A Review on Seismic Performance of Existing Water Tank after Condition Position Using Non-Destructive Testing

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Abstract

There has been a combined attempt to address the seismic performance of existing structures in India after an earthquake in Bhuj, Gujarat, in 2001. Seismic analysis and seismic retrofit for the existing tanks have become a remarkable problem to be worked since corrosion is a cosmopolitan and natural phenomenon. It is important to know the exact reason for suffering and type of distress. To succeed such problems, a proper technique of restoration and recovery with detailed plans and methodology is required. This research is targeted at evolving systematic investigation metrology for condition position method based on the analytical hierarchy process (AHP) and strengthening by various retrofitting strategies. For that case study, an existing raised water tank is considered, which was designed according to state of the art over 40 years ago as per old Indian Standard (IS) code. The position assessment of the raised service tank was carried out using different non-destructive tests (NDTs). DER, i.e., degree (D), extent (E) and relevancy (R) rating technique was employed to find out the condition index of the elevated service tank (ESR). After finding the condition ranking of the existing structure, an analysis was carried out using SAP 2000 to find the present-day seismic requirements using IS codes. After knowing the seismic demand of the water tank, various retrofitting methods were adopted for improving the drift capacity and flexural capacity of the structure. The results were finally used to discourse some of the critical problems of the seismic response of the retrofitted structure in terms of a time period, mode shapes, base shear, displacement, acceleration, and velocity. From the case study result of seismic retrofit for the existing raised water tank, it is confirmed that a relatively simple seismic retrofit method is effective to keep the tank functional after an earthquake.

Keywords-*Condition positioning, Strengthening, Retrofitting, Non-dangerous, Seismic reaction, Water tank.*

INTRODUCTION

Water tanks particularly water tanks are structures of high significance which are considered as the fundamental lifesaver components that ought to be equipped for keeping the normal execution that is an activity during and after earthquake. Numerous specialists have been done on the conduct, investigation, and structure of ground tanks. The Indian subcontinent is profoundly defenceless against cataclysmic events like earthquake, dry seasons, floods, violent winds, and so forth. Most of states or association regions are inclined to one or various catastrophes. These normal disasters are causing numerous setbacks and endless property misfortune consistently, According to seismic code IS 1893 (Part 1): 2000, over 60% of India is inclined to earthquake. The principle explanation behind life misfortune is the breakdown of the structure. It is said that the seismic tremor itself never executes individuals; it is seriously built structures that slaughter. Subsequently, it is critical to investigate the structure appropriately for quake impacts. Sloshing waves have been concentrated numerically, hypothetically, and tentatively in the previous, a very long while, and numerous critical marvels have been considered in those contemplated, particularly the direct and nonlinear impacts of sloshing for both thick and gooey water.

Elevated water tanks are important structures in water supply networks. Liquid storage tank are used extensively by municipalities and industries for storing water, inflammable liquids and other chemicals. Thus these type of structures are very important for public utility and for industrial purpose to secure necessary water supply. Reinforced concrete circular shafts type support (staging) is widely used for elevated tank of low to very high capacity. It is extremely essential for these systems to remain operational after earthquakes for post-earthquake damage mitigation. The poor seismic performance of these inverted pendulum-type constructions has been reported frequently during major earthquakes. Inadequate performance of these tank also prevented fire-fighting and other emergency activities in the past

Figure. 1 Concrete water tank.

Figure. 2 Reinforcement corrosion on water tank

1.1 Reinforcement corrosion

Collapse does not necessarily signify structural collapse only. Corrosion in concrete reinforcement is also a major contributory factor for early deterioration, leading to structural collapse. Corrosion of reinforcing steel in concrete is a serious problem from the point of persuasion of both safety and economy. There is a clear-cut need, from both the field of research in reinforcement corrosion in concrete construction and industrial requirement. Precise calculation of structural damage can assist civil engineers in achieving a structural safety and cost-effective approach to corrosion-affected concrete structures. Concrete provides corrosion resistance to the steel chemically due to its high pH and physically working as a barrier. However, reinforcing steel does corrode. The two main usual causes are a general breakdown of passivity due to the neutralization of the concrete by a reaction with atmospheric carbon dioxide and localized breakdown of the passive film on the steel by chloride ions. Therefore, it is indispensable to have authentic measurement techniques to assess the corrosion condition of the steel bars in the reinforcing concrete. Corrosion represents the full extent of the damage, or they may point to problems of more significant magnitude. The corrosion mechanism is complex, involving chemical, electrochemical, and physical operations. The parameters that impact corrosion progression is concrete cover thickness, quality of concrete, environmental conditions.

1.2 Retrofitting and repairs

When the structures get old and not constructed properly considering proper loads, they start showing the need for strengthening and retrofitting to enhance their strength and life. Among all the natural disasters, earthquakes, being the most destructive and affecting structures, have also created a need to raise the current safety levels in structures. As per the recommendations of the prevalent codes, several existing structures were analysed, designed and detailed. Such structures regularly may not meet the present seismic requirements and, consequently, strengthening and retrofitting of these structures are essential. To make existing weak structures safe against future natural forces and possible earthquakes, retrofitting is one of the best options. For retrofitting strategy, many other factors are considered for decision-making and few have been listed below. When the structures are analyzed and designed for gravity loads only.

⇒ When codes of practice, standards, and seismic zone map are not revised timely.

⇒ When structure does not fulfil current design requirement as per seismic code due to the change in loading.

⇒ When in the case of structure and material deterioration, the resistance level of the structure decreases and it will not be able to carry the present-day load requirements.

⇒ When constructed with a lack of understanding by the engineer, inappropriate planning and lousy quality of construction.

1.3 SAP2000 Software

SAP 2000 is 3D object based graphical modeling environment to the wide variety of analysis and design options completely integrated across one powerful user interface, SAP2000 has proven to be the most integrated, productive and practical general purpose structural program on the market today.

