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Effect of Modified Provisions of IS 1893 (Part 2):2014,on Design Base Shear of Elevated Water Tanks

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***Abstract:*— Elevated water tanks are essentially present in public water distribution systems. These tanks are regarded as lifeline structure due to their post-earthquake importance, which necessitates stringent code requirements for their seismic analysis and design. Recently BIS (Bureau of Indian Standards) has revised the provisions for seismic design of water tanks and published IS 1893 (Part 2):2014 which has significant modifications compared to the old code (IS 1893:1984). These revisions are largely based on IITK-GSDMA Guidelines (2007). However, some of the provisions in IS 1893 (Part 2):2014, particularly those related to response reduction factor and usage of 1-DOF and 2-DOF models need critical examination. In this paper, the main provisions of IS 1893 (Part 2):2014 are discussed.**

***Index Terms* :-- Seismic analysis, elevated water tanks, response reduction factor.**

I. INTRODUCTION

Elevated water tanks are generally categorized on the basis of container shape, staging type, and material used for construction. In India, reinforced concrete (RC) elevated tanks with circular or rectangular shape of container are commonly used. These are supported on RC frame type of staging (Fig. 1a) or RC shaft type of staging (Fig. 1b). The elevated water tanks are considered as lifeline structure and therefore, their seismic safety is a matter of great concern. In post-earthquake scenario, uninterrupted water supply is required not only for public distribution but also for firefighting. However, in many of the past earthquakes, the elevated water tank exhibited poor seismic performance (Manos and Clough,1983; Astaneh and Ashtiany, 1990; Mehrain, 1990; Jain et al., 1993; Saffarini, 2000; Rai, 2001; Soroushnia et al., 2011).

During an earthquake the water mass in the container vibrates in two different modes. The part of water which vibrates with the container is called impulsive mass and the part which moves relative to the container is called convective or sloshing mass. In addition to the impulsive mass, the sloshing of liquid also imparts hydrodynamic force. There are two approaches of modelling the water in an elevated water tank with rigid container viz. 1-Degree of freedom (DOF) system and 2-DOF system. In 1-DOF system the whole water is considered as impulsive mass along with structural mass of container and staging. In 2-DOF system approach (proposed by Housner, 1963), an equivalent mechanical model is considered in which the impulsive mass along with structural mass of container and staging corresponds to the first degree of freedom and convective mass corresponds to the second degree of freedom. In this model, the hydrodynamic force comprises of convective and impulsive components. Amount of liquid contributing to convective mass depends largely on height to diameter (h/D) ratio. In wider containers (small h/D ratio) convective liquid is more in comparison to that in taller containers (large h/D ratio).

In this study, seismic design forces for an elevated water tank calculated from IS 1893 (1984) and IS 1893: Part 2 (2014) are assessed. The IS 1893 (1984) considers 1-DOF approach whereas, the revised IS 1893: Part 2 (2014) adopts 2-DOF approach. To observe the variation in base shear from the aforementioned two approaches, fifty existing tanks have been considered. This comparison has been used to quantify the effect of new provisions of IS 1893: Part 2 (2014) like ductility, response reduction factor (R), effect of convective liquid mass etc. on seismic base shear.

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(a) (b)

