ISSN: 2348 - 2117

International Journal of Engineering Technology and Computer Research (IJETCR)
Available Online at www.ijetcr.org
Volume 3; Issue 6; November-December-2015; Page No. 77-82

Seismic Evaluation and Retrofitting of Existing Reinforced Concrete Water Tank Staging System"

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Abstract

The Indian standard "Criteria for Earthquake Resistant Design of Structures: IS 1893:2002" has been revised. The seismic zone factors have been changed. Response spectra are now specified for 03 types of founding soil strata & a response reduction factor has been introduced. Elevated water tanks are vulnerable to earthquakes, owing to large mass concentrated at the top of relatively slender supporting systems. Existing elevated water tanks in India designed using IS 1893:1984 needs to be checked for safety as per revised code (IS 1893-2002) by carrying out static analysis. It is observed that the structure is unsafe due to under estimation of seismic load as per old code provisions. Retrofit measures such as additional structural elements and passive devices like viscous and friction dampers are modelled and structure analysed again to check for compliance with the revised code.

Keywords: Seismic zone factors, Water tank, Dynamic properties, NDT test, Retrofit, Static Analysis by SAP.

Introduction

The basic design procedure for new structures consist of selection of an appropriate level of lateral forces for design purpose & then providing a complete appropriately detailed lateral force resisting system to carry these forces from mass level to foundation. Deformations are checked as secondary issue & except for the design of flexible structures they are not likely to control the design. seismic evaluation of existing tank – A higher degree of damage in a elevated tank is expected during an earthquake if the seismic resistance of elevated tank is inadequate. Hence a detail seismic evaluation of existing elevated tank needs to be performed to determine the nature and extent of deficiencies, which can cause poor performance in future earthquake.

Deformation control is the secondary consideration is design of many new structures to code of life safety requirements because the modern materials and ductile detailing practices specified by current codes allow new structures to experience large deformation while expressing limited damage. Older structures however do not have advantage of this inherent ductility. Therefore control of deformation become and extremely important issue in design of seismic retrofit.

Seismic evaluation of existing structure

A higher degree of damage in a elevated tank is expected during an earthquake if the seismic resistance of the elevated tank is an inadequate. Hence a detailed seismic evaluation of existing elevated tank needs to be performed to determine the nature and extent of deficiencies, which can cause poor performance in future earthquakes. This evaluation also helps to decide whether structural modifications are required at few locations in the structure for deficient components only or interventions are needed structural level so that global behavior is improved and thus seismic demands on components are reduced the decision to strengthen it before an earthquake occurs depends on the tanks seismic resistance. The seismic evaluation procedure gives a measure of the seismic resistance of the structure. The seismic performance of the structure may not be improved by retrofitting or rehabilitation unless the structural engineer selects an appropriate intervention technique based on seismic evaluation of structure. Hence to select appropriate retrofitting method, an accurate evaluation of the seismic performance and the condition of an existing structure is necessary based on this evaluation ,engineer can choose the most effective retrofit among the various intervention technique and optimize the improvement in seismic performance foe an existing structure seismic evaluation consists of gathering as –built information and obtaining the results of a structural analysis based on collected data as built information refers to the configuration of the structural system ,as well as the type, detailing , material strength and condition of the structural elements .

Summary of Previous Research

Ramaiah & Gupta {6}

Investigated the factors such as size of columns, braces, number of panels. With the increase in size of bracing rods, the period was found to decrease, while lateral force & seismic coefficient increased**.**

Shepherd {8}

As per IS 1893-1984 an elevated water tank may be modelled by a single degree of freedom system. However researches indicate that the single degree of freedom idealization is approximate only for closed tank, which are completely filled with liquid. Shepherd presented the two-mass idealization of elevated water tanks.

Jain & Sameer{9}

Proposed approximate methods to estimate lateral stiffness of tank staging the study of lateral stiffness and retrofitting techniques seen to strengthen the structures.

Ingle {18}

Suggested an approximate method to estimate lateral stiffness & fundamental time period for tank structures with rectangular configuration of columns & braces in plan It has also proposed an equation for the lateral stiffness of the staging of the overhead water tank.

