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Comparative Study of Dynamic Analysis of Rectangular Liquid Filled Containers Using Codal Provisions

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Abstract

Analysis of liquid containing tanks differs from other structures because during seismic excitation, liquid inside the tank exerts hydrodynamic force on the tank walls and base which makes the analysis a complex one. The objective of this research is to determine hydrodynamic pressure distribution on rectangular tanks of various geometries considering impulsive and convective components of liquid mass. The focus is also to develop design charts to analyse the effect of geometry of tank on design seismic forces and sloshing. To get a better picture, a comparative study of Draft IS 1893 Part 2, ACI 350.3 and Eurocode 8 for rectangular shaped tank has been performed. Further, the differences in the magnitude of shear and moment at base as obtained from static (IS 3370 IV) and dynamic (Draft IS 1892 Part 2) analysis of rectangular shaped tank have been evaluated which highlight the need for us to mature from the old code to a newer code, which is more accurate and reliable.

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Keywords: Liquid filled containers; Rectangular tanks; IS 1893 (Part 2); Seismic analysis; Sloshing

1. Introduction

Liquid storage tanks are one of the most critical lifeline structures which are extensively used in water distribution systems and in industries for storing toxic and flammable liquids. The dynamic interaction between fluid and structure

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is of significant concern for such structures as its response to transient and cyclic excitation are changed due to such interaction. Therefore, accurate modeling of these diverse systems with the inclusion of fluid-structure interaction becomes necessary for analysis of such structures.

During seismic excitation, the hydrodynamic pressure in a flexible tank can be significantly higher than in a rigid container due to the interaction effects between flexible structure and contained liquid. The hydrodynamic pressure induced by earthquake can usually be separated into impulsive and convective terms. The impulsive component is governed by the interaction between tank wall and liquid and is highly dependent on the flexibility of the wall while the convective component is induced by slosh waves. Sloshing is the dynamic load acting over a tank structure as a result of the fluid motion with free surface confined inside a tank. Its characteristics may vary considerably depending upon the tank configuration and seismic characteristics of the applied load, sometimes resulting in a highly localized pressure on the tank walls [1].

In this study, the design charts generated have been used to study the effect of geometry of tank on design seismic forces and sloshing. The focus is primarily to perform a comparative study of various codes on liquid containing tanks and highlight the need for us to mature from the old code to a newer code which is more accurate and reliable.

Nomenclature

m_i	impulsive mass of liquid
m_c	convective mass of liquid
T_i	impulsive mode time period
T_c	convective mode time period
K_c	stiffness of spring
h_i	height of impulsive mass of liquid when base pressure is not considered
h_c	height of convective mass of liquid when base pressure is not considered
h^*_i	height of impulsive mass of liquid when base pressure is considered
h_{*c}	height of convective mass of liquid when base pressure is considered

2. Dynamic Modeling

Evaluation of hydrodynamic forces exerted during a seismic activity requires a complex dynamic modeling of the tank liquid system which accounts for the hydrodynamic forces exerted by the fluid on tank wall. However, the availability of the mechanical models of tanks has considerably simplified the analysis. These mechanical models convert the tank-liquid system into an equivalent spring-mass system and design codes could be used to evaluate the seismic response of tanks. Eurocode 8 [2] mentions mechanical model of Housner [3] as an acceptable procedure for rigid rectangular tanks. The procedure given in NZSEE [4] guidelines is also described in Eurocode 8 for evaluating impulsive and convective mass of horizontal rectangular tank.

The rectangular tank-liquid system can be idealized as a spring-mass model, which considerably simplifies the evaluation of hydrodynamic forces. In this mechanical model, it is recognized that the vibrating fluid inside the container has two components, one that moves in unison with the tank, which is referred as the impulsive component and the other which undergoes sloshing motion, known as the convective component. The impulsive mass of the liquid, m_i is rigidly attached to tank wall at a height h_i (or h^*_i) and convective mass m_c is attached to the tank wall at a height h_c (or h^*_c) by a spring of stiffness K_c as shown in Fig.1. It may be noted that heights h_i and h_c are used when base pressure is not considered and if base pressure is included then corresponding heights are denoted by h^*_i and h^*_c respectively.