Fig. 1 Staging types (a) RC frame type of staging, (b) RC shaft type of staging

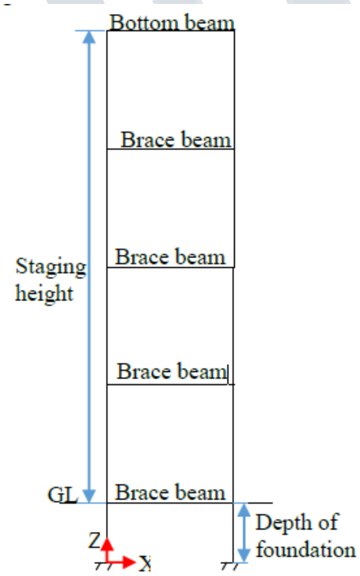
II. IS CODE PROVISIONS

The earlier Indian code IS 1893 (1984) considers 1-DOF modeling approach, whereas, the current IS 1893: Part 2 (2014) uses 2-DOF modeling approach. To assume that the base shear computed by the IS 1893: Part 2 (2014) (by considering 2-DOF modeling approach) will be lower than the base shear computed by IS 1893 (1984) (by considering 1-DOF modeling approach) may be misleading due to the fact that the response reduction factor (R) in IS 1893: Part 2 (2014) has also been revised. In fact, in the IS 1893 (1984), performance factor (K) is used for calculating the base shear of buildings, which is absent for elevated water tank (Jain and Sameer, 1993). It is interesting to note that the IS 1893 (1984) code uses performance (K) as 1.0 for ductile building and therefore it implicitly considers that the elevated water tank will behave in similar way as ductile building, which seems irrational. Further, the comparison of base shear for ductile building using IS 1893 (1984) (with performance factor 1.0) and IS 1893 Part 1, (2002) (with response reduction factor 5) yields almost similar base shear (Agarwal and Shrikhande, 2012). Therefore, it can be concluded that the IS 1893 (1984) approximately uses response reduction factor as 5 for elevated water tanks also. In IS 1893: Part 2 (2014), various response reduction factors depending on type and material of staging has been defined.

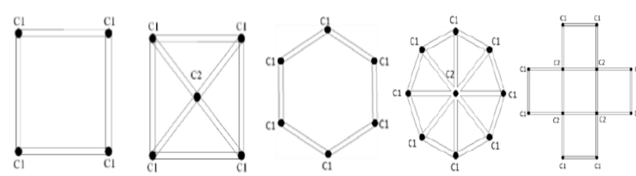
III. DESCRIPTION OF ELEVATED WATER TANKS

To identify the effect on seismic design force due to change in modeling approaches and response reduction factors of the two codes, as well as to observe the effect of common dimensional parameters viz. h, D and tank capacity, 50 existing elevated water tanks (Table 1) have been considered.

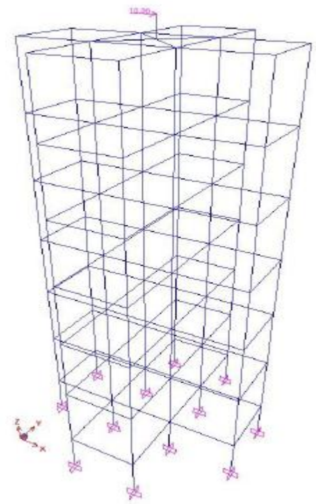
To keep similarity, elevated water tanks with only circular container on frame staging and situated in seismic zone II (peak ground acceleration 0.1g) have been considered. Typical elevation of elevated water tank supported on four column staging is shown in Fig. 2(a). The selected 50 elevated water tanks indicated in the Table are chronologically arranged in the order of their container capacity, however, the configuration of their staging are different as shown in Fig. 2(b). To determine the stiffness of staging all the 50 elevated water tank staging have been modeled in SAP 2000. A typical SAP 2000 model of staging with 12 columns (T5) is shown in Fig. 2(c). It is interesting to note from the Table 1 that the container capacity of the considered 50 ESR varies from 8 m3 to 330 m3, but the depth of water (h) in these containers hovers around 3 m (Fig. 3). The increase in capacity has been achieved by increasing the diameter (Fig. 3) rather than changing the height. Fig. 4 indicates that as the container capacity is increased, the h/D ratio decreases.



(a)



(b)



(c)

Fig. 2 Typical elevated water tank structure (a) Elevation for T1 plan configuration (b) SAP 2000 model of reinforced concrete frame staging (c) Various plan configuration at brace level