SAP2000 is general-purpose civil-engineering software ideal for the analysis and design of any type of structural system. Basic and advanced systems, ranging from 2D to 3D, of simple geometry to complex, may be modeled, analyzed, designed, and optimized using a practical and intuitive object-based modeling environment that simplifies and streamlines the engineering process. The SAP Fire Analysis Engine integral to SAP2000 drives a sophisticated finite-element analysis procedure. An additional suite of advanced analysis features are available to users engaging state-of-the-art practice with nonlinear and dynamic consideration. Created by engineers for effective engineering, SAP2000 is the ideal software tool for users of any experience level, designing any structural system.

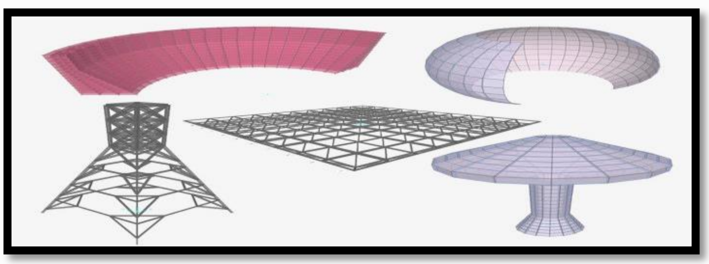


Figure. 3 Model Views

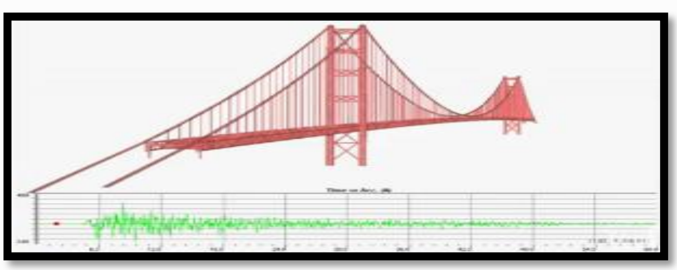


Figure. 4 Modeling

1. **Modeling**
2. **Loading**
3. **Analysis**

1.4 Objective

This research is targeted at evolving systematic investigation metrology for condition position method based on the analytical hierarchy process (AHP) and strengthening by various retrofitting strategies. For that case study, an existing raised water tank is considered, which was designed according to state of the art over 40 years ago as per old Indian Standard (IS) code. The position assessment of the raised service tank was carried out using different non-destructive tests (NDTs). DER, i.e., degree (D), extent (E) and relevancy (R) rating technique was employed to find out the condition index of the elevated service tank (ESR). After finding the condition ranking of the existing structure, an analysis was carried out using SAP 2000 to find the present-day seismic requirements using IS codes. After knowing the seismic demand of the water tank, various retrofitting methods were adopted for improving the drift capacity and flexural capacity of the structure. The results were finally used to address some of the critical issues of the seismic response of the retrofitted structure in terms of a time period, mode shapes, base shear, displacement, acceleration, and velocity.

LITRATURE REVIEW

[1]. Nateghi-A Fariborz et. al. The paper deals with the seismic retrofit of a multiple building structure belonging to the Hospital Centre of Avellino (Italy). At first, the paper presents the preliminary investigations, the in-situ measurements and laboratory tests, and the seismic assessment of the existing fixed-base structures. Having studied different strategies, base isolation proved to be the more appropriate, also for the possibility offered by the geometry of the building to easily create an isolation interface at the ground level. The paper presents the design project, the construction process, and the details of the isolation intervention. Some specific issues of base isolation for seismic retrofitting of multiple building structures were lightened. Finally, the seismic assessment of the base-isolated building was carried out. The seismic response was evaluated through nonlinear time-history analysis, using the well-known Bouc-Wen model as the constitutive law of the isolation bearings. For reliable dynamic analyses, a suite of natural accelerograms compatible with acceleration spectra of Italian Code was first selected and then applied along both horizontal directions. The results were finally used to address some of the critical issues of the seismic response of the base-isolated multiple building structure: accidental torsional effects and potential poundings during strong earthquakes.

[2]. Kodag PB et. al. Elevated tanks are very important structures and consist of various types. Water supply is vital to control fires during earthquakes. Also they are utilized to store different products, like petroleum supplies in cities and industrial zones. Damage to these structures during strong ground motions may lead to fire or other hazardous events. Elevated tanks should stay functional after and before earthquakes. However their dynamic behavior differs greatly in comparison with other structures. In this research, a sample of reinforced concrete elevated water tank, with 900 cubic meters capacity, exposed to three pair of earthquake records have been studied and analyzed in time history using mechanical and finite-element modeling technique. The liquid mass of tank is modeled as lumped masses known as sloshing mass, or impulsive mass. The corresponding stiffness constants associated with these lumped masses have been worked out depending upon the properties of the tank wall and liquid mass. Tank responses including base shear, overturning moment, tank displacement, and sloshing displacement have been calculated. Results reveal that the system responses are highly influenced by the structural parameters and the earthquake characteristics such as frequency content.

[3]. Alberto M et. al. Tension tests were carried out to investigate the effect of the corrosion pattern on the ductility of tension bars extracted from a 26-year-old corroded reinforced concrete beam. The tensile behavior of corroded bars with different corrosion patterns was examined carefully, as were two non-corroded bars extracted from a 26-year-old control beam. The results show that corrosion leads to an increase in the ratio of the ultimate strength over the yield strength, but reduces the ultimate strain at maximum force of the reinforcement. Both the corrosion pattern and the corrosion intensity play an important role in the ductile properties. The asymmetrical distribution of the corrosion around the surface is a decisive factor, which can influence the ultimate strain at maximum force more seriously.

[4]. P. Hénocq et. al. An experimental analysis of reinforced-concrete columns was conducted in the paper to evaluate the effectiveness of circular, rectangular and square cross sections strengthened with the glass fiber reinforced polymer (GFRP) when subjected to eccentric loading. Parameters analyzed in the paper are the type of cross section and eccentricity values. It was established that, due to uniform loading, the strength increase of circular sections is greater compared to square and rectangular sections. In addition, the strength and ductility of columns increase with the fiber reinforced polymer wrapping.

