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Evaluating Residual Strength of RCC Tanks Affected by ASR Using NDT Methods

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Abstract
This case study focuses on the groundwater level tanks (GLR) located in Netra Village, 35 km from Jodhpur, on Nagour Road. The investigation revealed that people and livestock in the area were grappling with water scarcity issues. Non-Destructive Testing (NDT) methods were employed to assess the residual strength of three tanks in the region. The results showed that Tank-1 had a residual strength of 35.41%, Tank-2 had 63.08%, and Tank-3 had 53.8%. Alkali-silica reaction (ASR) poses a significant threat to the structural integrity of concrete tanks, necessitating accurate and non-destructive methods for residual strength assessment. This research paper delves into the effectiveness of NDT methods, specifically rebound hammer and Ultrasonic Pulse Velocity (UPV), in evaluating the residual strength of ASR-affected tanks. Through an extensive review of literature, case studies, and experimental data, this study aims to shed light on the practical application of rebound hammer and UPV for ASR assessment in tank structures. The paper discusses the principles, advantages, and limitations of each NDT method, emphasizing their ability to detect ASR-induced damage and predict the remaining structural capacity of tanks. Moreover, the research addresses the challenges associated with implementing rebound hammer and UPV techniques in ASR-affected environments, offering recommendations for enhancing their reliability and accuracy. By harnessing the combined capabilities of rebound hammer and UPV, engineers and asset managers can make well-informed decisions regarding the maintenance, repair, and retrofitting of ASR-affected tanks, ensuring their long-term safety and functionality in critical infrastructure applications.
Keywords: *Alkali-silica reaction (ASR), Non-Destructive Testing (NDT), residual strength assessment, tanks, rebound hammer, Ultrasonic Pulse Velocity (UPV), structural health monitoring.*

1. Introduction

Alkali-silica reaction (ASR) poses a significant threat to the structural integrity of concrete tanks, potentially resulting in safety hazards and environmental risks [1]. Evaluating the residual strength of tanks affected by ASR is vital to ensure their continued functionality and longevity [2]. Non-Destructive Testing (NDT) methods serve as valuable tools for assessing ASR-induced damage without causing further harm to the structure. Among these methods, rebound hammer and Ultrasonic Pulse Velocity (UPV) have emerged as popular choices for evaluating the mechanical properties of concrete and predicting its residual strength [3]. The present study focuses on the RCC Ground Lever Reservoirs (GLR) managed by the Public Health Engineering Department (PHED), Government of Rajasthan. These reservoirs, situated in Netra village approximately 35 km from Jodhpur on the Nagour Road, play a crucial role in supplying water to a population of around 3000-4000 people and a cattle population of 1500-2000. Comprising three tanks, the GLRs are regularly filled by the PHED department to ensure a continuous water supply. However, challenges have arisen due to the

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alternating filling schedule and the quality of the water supplied, affecting water availability and storage [4]. The water supplied to the tanks is a mixture of saline and sweet water, posing challenges for both human consumption and livestock watering. The high salt content in the water has resulted in issues such as salinity attack and reduced storage retention periods due to ASR-induced damage. Villagers and their livestock face difficulties accessing proper water supply and adequate water storage due to the limited retention period of water in the tanks. Additionally, leakage from damaged tanks exacerbates the situation, with a significant amount of water seeping out within 2-3 days if not utilized promptly. To address the water scarcity issue, villagers' resort to alternative means such as hiring tankers from nearby villages at a cost of Rs. 500 per tanker. Moreover, local materials such as sand sourced from the Jojri river pits and aggregates from the Savaki village crusher are utilized for tank maintenance and repair [5]. This study aims to assess the extent of ASR-induced damage in the GLR tanks and propose suitable remedial measures to enhance water storage and availability for the community and livestock.

2. Methodology

In this paper, two main approaches are employed to identify Alkali-Silica Reaction (ASR) in concrete tanks: field methods and Non-Destructive Testing (NDT) methods [6].

2.1. Field Methods

Visual identification is adopted as the field method for ASR identification. The following visual symptoms are utilized in the field study:

After inspecting the tank's surface, the following pattern was identified on the structure, revealing numerous issues that could be observed through visual inspection.