Srisanthi{15}

Carried out analysis of braced steel frame with friction damper using FE software. It has concluded that increasing the size of dampers will cause reduction in the response & deflection in the structure. It has also concluded that load carrying capacity of the steel frame with friction damper was 20% more than that of the frame without a damper

S.C.Datta,jain and Murty CVR(12)

The companion paper [Dutta SC, Jain SK, Murty CVR assessing the seismic torsional vulnerability of elevated tanks with RC frame-type staging soil Dynamics and Earthquake Engineering 2000;19(3):183–97] shows that many of the currently designed reinforced concrete elevated water tanks supported on frame-type staging's have the ratio of torsional and lateral natural periods, t , in the critical range of 0.7– 1.25. This may amplify the effect of small accidental eccentricity and cause large torsional vibration during translational ground shaking in earthquakes [Dutta SC. Torsional behaviour of elevated water tanks with reinforced concrete frame-type stagings during earthquakes

It is seen in the companion paper [1] that elevated water tanks supported on reinforced concrete frame-type stagings having all the columns resting on the perimeter of a circle (shown in Fig. 1 of the companion paper [1] and referred as *basic configuration* in the rest of this paper) may often have their natural period ratio t (ratio of torsional and lateral natural periods) in the range 0:7 , t , 1:25: This tuning of torsional and lateral natural periods makes them prone to severe amplified torsional vibration during earthquake, arising out of any small accidental eccentricity (e.g. Refs. [2,3]).

Staging with radial beams

Addition of the radial beams to the basic staging configuration (Fig. 1a) provides increased lateral stiffness with no change in the torsional stiffness. Therefore, the natural period ratio (t) is increased. Addition of the radial beamsmay also is a feasible solution for seismic strengthening of the existing elevated water tanks.

. Lateral stiffness

. Due to bending deformation of staging members

The derivation of the stiffness is carried out as in the case of basic configuration in the companion paper [1]. The entire staging is modelled as a single equivalent column attached with a single equivalent rotational spring at each beam level. The moment of inertia of equivalent column is equal to the sum of moment of inertia of all the columns.

The equivalent rotational spring at each beam level accounts for the rotational spring action provided by both the circumferential as well as radial beams at that level to account for the additional effect of radial beams, *k*st and *k*sb in Eq. (3) of the companion paper [1], for basic configuration, are replaced by *k*st 1 *k*srt and *k*sb 1 *k*srb; respectively. Here, *k*st and *k*sb are the sum of rotational stiffness parameters of circumferential beams at top and bottom joints of a panel, respectively, in the direction of lateral force, as defined and derived in Eq. (4) of the companion paper [1]. Similarly, *k*srt and *k*srb are the sum of rotational stiffness parameters in the direction of lateral force of all radial beams at all the top and bottom joints, respectively, of the panel considered. Assuming that all the radial beams have their points of inflection at the centre of the staging circle,

***k*srt =*k*srt = *k*srb= .X*N*=c*i*.1*k*brt= .X*N* *i*.1*k*brb = . *E*b*I*br/2*R*sX=*N*c*i*.=1cos2 b*i* . *E*b*I*br*N*c/4*R*s**

Where *k*brt and *k*brb are the rotational stiffness parameters of individual radial beams at top and bottom joints of the panel, respectively

*K*p.lateral. =12*E*c*I*c*N*c*h*3/1 1g*K*r1 1 0:5d0sin.p*N*c.

Torsional stiffness

The addition of radial beams does not change torsional stiffness of the staging. The torsional stiffness of the panel is same as that for the basic configuration given by Eq. (10) of the companion paper [1]

METHODOLOGY

The elevated Water Tank (WT) consists of tank supported by staging system composed of columns, braces and foundations. Only R.C.C. WTs have been considered. The criteria for a seismic design of structures are given in IS 1893-2002 part 1 [3] and the explanatory code [4]. Elevated WTs have generally performed well in seismic zones. However large number of tank collapses have been observed during earthquakes from as early as the 1906 San Francisco Earthquake to the 2001 Bhuj Earthquake[5]. The seismic zone maps have been recently revised. The new zone map has only four seismic zones – 11, 111, 1V and V instead of the five zones in the earlier version.