[5]. Robles SI et. al. Aramid Fiber Reinforced Polymer (AFRP) composites provide a companionable and beneficial technique to strengthen structures and noticeable advantages in terms of fire and heat resistance and vapor permeability. AFRP also improves the corrosion resistivity of the structural members, and it delays the buckling. These characteristics of AFRP materials have been catching attention of the technical community to study the mechanical behavior to define comprehensive strengthening design guidelines. This research work studied the effect of AFRP on a steel beam with five types of strengthening and without strengthening pattern. Several tests were carried out to find the compressive and flexural behavior of structure considering with strengthening and without strengthening. From the experimental result, it can be concluded that the load carrying capacity and stiffness of structure considerably enhanced due to external bonding of normal modulus AFRP. The wrapping of AFRP effectively delayed the local buckling and punching for the compressive and flexural loading, respectively. Then, the beam was modeled by using ANSYS 16.0 to authenticate the experimental results and the numerical results such as deflection and maximum load carrying capacity for the different patterns of strengthening quite agreed with the experimental results. Finally, this study concluded with showing different experimental failure modes and comparison made with the numerical results. It is expected that the outcome of this research will be of significant help for the strengthening of the structure.

METHODOLOGY

The methodology of this investigation work is divided into two subparts, i.e., condition ranking using DER rating after various corrosion investigations and seismic analysis method for analysis of the water tank after and before retrofitting.

3.1 Corrosion investigation methods

To evaluate the condition index of the structure, corrosion assessment of the water tank is carried out. For corrosion investigation, different NDT methods are used such as a half-cell potential, cover depth measure, and surface hardness. The details of these methods are discussed below.

3.2 Half-cell potentiometer test

Reinforcement corrosion is an electrochemical process. Half-cell potential is used to calculate the presence of corrosion and potential vulnerability of element surface area to corrosion. The corrosion activity was found out due to the process of oxidation using the potential developed at the electrode of a half-cell. In an electrochemical cell, the overall potential is the total potential calculated from the potentials of two half cells. The higher the potential, the greater is the risk of corrosion rate. Interpretation of test results as per ASTM C876 has outlined the following probability levels for steel corrosion against measures of copper/copper sulphate half-cell potentials, as shown in Table 1 (ASTM C876-91 1999).

Table. 1 Interpretation of results

Seismic performance of existing water tank after condition ranking using non-destructive testing

Percentage chance of corrosion activity	Potential level
10%	Less than − 200
Uncertain	− 200 to − 350
90%	− 350 to − 500
95%	Above − 500

3.3 Profometer

To improve the toughness of the concrete structure and to forestall corrosion, the base spread to support is fundamental. To figure the genuine quality of concrete structures, spread to fortification, the evaluation of concrete and number of fortifying bars are required. It is getting testing in old structures whenever definite drawings are not accessible. The translation of the outcome acquired from the rebar locator is given in Table 2.

Table. 2 Interpretation of profometer readings

Interpretation	Test result
Relatively not	**Good quality concrete and required cover thickness**
Corrosion prone	**Bad quality concrete and required cover thickness**
Corrosion prone	**Good quality concrete and very less cover thickness**

3.4 Surface hardness

The test is led to evaluate the state of spread cement and to distinguish any delamination. Areas having extremely low bounce back numbers will be recognized as consumption inclined areas. The introduction of the outcome is given in Table 3 (IS 13311 1992).

Table. 3 Comparative hardness of the cover zone

Concrete quality	Avg. rebound number
Poor	**< 20**
Fair	**20–30**
Good	**30–40**

Very hard, very good	**> 40**

3.5 Non- destructive evaluation by DER rating

Based on the result obtained from the NDT testing, the structural adequateness is computed using the CI. The formula for CI is grounded in a point deduction system and weight average method. The CI of each inspection component can be found out first. Then the CI of each item is deducted from a perfect score of 100 to find out the overall deficiencies score point of the water tank. In the current approach, an evaluation method can be evolved by separating water tank deterioration into D (degree of the defect), E (extent of the defect), and R (relevance of defect). The DER rating is based on a point system from 0 (no defect) to 4 (most severe). A combination field and visual inspection are employed for calculating the 'D', 'E', and 'R' values. The values of E and R are calculated from visual inspection as per Table 5. The value of Dmax is calculated from the maximum value of D from the corrosion test, rebar locater test, and rebound hammer test from Tables 6, 7, and 8, respectively. Each of these parameters is combined with the prioritization module to define a priority ranking of water tanks demanding repair. Based on the inspection results of all items, the CI of the water tank is worked out using Eq. (1)

CI=∑ni=1Ici×wi∑ni=1wi,

Where

∑i=1nwi=100,CI=∑i=1nIci×wi∑i=1nwi,

Where

∑i=1nwi=100,

(1)

where,

WW_i, is the weighting of the water tank components. (Assume that the total weight of an all component group value is 10, 100, 1000—so on, it is not unique), in which '*n*' is the number of relevant inspection items and IciIci is the condition index of each component calculated as in Eq.

(2)

Ici=100−100×[max(D)+E]×Ra(4+4)×4a.Ici=100−100×[max(D)+E]×Ra(4+4)×4a.