Table 1. Details of elevated water tanks

S.N.	Q (m^3)	$h_{stag.}$ (m)	NBL	NC*	$D_{Col.}$ (C1 and C2) (mm)	Brace size (mm)	Floor beam (mm)	D (m)	h (m)	$h_{foot.}$ (m)	m_{cont} (kN)	m_{stag} (kN)
1	8	11.6	3	4 (T1)	350	250x250	250x300	2.5	1.5	3.0	177.5	163.9
2	12	10.0	3	4 (T1)	350	250x300	250x300	3.2	1.5	3.0	240.5	160.6
3	13	9	2	4 (T1)	350	250x250	250x300	2.35	3	3.0	221.15	115.22
4	15	12.0	3	4 (T1)	350	250x300	250x300	2.5	3.0	3.0	243.5	163.8
5	20	12.0	3	4 (T1)	350	250x300	250x300	2.8	3.0	3.0	277.0	170.9
6	20	9.0	2	4 (T1)	350	250x350	250x350	3.2	2.5	3.0	294.0	135.7
7	20	15.0	4	4 (T1)	350	250x350	250x350	3.0	3.0	3.0	295.6	239.1
8	25	12.0	4	4 (T1)	400	250x300	250x300	3.6	2.5	2.0	316.5	229.3
9	25	9.0	2	4 (T1)	350	250x350	250x350	3.2	3.0	3.0	321.4	135.7
10	25	17.6	4	4 (T1)	400	250x400	250x400	3.2	3.0	3.0	317.4	325.2
11	30	11.6	3	4 (T1)	350	250x400	250x300	4.0	2.5	3.0	368.9	190.2
12	30	12.0	4	4 (T1)	400	250x300	250x300	3.6	3.0	2.0	346.5	229.3
13	33	12.0	3	4 (T1)	350	250x350	250x350	3.8	3.0	3.0	378.7	175.9
14	33	11.4	3	4 (T1)	350	250x400	250x400	3.8	3.0	3.0	388.0	188.2
15	35	8.6	2	4 (T1)	400	250x300	250x300	3.9	3.0	3.0	391.7	144.9
16	40	11.6	3	4 (T1)	350	250x400	250x400	4.0	3.3	3.0	423.3	189.7
17	45	8.5	3	4 (T1)	350	250x300	250x300	4.7	2.7	3.0	463.9	151.0
18	45	8.6	2	4 (T1)	400	250x300	250x300	4.7	2.7	3.2	467.3	152.8
19	50	11.6	3	4 (T1)	400	250x300	250x300	4.7	3.0	3.0	486.4	213.2
20	50	12.0	4	4 (T1)	400	250x300	250x500	4.7	3.0	2.0	490.3	250.6
21	55	9.0	4	4 (T1)	400	250x300	250x500	4.9	3.0	2.0	524.6	217.3
22	60	15.0	5	4 (T1)	400	250x300	250x500	5.1	3.0	2.0	557.9	325.1
23	75	12.0	4	4 (T1)	400	250x300	250x600	5.7	3.0	2.0	666.2	272.0
24	80	8.1	2	6 (T3)	400	250x350	250x450	5.9	3.0	3.0	686.9	221.9
25	80	12.0	4	4 (T1)	400	250x300	250x600	6.0	3.0	2.0	700.2	276.4
26	90	12.0	4	4 (T1)	450	250x350	250x700	5.7	3.6	2.0	741.7	331.1
27	100	11.0	3	6 (T3)	450	250x450	250x700	5.1	5.0	3.0	732.2	352.0
28	100	9.0	3	4 (T1)	450	250x350	250x700	5.7	4.0	2.0	791.5	246.3
29	105	9.0	2	6 (T3)	400	250x350	250x450	6.7	3.0	3.0	889.7	231.0
30	110	12.0	3	4 (T1)	500	250x400	350x740	6.9	3.0	3.0	926.0	318.8
31	110	25.0	6	6 (T3)	550	250x500	250x670	6.9	3.0	3.0	883.3	1194.8
32	115	18.0	4	6 (T3)	450	250x350	250x670	7.0	3.0	3.0	736.2	586.8
33	125	14.0	3	6 (T3)	450	250x500	250x650	5.7	5.0	3.0	831.3	449.1
34	125	18.0	4	6 (T3)	450	250x350	250x500	7.3	3.0	3.0	985.4	578.6
35	140	11.5	3	8+1 (T4)	300	250x350	250x350	8.1	2.8	3.0	1004.8	523.2
36	150	14.8	4	8+1 (T4)	400	250x250	250x350	8.1	3.0	3.0	1021.6	682.5
37	150	11.5	3	8+1 (T4)	400	250x350	250x350	8.1	3.0	3.0	1031.0	523.2
38	150	11.3	3	4+1 (T2)	450 and 550	250x450	250x550	8.1	3.0	3.0	1114.7	541.4
39	160	25.5	6	8+1 (T4)	500	250x300	250x300	8.3	3.0	3.0	1081.5	1576.0
40	165	11.2	3	4 (T1)	600	250x400	250x600	6.5	5.0	2.0	1030.1	583.9
41	165	14.3	3	4+1 (T2)	450 and 550	250x400	250x500	8.5	3.0	3.0	1234.8	588.5
42	175	11.3	3	4+1 (T2)	450 and 550	250x400	250x500	8.5	3.1	3.0	1238.3	503.9
43	175	22.8	6	6 (T3)	500	300x540	350x700	8.3	3.2	3.0	1500.9	1454.6
44	180	18.5	4	8+1 (T4)	400	250x350	250x300	8.7	3.0	3.0	1154.6	810.1
45	180	14.5	4	8+1 (T4)	400 and 450	250x350	250x300	8.7	3.0	3.0	1174.6	705.2
46	210	28.0	7	8+4 (T5)	600	250x500	250x500	10.3	2.5	3.0	1580.5	3387.3
47	230	16.0	4	8+4 (T5)	400 and 450	250x400	250x450	7.6	5.0	3.0	1241.4	958.2
48	250	12.0	3	8+4 (T5)	450	250x350	250x285	10.4	3.0	3.0	1533.8	863.7
49	300	10.0	3	8+4 (T5)	400 and 450	250x350	250x415	11.4	3.0	3.0	1841.3	726.4
50	330	12.0	3	8+4 (T5)	400 and 500	250x300	250x500	11.8	3.0	3.0	2092.4	854.9