1. Assessment of safety of existing R.C. water tanks (designed using IS 1893:1984) under revised provisions of is 1893:2002.
2. To check the efficiency of additional structural members as retrofit scheme.
3. To find suitability of appropriate retrofitting Technique

EXPERIMENTAL & ANALYTICAL PART

3. Visual Observation and Documentation

The visual observation and documentation was made on the structural members of the reservoir. Delamination and spalling of concrete was observed at many places in brace beams and at some places in columns between level-III & IV. Voids, honeycombing and cracks were observed at all junctions of columns. Exposure of rebars at some places of brace beams and junctions of columns were also observed. Shows the spalling of concrete and exposure of rebars of column C4 at Junction. In general it was observed that the damage was mainly due to poor compaction of concrete, inadequate cover thickness and also due to poor maintenance. Voids and honeycombs were present at many places where the damage was severe.

4. Non-Destructive and Partially

Destructive Tests keeping in view the visual observations, a comprehensive test programme was planned for condition assessment. The tests conducted were ultrasonic pulse velocity test on columns and brace beams for assessing the integrity and quality

4.00 Rebound hammer Test

Figure 1:

The test is bsed on principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impingines. The is therefore a measure of the relative hardness of the concrete surface. Although there is no unique relation between hardneess and strength of concrete, however empirical relationship can be established for similar concretes by means of both Schmidt hammer and destructive tests.

Ultrasonic Pulse velocity test

Figure 2:

4.1 Ultrasonic pulse velocity (UPV) test

UPV test is basically a wave propagation test and consists of transmitting ultrasonic pulses of 54 kHz frequency through concrete medium and measuring the transit time. The equipment used is known as PUNDIT (Portable Ultrasonic Non- Destructive Digital Indicative Tester). The path length divided by transit time gives the velocity which is usually expressed in km/sec and can be correlated to concrete quality. The UPV testing was carried out on randomly selected members of columns and brace beams in a systematic way by dividing the members into well defined grid points. Measurement of transmit time was made at each grid point and the velocity was calculated by dividing the thickness of the member with transit time. UPV values have8.8 to 10.0 and 20-40mm cover zone were in between 10.0 to 12.2. The chloride contents present in the structure were very minimal.

Analysis of Existing structure by using software SAP

According to Is 1893:2002 the structure is designed by using SAP software

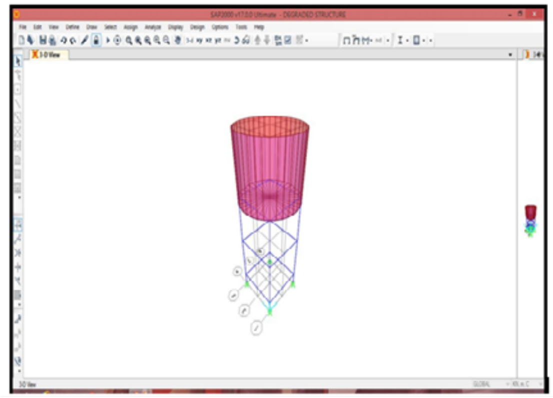
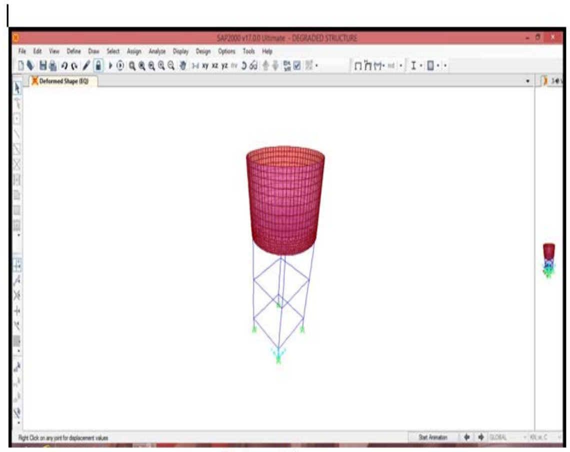