(2)

Table. 5 DER rating scale for visual inspection

Test results	D value rating
Ve<V1Ve<V1	**4**
V1≤Ve<V2−0.5ΔVV1≤Ve<V2−0.5ΔV	**3**
V2−0.5ΔV≤V2<VeV2−0.5ΔV≤V2<Ve	**2**

V2≤VeV2≤Ve	**1**
None	**0**

Table. 6 *D* value rating for corrosion test

1. V_e is the measured electrical potential; $V_1 = -350$ mV, $V_2 = -200$ mV when electrical solution is $CuSO_4$,

Rating	**4**	**3**	**2**	**1**	**0**
D	Severe	Poor	Fair	Good	No such item
E	< High	< 60%	< 30%	< 10%	Cannot be inspected
R	High	Medium	Small	Minor	Cannot be decided

while $V_1 = -90$ mV, $V_2 = -240$ mV when electrical solution is $AgNO_3$

3.6 Seismic analysis methods

ESR is considered a vital lifeline structure in the many areas in India. During and after strong earthquakes, serviceability functioning is a crucial concern. During an earthquake episode, the collapse of these structures may cause several hazards to the health of citizens. ESR did not show good seismic performance; hence, remarkable damages have been observed during past earthquakes. For calculating seismic design force for a particular region or country, seismic codes are unique. In India IS (India standard) 1893-2016 is the main code for seismic analysis. The codes recommend the three methods of analysis name as equivalent static analysis, dynamic analysis: (a) response spectrum analysis, (b) time history analysis, pushover analysis respectively (IS 1893: 2002, 2016).

3.7 Model provisions

After the Chilean earthquake of 1960, two mass–spring models were proposed to distinguish the basic dynamic properties of the elevated tank. The dynamic motion of the tank can be divided into two parts, viz convective and impulsive when the pressure is generated within the fluid. Horizontal acceleration developed on the tank wall and liquid when the tank was subjected to horizontal earthquake ground motion when containing a liquid with a free surface (Housner 1963).

Lower region liquid mass, i.e., impulsive mass (mi), is rigidly attached to the tank wall. The upper region liquid, i.e., convective mass (mc), is attached to the tank wall by the spring having stiffness (Kc) in the spring–mass model. Instead of the spring–mass model, elevated tanks are considered as two-mass model systems with two degrees of freedom because two-mass model idealization is nearer to actuality.

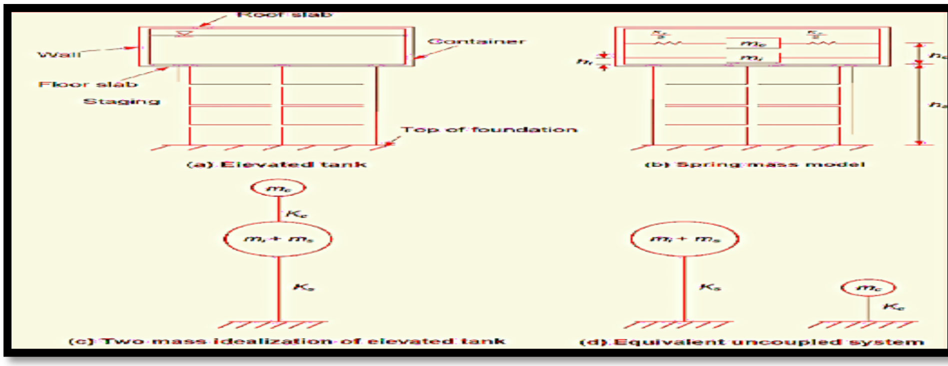


Figure. 7 Spring mass model and two mass idealizations for elevated tank.

3.8 Uttarkashi earthquake

The first of the serious earthquake to strike the Indian subcontinent during the 1990s, the shake crushed Garhwal, particularly Uttarkashi, Tehri, and Chamoli regions on Dusshera night happened at 02:53:16 October 20, 1991, neighbourhood time with a second extent of 6.1 and most extreme Mercalli force of IX (Violent). The upper east of the Uttarkashi district of the Higher Himalaya is the focal point of the ruinous seismic tremor. Table 9 sums up the seismic tremor information. The greatness of the tremor was allotted as 6.1 by the Indian Meteorological Department (IMD) in view of body wave information. The United States Geological Survey (USGS) relegated a surface wave size of 7.1. There was disarray about the focal point of the quake, with primer gauges by IMD showing its area near Almora, around 170 km from Uttarkashi.

S. no.	Name of ground motion	PGA	Richter magnitude	Year	Duration (s)	Scaling factor
1.	Uttarkashi	0.30 g	7.1	1991	23	–

Table 9 Selected ground motions

3.11 Retrofit measures for ESR

The primary purpose of retrofitting is to increase the stiffness and reduce the seismic demand of the structure with respect to its previous condition. In this research work, retrofitting techniques used are diagonal braces as a retrofitting system, FRP as a newly emerging material, and damper as technology.

In this seismic retrofit method, diagonal braces are installed on ESR to be retrofitted to absorb earthquake energy input to the ERS and thereby enhance its seismic performance. Figure 2a shows the SAP 2000 model with the addition of the diagonal braces. The material properties of bracing are the size of bracing 0.2 m × 0.6 m and stiffness of bracing 100 kN/mm, with 5% damping as tension and compression member. Figure 2b shows that the configuration of a damper improves the seismic resistance performance of the existing ESR by giving damping. The damper properties are stiffness 200 kN/mm, 5% of critical damping (damper properties are worked out for targeted displacement or permissible displacement or to control the displacement), damping coefficient 200, and damping exponent 1. Wrapping around the surfaces of concrete structures increases the durability and the ductility of the structural members. Figure 2c shows the SAP 2000 model retrofitted with FRP. The material properties of FRP are specific gravity 1.75 g/cm3, tensile strength 3100 N/mm2, and modulus of elasticity 220,000 N/mm2.