The impulsive and the convective components have periods associated with them that are generally far apart. The total approximate response of the system can be estimated by the square-root-of-the-sum-of-the-squares (SRSS) combination of the responses of the two components [5, 6, 7]. Except Eurocode 8, all the codes suggest SRSS rule to

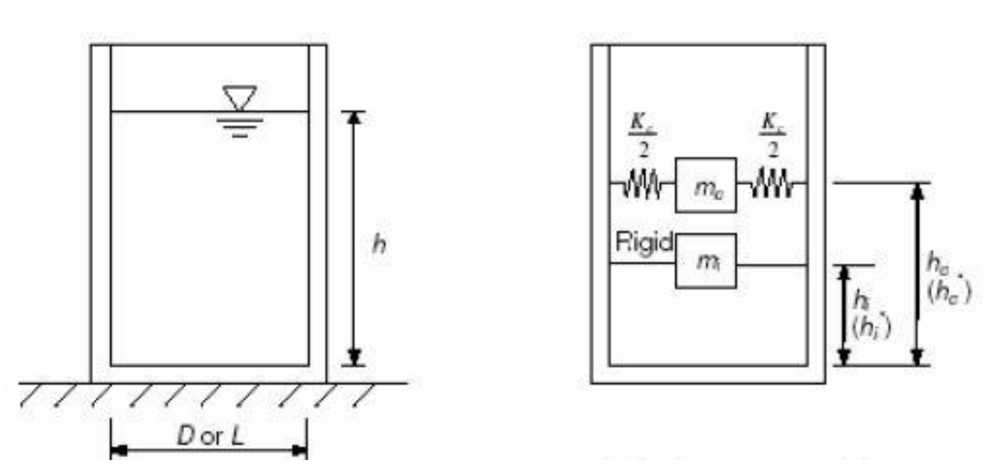

Fig. 1. (a) Elevation of ground supported rectangular tank; (b) Spring mass model for ground supported rectangular tank [8].

combine impulsive and convective forces. Eurocode 8 suggests the use of absolute summation rule. Malhotra, [9] through numerical analysis of large number of tanks, has proved that SRSS rule is better than absolute summation. For evaluating the impulsive force, the mass of tank wall and roof is also considered along with impulsive fluid mass. ACI 350.3 [10] and Eurocode 8 suggest a reduction factor to suitably reduce the mass of tank wall. Such a reduction factor was suggested by Veletsos [8] to compensate the conservativeness in the evaluation of impulsive force.

3. Parametric Study

The seismic response of a ground supported liquid filled tank as shown in Fig.2 is primarily influenced by its geometrical properties. According to various international codes such as Eurocode 8, the ratio of liquid height to the inner lateral dimension of the tank defines the parameters of the dynamic model of the liquid storage tank. Thus, a comparative analysis of the seismic response of tanks with various geometrical properties as mentioned in Table 1 has been conducted. Constants considered for calculation are listed in Table 2. Constant volume has been taken in the various iterations, since the main idea of the study is to investigate the influence of the geometry of tank on its dynamic responses. As far as possible, realistic data input has been taken with slight exceptions in the case of wall and base slab thickness. The seismic responses have been analyzed on Indian conditions only.

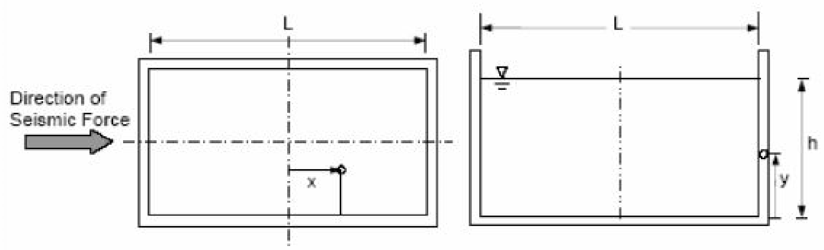

Fig. 2. (a) Plan of the rectangular tank; (b) Sectional elevation of the rectangular tank

Table 1. Geometrical parameters of various rectangular liquid tanks.