(a) Crack Pattern

The pattern of cracking is influenced by various factors such as the shape and geometry of the structure, environmental conditions at the site, presence and arrangement of reinforcement, load and stress fields, drying-shrinkage effects, freezing-thawing cycles, and sulfate attacks. The cracks observed on the surface of the GLR (Ground Lever Reservoir) exhibit a map-type pattern. The environmental conditions in Jodhpur, Rajasthan, are characterized by hot and dry weather, with temperatures often exceeding 55 degrees Celsius during the summer months. In contrast, winters experience significant temperature drops. These extreme temperature fluctuations contribute to high levels of drying, shrinkage, freezing, and thawing cycles. Consequently, these environmental factors lead to the development of temperature-induced stresses on structures in the region [7].

(b) Surface Discoloration

Surface discoloration refers to changes in the color or appearance of the concrete surface. This can be caused by various factors such as exposure to environmental elements, chemical reactions, or the presence of contaminants. In the context of ASR, surface discoloration may indicate the presence of alkali-silica gel formation, which can manifest as whitish or yellowish patches on the concrete surface [8].

(c) Gel Exudation

Gel exudation occurs when alkali-silica gel, formed as a result of ASR, is pushed out from within the concrete matrix and appears on the surface. This gel may have a gelatinous or crystalline appearance and is typically observed in cracks or fissures. Gel exudation is a visible indicator of ASR-induced damage and can contribute to the deterioration of concrete structures over time [9].

(d) Surface Pop-Out

Surface pop-out refers to the localized detachment or spalling of concrete from the surface. This phenomenon can occur due to the expansion of aggregates affected by ASR, leading to the formation of internal pressure within the concrete matrix. Surface pop-outs often result in irregular depressions or holes on the concrete surface and can compromise the structural integrity of the affected area [10].

(e) Localized Crushing of Concrete

Localized crushing of concrete occurs when certain areas of the concrete structure experience excessive compressive forces, leading to the collapse or failure of the material. In ASR-affected concrete, localized crushing may occur due to the expansion of alkali-

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silica gel, which exerts pressure on the surrounding concrete matrix. This can result in the formation of cracks or deformations in the affected area [11].

(f) Extrusion of Joint (Sealant) Materials

Extrusion of joint or sealant materials refers to the displacement or expulsion of sealing compounds or joint fillers from their intended position. ASR-induced expansion can exert pressure on joints and sealants, causing them to deform or displace over time. Extrusion of joint materials can compromise the effectiveness of waterproofing and structural sealing systems, leading to moisture infiltration and further deterioration of the concrete structure [12].

(g) Expansion Causing Deformation, Relative Movement, and Displacement

Expansion resulting from ASR can cause deformation, relative movement, and displacement within the concrete structure. This expansion occurs as alkali-silica gel forms and absorbs moisture, leading to an increase in volume and internal pressure. Deformation may manifest as bulging or distortion of concrete elements, while relative movement refers to shifts or separations between adjoining components. Displacement can occur when ASR-induced expansion forces exceed the tensile strength of the concrete, leading to cracking or separation of structural elements. These forms of deformation and displacement are characteristic symptoms of ASR-induced damage and can significantly impact the structural integrity of concrete tanks in Figure 1.