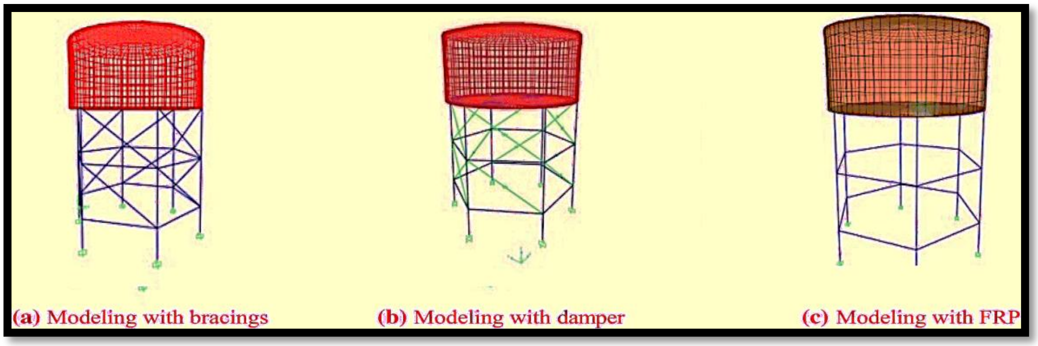


Figure. 8 Modeling of water tank with different retrofitting techniques

RESULTS AND DISCUSSIONS

A guideline for identifying the primary causes of deterioration in the district of Pune and a guideline for the selection of suitable condition assessment of reinforced concrete ESRs by using various NDT and strengthening by different retrofitting methods were proposed.

4.1 Case study of ESR

The following are the details of the water tank located in Baramati. The salient features are given in Table 10 and the overall view in Fig. 7.

Table 10 Salient features of ESR

S. no	Features	Description
01	Period of construction	1975
02	Location	Baramati, Pune
03	Owned and maintained	Baramati Nagar Palika
04	Total period of use	40 years
05	Utility of water tank	Yes
06	Number of columns	06

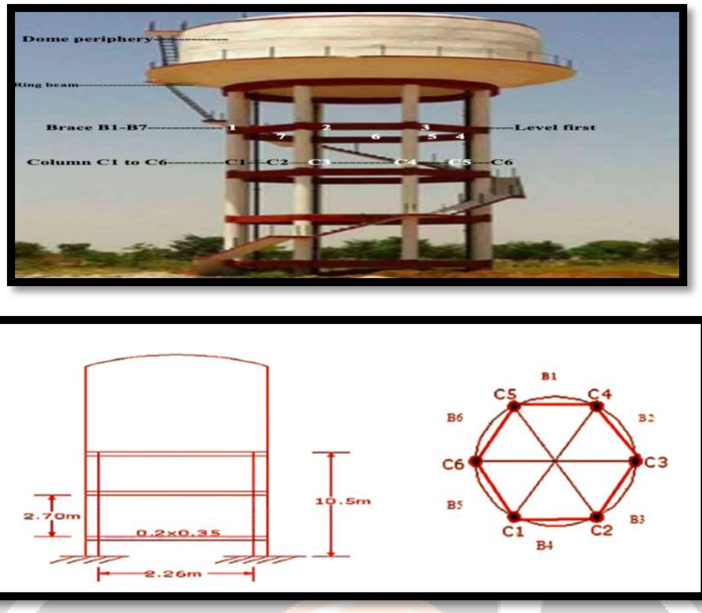


Figure. 9 Examined structure Corrosion investigation results

4.2 Visual observation

The amount of corrosion can be inspected visually by the human eye without any accompanying aids. Figure 8 shows some damages in the water tank and some observations are listed below after visual inspection. Blackish patches were seen on the dome periphery, corrosion damage of ring beam on the inner side of the ESR, and bottom the reinforcement of bracings exposed and corroded

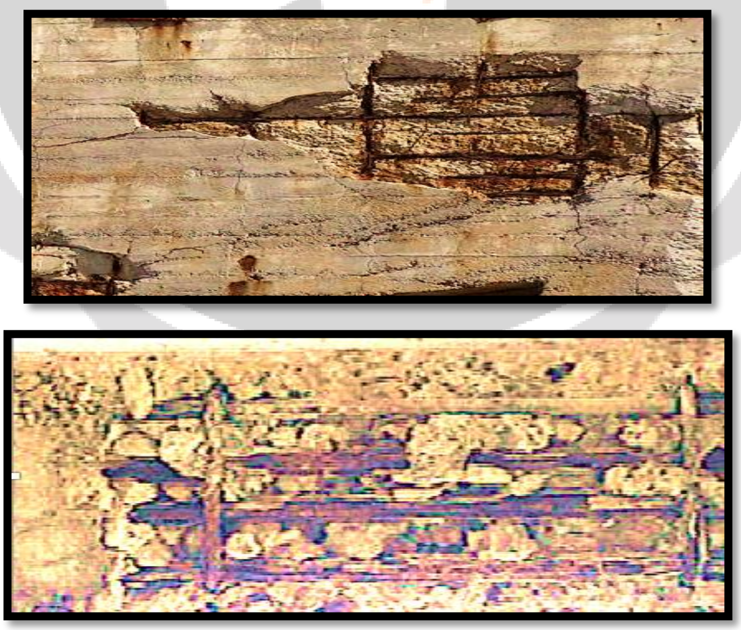


Figure. 10 Corrosion damage on ring beam inner side

4.3 Half-cell potentiometer test

Half-cell potential testing was carried out at representative locations on braces, column, and container of ESR. For this test, exposed reinforcement bars were either located or sometimes chiselled out to provide connectivity to the instrument. The surface was cleared of any dust and deposition. Tests were conducted in a grid of 150×150 mm using the procedure mentioned in ASTM 876. From Figs. 5 and 6, the average potential difference is in the range of -240 mV and -250 mV for column C5 and beam B2, respectively.