*The value in parenthesis corresponds to the plan configuration type given in Fig. 2(b).

Q – Capacity; hstag. – Staging height; NBL – Number of brace levels; NC – Number of columns; DCol. – Diameter of column; D – Diameter of container; h – Depth of water; hfoot. – Depth of foundation; mcont. – Mass of container; mstag. – Mass of staging.

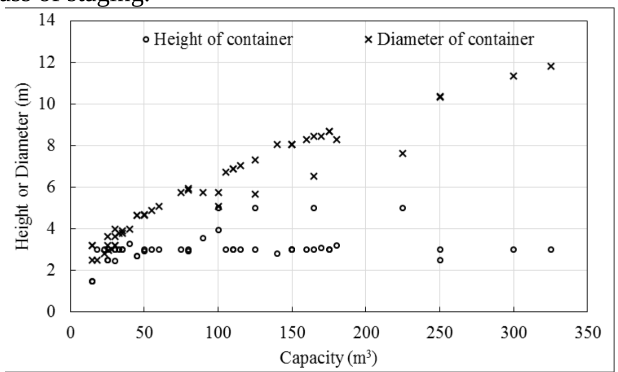


Fig. 3 Variation of height and diameter of container with capacity of elevated water tanks

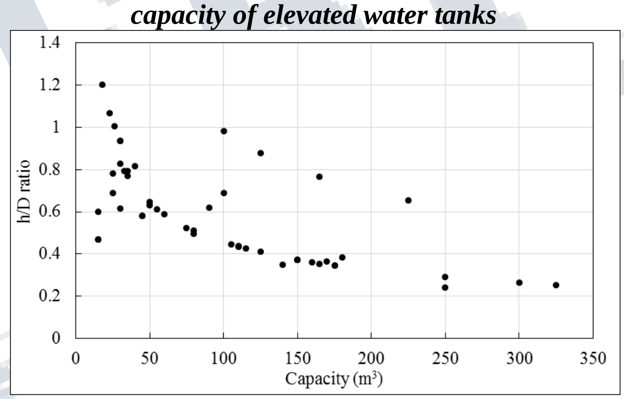


Fig. 4 Variation of h/D ratio with capacity of elevated water tanks

IV. COMPARISON OF SEISMIC BASE SHEAR FROM OLD AND NEW IS CODE

If sloshing effect of liquid is not considered i.e. entire water is considered to be a rigid mass, then the elevated tank is modelled as 1-DOF model. In this model water mass and structural mass of tank contributes to mass component and staging stiffness contributes the lateral stiffness. If sloshing of water is included, then, the elevated tank is considered as 2-DOF model, wherein, sloshing mass constitutes one degree of freedom and impulsive mass along with structural mass constitutes second degree of freedom.

As per the old IS code, IS 1893 (1984), the seismic base shear has been calculated using (1).

$$V_{old} = \alpha_h W \qquad (1)$$

α is the design horizontal seismic coefficient and W is seismic weight (sum of weight of water, weight of container

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and one-third mass of staging). h α has been calculated by using (2)

$$\alpha_h = \beta I F_o \frac{S_a}{g} \qquad (2)$$

β is a coefficient depending upon the soil-foundation system (considered as 1, since all the ESRs considered in the study is situated on hard soil), I is the importance factor (considered as 1.5), F_0 is seismic zone factor for average acceleration spectra (considered as 0.1, according to IS: 1893-1984 for seismic zone II), S_a/g is average acceleration coefficient obtained from 5% damped average acceleration response spectra as per IS: 1893-1984 for the period T given by (3).

