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.

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.

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.

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.

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).

3.3Profometer

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.

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).

3.5 Condition rankings/condition index (CI)

It is a numerical list of harm level of the component and the entire structure, in light of in situ tests and visual perception of the power and degree of harm and making a decision about the earnestness of fix. The evaluation depends on physical disintegration as controlled by quantifiable misery. The CI is spoken to by a quantitative positioning somewhere in the range of 0 and 100, with 0 being the most noticeably terrible condition and 100 being the best condition. The CI scales were utilized to change over the physical condition of the structure into quantitative qualities, as appeared in Table 4.

3.6 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)

$$CI=\sum ni=1Ici\times wi\sum ni=1wi,$$

Where

$$\sum i=1nwi=100,CI=\sum i=1nIci\times wi\sum i=1nwi,$$

Where

$$\sum i=1nwi=100,$$

(1)

where,

W_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)

$$Ici=100-100\times[max(D)+E]\times Ra(4+4)\times 4a.Ici=100-100\times[max(D)+E]\times Ra(4+4)\times 4a.$$

3.7 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).

3.8 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).

3.9 Time history analysis

The general seismic presentation assessment of a structure must be founded on its as-fabricated data, kind of structure, area of the structure, direction, material quality, and so forth. For the most part, four unique methodology, for example, the straight static, the direct powerful, the nonlinear static, and the nonlinear powerful techniques, are accessible for the seismic assessment of existing structures. The consequences of direct static examinations are utilized to plan the structures. The direct unique investigation gives the thought with respect to the characteristic time frame and mode states of the structures. Nonlinear static, i.e., weakling examination, gives the estimation of the limit of the structure. The limit of the structure is needy exclusively on the limit of its individuals. Consequently, really, the dissemination of the stacking on the structure ought not to influence the consequences of weakling investigation. The impact of mass dispersion along the stature of the structure will influence the dynamic reaction of the structure. In this regard, nonlinear time history examination is fit for demonstrating the distinctions in the conduct of the casings. This examination work presents the correlation of dynamic seismic reaction of the water tank and arranging outlines by direct time history investigations, for a lot of chosen ground movement records.

3.10 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.

RESULTS

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**.**

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

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.

The amount of corrosion can be inspected visually by the human eye without any accompanying aids.

CONCLUSIONS

An earthquake is one of the most destructive cause recorded in India, resulting in death, devastation, and damage to infrastructure.

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.

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.

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