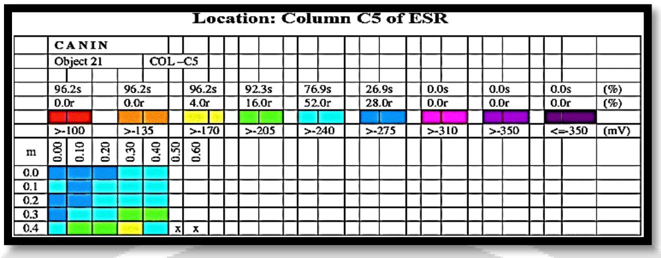


Figure. 11 Corrosion mapping of column C5

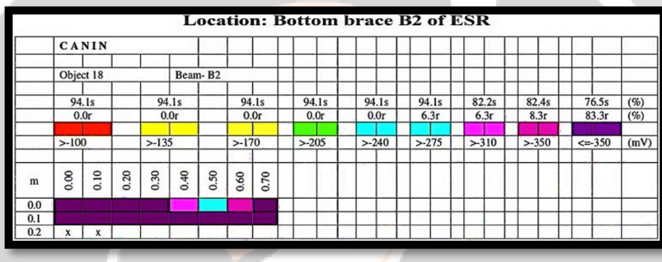


Figure. 12 Corrosion mapping of beam B2

4.4 Profometer

Testing was done at delegate areas on the support, section, and compartment of ESR. The outcomes acquired in the test are as per the following. Figures 11 and 12 show the subtleties of support of segment C5 and bar B2, individually.

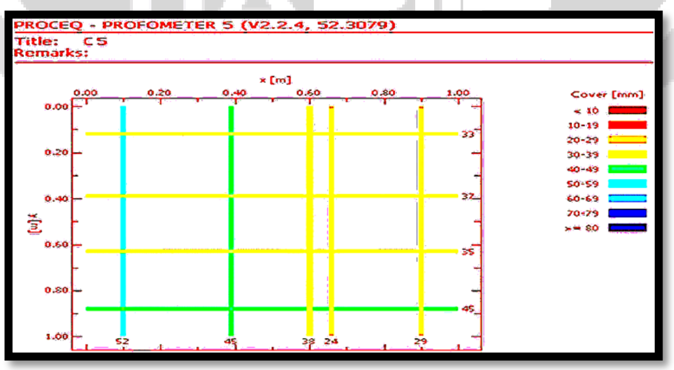


Figure. 13 Details of reinforcement in column C5

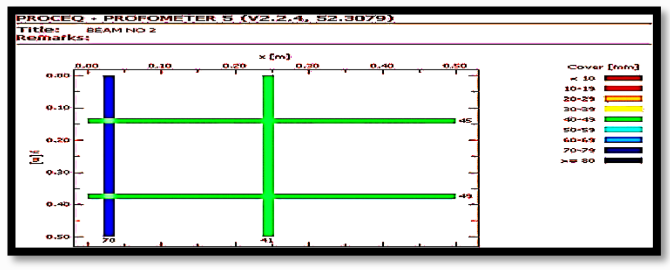


Figure. 14 Details of reinforcement in beam B2

Tables 11 and 12 show the different parameters, insights, and estimated spread for section C5 and bar B2, individually. The solid spread along the X-course was 37.6 mm and along Y-bearing 37.5 mm for segment C5. Various bars were estimated in section C5, five in the X-heading, and four in the Y-bearing. The profilometer rebar locator test on pillar B2 gives a normal solid spread along X-course 55.5 mm and along Y-bearing 47.0 mm. The quantity of bars estimated in bar B2 of ESRs was two in the X-course and two in the Y-heading.

Table 11 Parameters and results of profometer for column C5

SET PARAMETERS			
Bar diameter (*D*)		16 mm	
X grid width (d*X*)		10 mm	
Y grid width (d*Y*)		10 mm	
Statistics			
Direction		*X*	*Y*
Number of measured bars		05	04
Average measured cover		37.6 mm	37.5 mm
Standard deviation		11.4 mm	5.3 mm
Maximum of measured covers		52 mm	45 mm
Minimum of measured covers		24 mm	33 mm
Span		28 mm	12 mm
MEASURED COVERS			
X (m)	Cover (mm)	*Y* (m)	Cover (mm)
0.10	52	0.12	33
0.39	45	0.39	37
0.60	38	0.63	35
0.66	24	0.88	45
0.90	29		

Table 12 Parameters and results of profometer for beam B2

SET PARAMETERS			
Bar diameter (*D*)		16 mm	
X grid width (d*X*)		05 mm	
Y grid width (d*Y*)		05 mm	
Statistics			
Direction		*X*	*Y*
Number of measured bars		2	2
Average measured cover		55.5 mm	47 mm
Standard deviation		20.5 mm	2.8 mm
Maximum of measured covers		70 mm	49 mm
Minimum of measured covers		41 mm	45 mm
Span		29 mm	4 mm
Measured covers			
X (m)	Cover (mm)	*Y* (m)	Cover (mm)
0.03	70	0.14	45
0.25	41	0.38	49

4.5 Surface hardness

To calculate the compressive strength of the water tank at the site, a bounce-back mallet test was performed. The test focuses remembered explicit focuses for the segments, bar's top arch, and compartment, and the outcomes are deciphered according to Table 13.

Table 13 Results of rebound hammer

S. no.	Location	Rebound hammer value			Average	Surface condition
01	C5	17.1	16.7	17	17	Dry
02	B2	10	11.1	11.3	10.8	Dry
03	Top dome	17	18	17.4	17.5	Dry
04	Water tank container	18	18.5	17.7	18.06	Dry

1. The average rebound hammer value of the column C5 and beam B2 are 17 N/mm^2 and 10.7 N/mm^2, respectively

4.6 Analysis of condition index

Condition index is dictated by NDT assessment by DER Rating approach of all the part/component of the water tank.

⇒ Design strength of concrete pd = 25 N/mm2.

⇒ Design solid spread for sections Dc = 50 mm.

⇒ Design solid spread for support bars Dc = 50 mm.

⇒ Design solid spread for tank compartment, top vault, and flight of stairs Dc = 25 mm.

⇒ Parameter 'an' is identified with the significance of water tank = 2.

⇒ Number of parts of water tank n = 15.

Condition ranking/condition index for column C5 (Ic1Ic1).

⇒ Value of 'E' and 'R' from visual inspection using Table 5 is $E = 3$ and $R = 4$.

⇒ Average potential difference measured by half-cell potential $V_e = -240$ mV, from Table 6, $D = 1$.