$$T = 2\pi\sqrt{\frac{\Delta}{g}} \qquad (3)$$

Where is the static horizontal deflection at the top of the tank under a static horizontal force equal to a weight acting at the centre of gravity of tank and g is acceleration due to gravity. Δ

As per new IS code, IS 1893 part 2 (2014), the base shear has been calculated using (4). Total base shear is combination of base shear in impulsive mode, V_i and base shear in convective mode, V_c which are calculated using (5) and (6). The impulsive mass of liquid is indicated as m_i and the convective mass as m_c. $(S_a/g)_i$ and $(S_a/g)_c$ are the average acceleration coefficient for impulsive and convective mode which depends on the impulsive time period T_i and convective time period T_c respectively. T_i is given by (7). T_c for circular tank is calculated as per the (8). Where, Z, I, R are respectively zone factor (Z = 0.1), importance factor (I = 1.5) and response reduction factor. For the ESRs considered in the study it is assumed that the tank staging has been designed as special moment resisting frame (SMRF) type conforming ductility requirements of IS 13920 (1993) and therefore, R equal to 4 have been considered. m is the total mass of water in tank, m_s is the mass of empty container of elevated water tank and one-third mass of staging; Sa/g is average response acceleration coefficient which is obtained from response spectrum based on fundamental period of the tank T ($T = 2\pi\sqrt{m/K_s}$). K_s is the lateral stiffness of elevated tank staging.

$$V_{new} = \sqrt{V_i^2 + V_c^2} \qquad (4)$$

$$V_i = \left[\frac{Z}{2}\frac{I}{R}\left(\frac{S_a}{g}\right)_i\right](m_i + m_s)_g \qquad (5)$$

$$V_c = \left[\frac{Z}{2}\frac{I}{R}\left(\frac{S_a}{g}\right)_i\right] m_c g \qquad (6)$$

$$T_i = 2\pi\sqrt{\frac{m_i + m_s}{K_s}} \qquad (7)$$

$$T_c = \left[\frac{2\pi}{\sqrt{3.68\tanh(3.68h/D)}}\right]\sqrt{\frac{D}{g}} \qquad (8)$$

The expression for calculating base shear are identical in case of 1893: Part 2 (2014) and IITK-GSDMA (2007) Guideline. However, IITK-GSDMA (2007) Guideline recommends response reduction factor of 2.5 for elevated water tank supported on frame conforming to ductile detailing, i.e., special moment resisting frame (SMRF).

The base shear from old code, new code and IITK-GSDMA (2007) are shown in Table 2. It can be observed from the table that for the considered elevated water tanks the base shear from new code is more than the old code, except in few cases with large capacity tanks. Moreover, for all considered tanks the design base shear as per IITK-GSDMA (2007) Guideline is on the higher side than the old code and for some tanks the difference is even 1.4 times.

