hambantota	Elevated Tank	160	1982 (38)

The visual Inspection data are tabulated in the Table 3.

Table 3: Visual Inspection Data

Structure	Visual Observations	Photographs
A	An old structure. Cracks more than 2mm width, plant vegetation inside the cracks, spalling and water leakage can also be identified. The quality maintenance is very poor state.	
B	The structure is very old (more than 58 yrs.). Spoiling, vegetation can be seen on the structure. More than 80% of the tank walls were covered by soil. The quality of maintenance cannot be satisfied.	
C	Structure was a recently build. There are can't be seen any structural failures, minor cracks, vegetation cover or any other visual defects. Well maintained.	
D	It is an old structure and located very close to the sea. Spoiling was occurred on bottom surface of the dome, conical part of the base slab and on the shaft in addition to some crack on the concrete surface. Delamination also visualized at the roof top. Maintenance is in poor level. Spot water leakages can be seen.	 

The result from non-destructive tests are given in the Table 4

Table 4: Non-destructive test results

Structure	Rebound hammer test			Corrosion Resistivity (kΩcm)		Cover (mm)
	Rebound number	Strength (MPa)	Condition Rating	Value	Possible corrosion rate	
A	30	29	Acceptable	6.7	High	42
B	38	39	Very Good	7.3	High	45
C	38	37	Very Good	48	Insignificant	40
D	38	47	Excellent	17.4	Moderate to low	38

4. Results and Discussion

The final output of the study based on the proposed condition assessment procedure is illustrated in the Table 5.

Table 5: The output of the condition assessment of the RC water tanks

Structure	Distance to sea (m)	TSS (%)	Overall state of the tank
A	420	41	Poor condition
B	420	46	Poor condition
C	7468	81	Good condition
D	163	47	Poor condition

According to the proposed condition assessment procedure, structure A indicates the minimum TSS (41%) value and the overall state of the tank as in '**poor condition'**. The tank is located very closed to the coastal belt (nearly 420 m). Further, the quality of construction seems to be very poor, and the tank is exposed to direct wind with high salt concentration blowing from the sea. The prevailing physical condition of this structure is worst compared to other structures used for the study.

Both structures A and B are located in the same place. However, structure B indicates a higher TSS (46%) value than the TSS of structure A even though B is older than A. The reason for that is more than 80% of structure

B has been covered by a soil layer, and it protects the concrete surface of the structure from aggressive environmental conditions such as the air with high chloride ion concentration, that blowing from the sea. Therefore, deterioration of the reinforced concrete structure due to chloride ingress has being minimized. However, its overall condition of the tank indicates '**poor condition'** since the tank is very old and built-in more than 58 years ago.

Structure C indicates the maximum TSS (81%) value. It is located considerably far away from the sea (nearly 7468 m). According to the visual inspection, any structural failures, minor cracks, vegetation cover, or any other visual defects couldn't be seen. Hence it is clear that the prevailing physical state of the structure is in good condition.

The structure D is located very close to the sea and exposed to the air with high chloride ion concentration blowing from the sea. It has been used for service for more than 38 years. Further, serious delaminating and spalling zones at the conical part of the tank could be seen.

Therefore, the '**poor condition'** with a relatively low TSS value (47%) can be expected for such a structure.

5. Conclusion

According to the result and discussion, it can be identified that the deviation of the actual and assessed condition of the structures has not much difference. Hence, the proposed condition assessment procedure is suitable to assess the existing reinforced concrete water tanks and that can be used as a predicting tool for the decision-making process during the planning and management activities to ensure safe and durable service from the structures.

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