⇒ Average cover measured by rebar locator $D_t = 37.6$ mm, then from Table 7, $D = 1$.

⇒ Rebound hammer value measured by rebound hammer test $p_t = 17$ N/mm^2 from Table 8, $D = 4$.

From the above three value of 'D' then Dmax = 4, using Eq. (2):

Ic1=100−100×[(4)+3]×42(4+4)×42=12.5.Ic1=100−100×[(4)+3]×42(4+4)×42=12.5.

Condition index for bracing beam B2 (Ic5Ic5)

Value of 'E' and 'R' from Table 5, E = 4 and R = 4.

1. Average potential difference measured by half-cell potential Ve = − 250 mV from Table 6, D = 1.
2. Average cover measured by rebar locator Dt = 55 mm from Table 7, D = 2.
3. Rebound hammer value measured by rebound hammer test pt 10.7 N/mm2, from Table 8, D = 4

From the above three values of 'D', Dmax = 4 using Eq.
(2):

Ic5=0.Ic5=0.

Similarly, all other components of the water tank are calculated. Finally, using Eq. (1) the CI of water tank is

CICI=∑ni=1Ici×wi∑ni=1wi,where∑i=1nwi=100,=100+406.24+406.24+100+0+0+0+75+100+0+0+75+0+355.46+253.98+8+8+8+8+8+6+6+6+6+6+6+6+5+5.=18.71.CI=∑i=1nIci×wi∑i=1nwi,where∑i=1nwi=100,=100+406.24+406.24+100+0+0+0+75+100+0+0+75+0+355.46+253.98+8+8+8+8+8+6+6+6+6+6+6+6+5+5.CI=18.71.

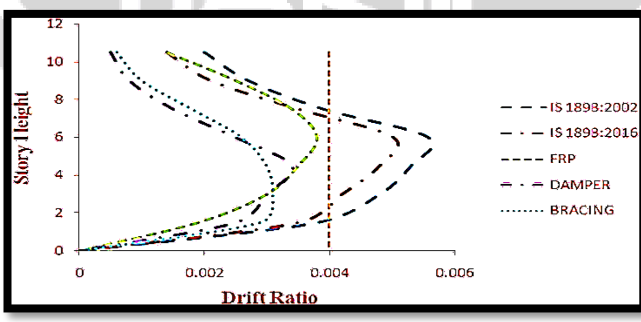
From Table 4, the condition index scales CI = 18.71 between CI = 10–24, which implies that the condition of the water tank is very poor, extensive deterioration has occurred, and the water tank is barely functional. As per condition index recommendation, rehabilitation or reconstruction is required to meet up the present-day requirement.

4.7 Seismic analysis and retrofitting results

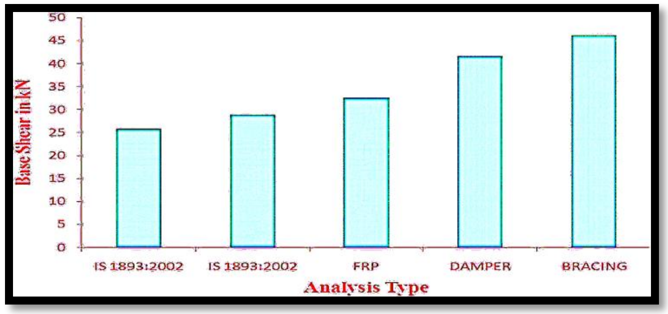
The majority of the water tanks were planned dependent on IS "Standards for Earthquake Resistant Design of Structures 1893", however after the event of tremor in Gujarat (Bhuj, 26 Jan 2001) the IS code was re-examined by IS 1893-2002, and again amended by another 1893-2016. Regardless of whether the codes were given a similar sort of structure, their seismic reaction could be very extraordinary, which may bring about an alternate degree of remaining malleability. For the security of the current water tank in India, the seismic examination ought to be checked according to the amended code IS 1893-2016 for the present-day prerequisite.

4.8 Drift ratio of ESR

From Graph 1, of the float proportion of ESR, thinking about five distinct cases, it very well may be said that the float proportion of the water tank is greatest according to IS code when contrasted with other retrofitting cases. The most reduced float was watched for the supporting framework



Graph. 1 Comparison drift ratio of ESR



Graph. 2 Comparison of base shear

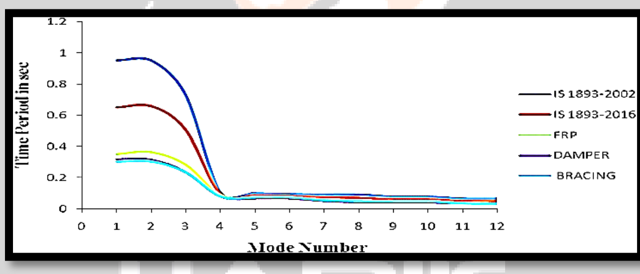
4.9 Base shear of ESR

A graph is plotted taking analysis type as abscissa and base shear as ordinate for the different types of analyses.

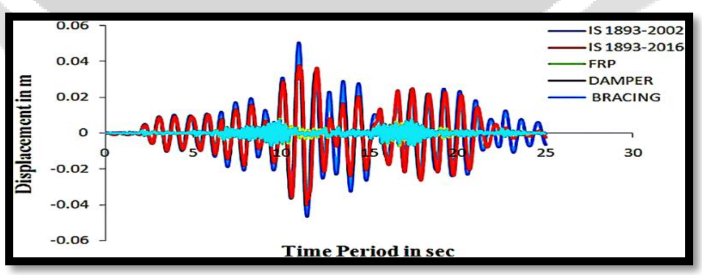
From Graph 2, it can be said that the value of the base shear was increased by 11.66%, 25.67%, 60.86%, and 78.88% by the provision of IS 1893-2016, for FRP, damper and bracing, respectively, as compared to IS 1893-2002

4.10 Time period of ESR

Any acknowledged redirection profile can be created by a blend of secluded shapes. It has been seen that the condition of higher mode for all cases is truly tantamount. Nevertheless, the condition of the lower mode will as a rule differentiate more. It is found in Graph 3 that the time span for every dynamic mode lessens as the mode number additions.