Table 2. Comparison of base shear ratio

Sr. No.	Capacity (m3)	h/D	T (s)	T_i (s)	T_c (s)	V_{old} (kN)	V_{new} (kN)	$V_{guideline}$ (kN)	$\frac{V_{new}}{V_{old}}$	$\frac{V_{guideline}}{V_{old}}$
							R=4	R=2.5		
1	8	0.47	1.13	1.05	1.93	6.2	6.4	10.2	1.03	1.65
2	12	0.60	0.90	0.86	1.67	5.4	6.0	9.6	1.11	1.78
3	13	1.27	0.87	0.85	1.60	7.0	8.1	13.0	1.16	1.85
4	15	1.20	1.27	1.24	1.65	5.9	6.4	10.2	1.08	1.74
5	20	1.07	1.22	1.19	1.75	7.2	7.7	12.3	1.07	1.71
6	20	0.78	0.98	0.93	1.88	9.0	9.8	15.7	1.09	1.74
7	20	1.01	1.28	1.23	1.81	7.7	8.3	13.3	1.08	1.72
8	25	0.69	0.93	0.87	2.00	11.2	12.2	19.5	1.09	1.74
9	25	0.94	1.04	1.00	1.87	9.7	10.5	16.8	1.08	1.73
10	25	0.62	1.21	1.12	2.11	10.3	10.6	17.0	1.03	1.65
11	30	0.94	1.40	1.35	1.87	8.0	8.6	13.8	1.08	1.72
12	30	0.83	0.99	0.94	1.99	12.1	13.1	21.0	1.08	1.73
13	33	0.79	1.32	1.24	2.04	9.9	10.4	16.6	1.05	1.68
14	33	0.79	1.24	1.16	2.04	10.8	11.3	18.1	1.05	1.67
15	35	0.77	1.11	1.04	2.07	12.1	12.6	20.2	1.04	1.67
16	40	0.82	1.33	1.25	2.10	11.3	11.9	19.0	1.05	1.68
17	45	0.58	1.22	1.10	2.29	13.5	13.6	21.8	1.01	1.61
18	45	0.58	1.31	1.18	2.29	12.6	12.8	20.5	1.02	1.63
19	50	0.65	1.54	1.41	2.27	11.3	12.0	19.2	1.06	1.70
20	50	0.63	1.16	1.06	2.28	15.8	16.1	25.8	1.02	1.63
21	55	0.61	0.94	0.85	2.34	19.9	21.0	33.6	1.06	1.69
22	60	0.59	1.56	1.41	2.39	13.4	14.1	22.6	1.05	1.68
23	75	0.52	1.38	1.22	2.56	18.6	18.7	29.9	1.01	1.61
24	80	0.51	1.11	0.97	2.60	23.9	23.6	37.8	0.99	1.58
25	80	0.50	1.41	1.24	2.62	19.0	19.1	30.6	1.01	1.61
26	90	0.62	1.19	1.07	2.53	25.1	25.3	40.5	1.01	1.61
27	100	0.98	0.98	0.92	2.36	31.2	33.7	53.9	1.08	1.73
28	100	0.69	0.95	0.87	2.52	32.2	33.9	54.2	1.05	1.68
29	105	0.45	1.26	1.08	2.81	27.1	26.3	42.1	0.97	1.55
30	110	0.43	1.41	1.21	2.86	25.5	25.1	40.2	0.98	1.57
31	110	0.44	1.60	1.40	2.86	24.2	25.0	40.0	1.03	1.65
32	115	0.43	1.98	1.67	2.90	16.5	17.8	28.5	1.08	1.73
33	125	0.88	1.32	1.23	2.50	28.6	29.8	47.7	1.04	1.67
34	125	0.41	2.13	1.81	2.97	17.7	19.4	31.0	1.10	1.75
35	140	0.35	1.28	1.05	3.21	34.2	31.9	51.0	0.93	1.49
36	150	0.37	1.48	1.22	3.16	30.9	30.0	48.0	0.97	1.55
37	150	0.37	1.32	1.08	3.16	34.9	32.9	52.6	0.94	1.51
38	150	0.37	1.33	1.10	3.17	35.7	33.8	54.1	0.95	1.51
39	160	0.36	1.79	1.50	3.23	28.6	29.6	47.4	1.03	1.66
40	165	0.77	1.24	1.14	2.68	39.3	40.0	64.0	1.02	1.63
41	165	0.35	2.01	1.66	3.27	24.1	25.4	40.6	1.05	1.69
42	175	0.37	1.53	1.26	3.25	33.6	32.8	52.5	0.98	1.56
43	175	0.39	1.62	1.39	3.19	37.2	37.9	60.6	1.02	1.63
44	180	0.35	2.14	1.75	3.33	23.0	24.7	39.5	1.07	1.72
45	180	0.35	1.53	1.25	3.33	34.1	33.0	52.8	0.97	1.55
46	210	0.29	1.31	1.03	3.79	55.9	50.2	80.3	0.90	1.44
47	230	0.65	1.35	1.21	2.91	47.8	48.0	76.8	1.00	1.61
48	250	0.24	1.42	1.18	3.98	56.4	53.5	85.6	0.95	1.52
49	300	0.26	1.34	1.03	4.07	64.1	56.7	90.7	0.88	1.42
50	330	0.25	1.50	1.16	4.20	61.9	56.4	90.2	0.91	1.46

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V. OBSERVATIONS

The old Indian code IS 1893 (1984) considers 1-DOF modeling approach while the current Indian code IS 1893 (2014) considers 2-DOF modelling approach. From general perception, designers can assume that the base shear from new IS code will be lesser compare to old IS code, which is misleading due to the fact that the response reduction factor in new code has been reduced. To identify the effect of modelling approaches and response reduction factor on design seismic force, 50 existing circular water tank situated in seismic zone II (Maximum PGA 0.1 g) have been considered. By comparing design base shear from the two IS codes and Guideline viz. IS 1893 (1984), IS 1893 (2014) and IITK-GSDMA (2007), it has been observed that for most of the tanks considered, the new code and IITK-GSDMA (2007) Guidelines demands higher design base shear in comparison to the old code.

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