S. No.	Iteration	Volume (l)	Length (m)	Height (m)	Free board (m)
Case 1					
1	1	50000	4.65	3.3	0.3
2	2	50000	4.25	3.83	0.3
3	3	50000	3.75	4.83	0.3
4	4	50000	3.5	5.5	0.3
5	5	50000	3.25	6.4	0.3
Case 2					
6	1	100000	6.5	3.3	0.3
7	2	100000	6	3.83	0.3
8	3	100000	5.75	4.15	0.3
9	4	100000	5.5	4.5	0.3
10	5	100000	5	5.45	0.3
Case 3					
11	1	200000	8.5	3.82	0.4
12	2	200000	8	4.28	0.4
13	3	200000	7.5	4.9	0.4
14	4	200000	7	5.5	0.4
15	5	200000	6.5	6.4	0.4

Table 2. Constants considered for calculation as a part of parametric study.

S. No.	Quantity	Constant considered
1	Seismic Zone	III
2	Importance Factor	1.5
3	Response Reduction Factor	2
4	Base Condition	Fixed Base
5	Concrete	M 20
6	Wall Thickness	250 mm
7	Base Thickness	400 mm

4. Results and Discussions

The results of the parametric study were analyzed and a comparative study of the seismic response of tanks with various geometrical properties is presented in this section.

4.1. Comparative study of base shear and moment for IS 3370 (IV) and Draft IS 1893 Part 2 for rectangular shaped tank

With the parameters of the model remaining same, moment and shear at base were calculated based upon the relevant tables of IS 3370 IV -1967. The objective of this comparative study is to highlight the differences in the magnitude of shear and moment at base as obtained from static (IS 3370 IV) and dynamic (Draft IS 1893 Part 2) analysis of ground supported tanks. It has been observed that values obtained as per Draft IS 1893 Part 2 are considerably higher than those obtained by IS 3370 IV -1967 highlighting the need for us to mature from the old code to newer code which is more accurate and safe.

Table 3. Shear and Moment at Base with h/l as per IS 3370 Part IV and IS 1893 Part 2

S. No.	Volume (l)	h/l	Shear at Base (kN)		Moment at Base (kN-m)	
Case 1			IS 3370 Part IV	IS 1893 Part II	IS 3370 Part IV	IS 1893 Part II
1	50000	0.645162	76.00484	109.0225	21.85760214	155.2504389
2	50000	0.83058	72.41144	119.9676	24.80149402	206.8797597
3	50000	1.208	67.28381	135.7462	28.7398004	286.5293616
4	50000	1.48571	64.70688	143.7027	34.43812763	337.8093301
5	50000	1.876923	64.773	152.84	41.4032855	405.4658568
Case 2						
6	100000	0.461538	142.3522	160.1203	31.79928569	225.7096151
7	100000	0.58833	140.7361	180.9718	39.24147498	294.5011926
8	100000	0.669565	144.7502	192.2154	42.06922853	338.3418091
9	100000	0.763636	139.8514	203.2319	43.80287625	410.9307238
10	100000	1.03	137.6778	227.8376	54.94581417	544.4242783
Case 3						
11	200000	0.41411	285.945	265.4485	57.41804419	428.3241364
12	200000	0.4975	293.2761	294.2493	66.14526575	529.2129135
13	200000	0.61333	280.8792	329.5228	77.32715823	676.1166813
14	200000	0.74285	270.2525	358.7462	84.2183595	823.6086908
15	200000	0.93846	250.9954	394.8627	91.55012198	1107.328377

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4.2. Comparative study of Draft IS 1893 Part 2, ACI 350.3 and Eurocode 8 for rectangular shaped tank

The geometry details considered being same as per Table 1 and using constants listed in Table 2 parameters of the proposed model of the relevant codes were considered in analysis. Once the model parameters were obtained, they were used for analysis in Indian conditions.