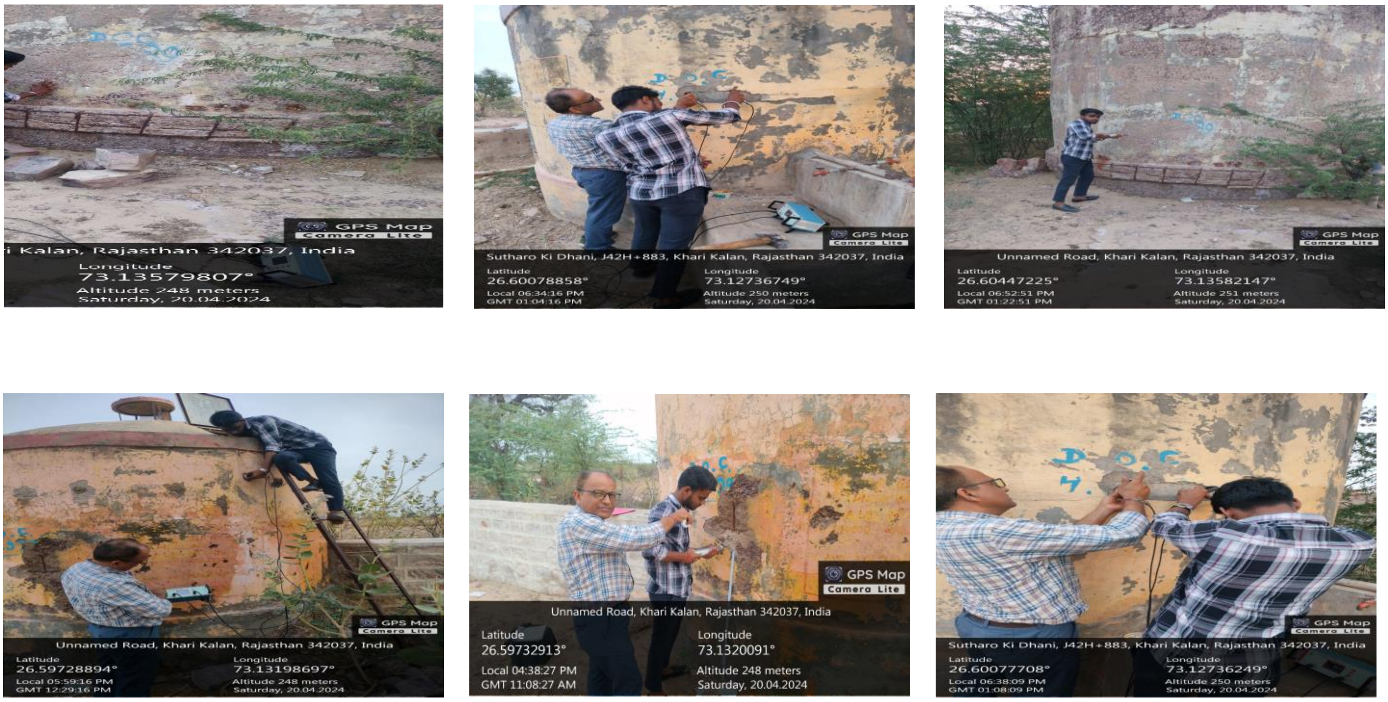

Figure 1 Depicts Conditions Such as Cracks, Surface Discoloration, Gel Exudation, Tank Crushing, Visible Reinforcement, and Material Extortion Observed During the Investigation

(h) Reinforcement Condition in RCC Tank:

The visible reinforcement within the RCC tank exhibits corrosion indications, likely triggered by ASR-affected concrete [14]. Moreover, water seepage from the tank underscores the adverse impact of ASR on the concrete structure [13].

- **Description of concrete:**

When examining older structures, one may notice the presence of map cracking on the surface of the concrete. This could potentially indicate the presence of expansive aggregate (ASR), which causes an increase in the volume of concrete beyond

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the capacity of the cement paste binder and aggregate tension. This phenomenon is sometimes colloquially referred to as a 'varicose vein' surface.

3. NDT Methods

Rebound Hammer Technique

The rebound hammer technique, also known as the Schmidt hammer test, is employed to measure the surface hardness of concrete. This method involves rebounding a mass-loaded plunger against the material, with the rebound distance correlating with the concrete's compressive strength. In ASR-affected tanks, the rebound hammer detects variations in concrete hardness due to expansive gel formation and micro cracking. This provides insights into the extent of damage and aids in predicting the remaining structural capacity of the tanks. The rebound number was documented during the investigation of tanks Tank1, Tank2, and Tank3, each recorded at varying heights in Table 1.

Table 1 Displays the Rebound Numbers for Tank 1, Tank 2, And Tank 3

S. No	Structure	1	2	3	4	5	6	Average	Residual Strength (35Mpa)
1	Tank-1 (1.6m)	12	13	11	10	10	11	11.16	11.16
2	Tank-1 (1m)	14	18	12	12	12	14	13.66	13.66
3	Tank-2 (1.6m)	28	22	20	25	22	20	22.83	22.83
4	Tank-2 (1m)	16	20	20	28	26	18	21.33	21.33
5	Tank-3 (1.6m)	14	20	22	24	28	22	21.66	21.66
6	Tank-3 (1m)	16	18	16	14	16	16	16	16

Ultrasonic Pulse Velocity (UPV) Method

The Ultrasonic Pulse Velocity (UPV) method assesses the uniformity, density, and integrity of concrete by measuring the travel time of ultrasonic pulses through the material. In ASR-affected tanks, UPV detects changes in material properties resulting from aggregate expansions and micro cracking. By analyzing the velocity of ultrasonic waves, engineers can estimate the extent of ASR-induced damage and predict the residual strength of the tank structure. The UPV test was reconfigured following an investigation, revealing the direct and indirect effects of ASR on tanks 1, 2, and 3 upon visual inspection show in Table 2.