Graph. 3 Comparison between time period vs mode number



Graph. 4 Comparison between displacement vs time period

4.11 Displacement of ESR

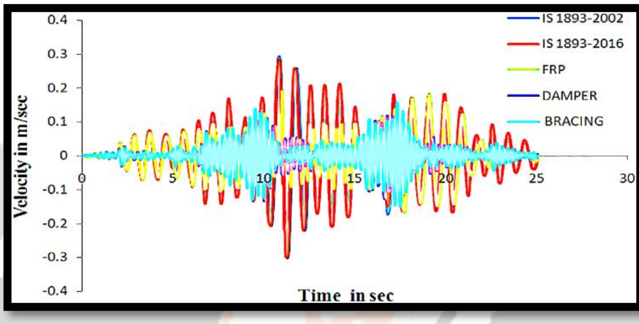
A correlation of dislodging was done to check the presentation of the structure from the thought of functionality.

From Graph 4, it tends to be said that the dislodging of the water tank was diminished 21.33%, 84.89%, 88.28%, and 92.89.45% by the arrangement of IS 1893-2016, for FRP, damper and supporting, separately, when contrasted with IS 1893-2002.

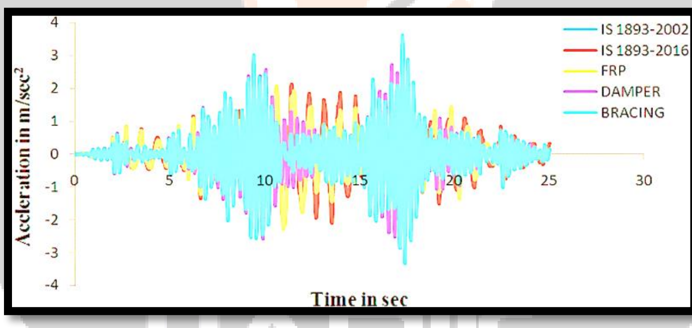
4.12 Velocity of ESR

A graph was plotted taking time as an abscissa and velocity as ordinate for the different types of cases. It was observed that the velocity was less in retrofitting cases than that of the IS code.

Graph 5, clearly shows that the velocity decreased 8.85% for IS1893-2016, 34.85% for FRP, 48.39% for damper, and 54.57% for bracing with respect to IS 1893-2002.



Graph. 5 Comparison between velocity vs time period



Graph. 6 Comparison between acceleration vs time period

4.13 Acceleration of ESR

A graph was plotted taking time as an abscissa and acceleration as ordinate for the different types of cases.

Graph 6, clearly shows that the acceleration increased 6.56% for IS 1893-2016, 13.63% for FRP, 69.19% for damper, and 78.78% for bracing with respect to IS 1893-2002.

FINDING & CONCLUSIONS

An earthquake is one of the most destructive cause recorded in India, resulting in death, devastation, and damage to infrastructure. Earthquakes cause significant damages in the cities of Bhuj, Koynanagar, Khandala port, Ahmedabad, Rajkot, Morbi, etc. Every earthquake leaves a trail of misery by loss of life and destruction. The research work carried on various aspects related to the development of systematic analysis metrology for condition ranking and strengthening by various retrofitting strategy for existing ESR, the significant findings and conclusions are as follows.

CONCLUSIONS

5.1 FINDINGS

- A condition ranking procedure based on AHP has been proposed. DER rating method was used to find out the condition ranking of ESR at Baramati, Pune, Maharashtra (India).
- The CI of ESR was found to be very poor, there was extensive deterioration, and the water tank was barely functional. Restoration or reconstruction is required with safety evaluation.
- In the seismic analysis, the value of story drift exceeds the limit given by IS 456-2000. Hence to maintain the given structure, resisting the seismic force retrofitting of the given structure is necessary.
- The value of story drift was reduced 9.50%, 30.01%, 39.06%, and 44.45% by the provision of IS 1893-2016, for FRP, damper, and bracing, respectively, as compared to IS 1893-2002. The lowest drift was observed for the bracing system.
- After retrofitting, the base shear was increased. The increase in base shear was more pronounced.
- It has been observed that the time period of higher mode for all cases is quite similar. However, the time period of lower mode tends to differ more.
- The movement of water tank was reduced 21.33%, 84.89%, 88.28%, and 92.89.45% by the provision of IS 1893-2016, for FRP, damper, and bracing, respectively, as compared to IS 1893-2002. The maximum reduction in displacement was observed in the bracing system than all other cases.
- The velocity was decreased 8.85% for IS 1893-2016, 34.85% for FRP, 48.39% for damper, and 54.57% for bracing with respect to IS 1893-2002.
- After retrofitting, the acceleration was increased 6.56% for IS 1893-2016, 13.63% for FRP, 69.19% for damper, and 78.78% for bracing with respect to IS 1893-2002.

5.2 CONCLUSIONS

- The DER rating based on the combination of field and visual inspection is found to be more effective to find out condition ranking of ESR without affecting the integrity of the structure.
- The value of story drift increased the limit of IS. To maintain the given structure and to resist the seismic force, retrofitting of the given structure is necessary. From the analysis, the drift ratio of the water tank is maximum as per IS code as compared to other retrofitting cases.
- It was also observed that time period for each successive mode decreases as the mode number increases.
- Implementation of different retrofitting techniques results in a reduction in displacement. This reduction enables the structure to behave almost stiffly.
- Different retrofitting techniques used in this study result in a decrease in velocity and increase in acceleration.
- From a case study result of seismic retrofit for the existing elevated water tank, it was confirmed that a relatively simple seismic retrofit method is really effective to keep the tank functional after an earthquake.

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