Figure 3:



Deformed Shape

Figure 4:

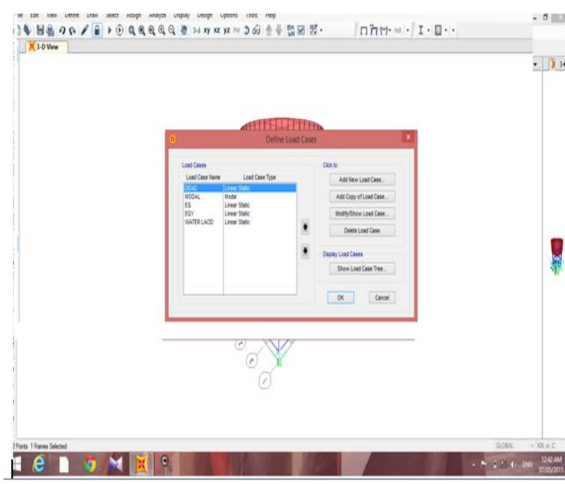


Figure 5:

Table 1:

Mix. Prop.	Member	Pluse velocity (km/sec)	Rebound Hammer H	Rebound Hammer V	Strength Predicted (4)	Strength Predicted (5)
1:1:2	B_{11}	4.3	42	39	45.85	55.08
	B_{12}	4.2	40	36	42.57	51.54
	B_{13}	4.2	40	34	42.57	49.06
	B_{14}	3.4	22	30	22.66	22.69
	C_{11}	4.0	38	34	38.25	35.61
	C_{12}	3.5	28	30	22.5	26.8
	C_{13}	4.0	40	39	40.4	45.5
	C_{14}	4.1	41	36	42.55	54.8
	B_{21}	4.0	41	32	41.49	45.07
	B_{22}	3.3	30	26	22.86	32.3
	B_{23}	3.9	38	36	37.2	39.2
	B_{24}	3.8	38	36	31.57	39.3
	C_{21}	4.5	44	41	50.35	58.7
	C_{22}	4.2	42	39	44.73	52.1
	C_{23}	4.0	39	36	39.33	33.19
	C_{24}	3.4	32	26	22.00	33.73
	B_{31}	3.2	32	26	24.16	42.6
	B_{32}	3.8	36	36	33.97	47.1
	B_{33}	3.9	40	38	39.36	39.9
	B_{34}	4.0	41	36	40.41	48.7
	C_{31}	4.0	42	34	42.57	42.6
	C_{32}	4.1	40	40	41.57	42.6
	C_{33}	3.4	30	28	23.74	36.95
	C_{34}	3.8	38	36	36.19	42.18

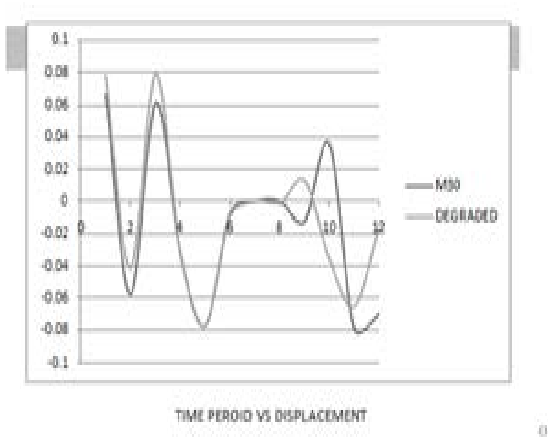


Figure 6:

Summary and Conclusions:

1) There is significant 8% of variation in the maximum displacement in both structures that is in retrofitted and in degraded structure.

2) The significant variation of 5% in the time period is observed.

3) Variation in the base shear is seen to be 6% more in the degraded structure resulting in maximum induced forces in columns.

4) As structure is symmetrical the variation in result for X and Y direction is seen to be similar.

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