Table 2 Displays the UPV for Tank 1, Tank 2, and Tank 3

S No.	Tank1 (1.6m)	Distance between probes	UPV Reading (m/s)	Average
1	Tank1 (1m)	510mm (indirect)	568	532.5
2	Tank1 (1.6m)	200mm (direct)	567.5	
3	tank 2 (1m)	510mm (indirect)	565	532.5
4	Tank2 (1.6m)	200mm (direct)	500	
5	Tank3 (1m)	510mm (indirect)	565	562.5
6	Tank3 (1.6m)	200mm (direct)	560	

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4. Experimental Studies and Result Discussion

This section presents experimental studies and case examples illustrating the application of rebound hammer and UPV techniques in ASR assessment for tank structures. Through comparative analysis and statistical validation, the effectiveness and reliability of these NDT methods are evaluated, providing practical insights for engineers and asset managers in Figure 2.

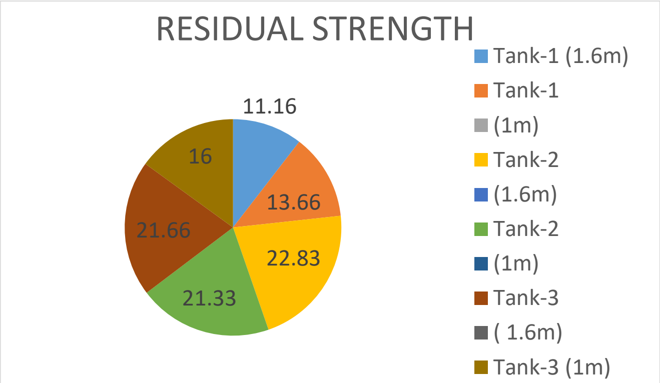

Figure 2 Illustrates the Residual Strength of Concrete Following the Impact of Alkali Silica reaction

The results were determined following an assessment of the tank's condition. The accompanying graph depicts the actual condition of the tank, assessed via rapid visual screening and non-destructive testing methods in Figure 3.

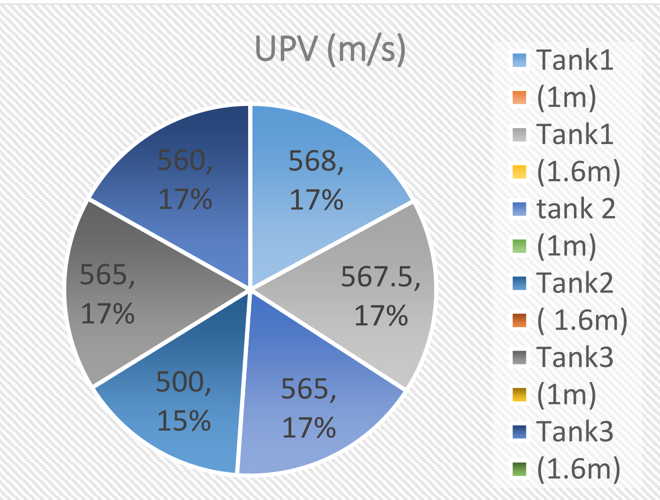

Figure 3 Depicts UPV Readings in Meters Per Second (M/S) For Tank 1, Tank 2, And Tank 3

Conclusions

The combined utilization of rebound hammer and Ultrasonic Pulse Velocity (UPV) techniques presents a dependable and non-destructive methodology for assessing the residual strength of tanks influenced by Alkali-Silica Reaction (ASR). By harnessing the capabilities of these Non-Destructive Testing (NDT) methods, engineers and asset managers can gauge the extent of ASR-induced damage, forecast the remaining structural capacity, and make well-informed decisions concerning maintenance, repair, and retrofitting strategies for ASR-affected tanks. Upon investigation, it was determined that the residual strength of Tank-1 remains at approximately 35.41%, influenced by numerous factors affecting the tank materials. Tank-2 exhibits a remaining strength of approximately 63.08%, while Tank-3, an extreme ASR case, constructed approximately 15 years ago, only retains a residual strength of 53.8%. Consequently, these tanks require repairs and retrofitting efforts to address the deteriorating conditions and ensure long-term structural integrity.

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