Table 4. T_i and T_c with h/l as per IS 1893 Part II, ACI 350.3 and Eurocode 8

S. No.	Volume (l)	h/l	T_i			T_c		
Case 1			IS 3370 Part IV	IS 1893 Part II	Eurocode 8	IS 3370 Part IV	IS 1893 Part II	Eurocode 8
1	50000	0.645162	0.076475	0.088608	0.076324	2.47541	2.47541	2.48348
2	50000	0.83058	0.116939	0.12875	0.116619	2.339016	2.339016	2.34608
3	50000	1.208	0.176217	0.18208	0.175399	2.186672	2.186672	2.192974
4	50000	1.48571	0.216319	0.216448	0.215987	2.111682	2.111682	2.117732
5	50000	1.876923	0.268576	0.269294	0.267936	2.034712	2.034712	2.040533
Case 2								
6	100000	0.461538	0.078051	0.085414	0.077905	3.037617	3.037617	3.049077
7	100000	0.58833	0.10886	0.119934	0.107316	2.832558	2.832558	2.842137
8	100000	0.669565	0.129842	0.132801	0.123842	2.74601	2.74601	2.754841

9	100000	0.763636	0.175559	0.203671	0.171559	2.668218	2.668218	2.676448
10	100000	1.03	0.248183	0.258793	0.248183	2.527492	2.527492	2.534864
Case 3								
11	200000	0.41411	0.109941	0.126693	0.108441	3.540217	3.540217	3.55426
12	200000	0.4975	0.142391	0.167788	0.141611	3.332986	3.332986	3.345128
13	200000	0.61333	0.192138	0.229785	0.19003	3.155674	3.155674	3.166166
14	200000	0.74285	0.248176	0.294938	0.245214	3.013545	3.013545	3.022914
15	200000	0.93846	0.376776	0.438989	0.371245	2.885148	2.885148	2.893665

Table 5. Maximum sloshing height with h/l as per IS 1893 Part II, ACI 350.3 and Eurocode 8

S. No.	Volume (l)	h/l	Maximum Sloshing Height		
Case 1			IS 1893 Part II	ACI 350.3	Eurocode 8
1	50000	0.645162	0.26935	0.268246	0.224595
2	50000	0.83058	0.259567	0.259468	0.217297
3	50000	1.208	0.245545	0.244893	0.205119
4	50000	1.48571	0.239767	0.236683	0.198246
5	50000	1.876923	0.230072	0.228091	0.19105
Case 2					
6	100000	0.461538	0.307467	0.305568	0.255713
7	100000	0.58833	0.30644	0.302483	0.253229
8	100000	0.669565	0.309089	0.299016	0.250368
9	100000	0.763636	0.303541	0.294354	0.246497
10	100000	1.03	0.284493	0.282493	0.236604
Case 3					
11	200000	0.41411	0.34786	0.34286	0.286865
12	200000	0.4975	0.348756	0.342756	0.28687
13	200000	0.61333	0.341365	0.339389	0.284142
14	200000	0.74285	0.334713	0.331702	0.277766
15	200000	0.93846	0.327643	0.321717	0.269447

From Table 4 & 5, it is observed that Impulsive time period obtained from Eurocode 8 are higher than ACI 350.3 and Draft IS 1893 Part 2 with values obtained from ACI 350.3 being slightly lower than Draft IS 1893 Part 2. Also, Convective time period obtained is nearly constant for all the codes.

4.3. Comparative analysis of seismic response of tanks with various geometrical properties

The observations made from the comparative analysis of various tanks with different geometrical properties while evaluating their seismic responses are summarized as follows:

- With increase in h/l ratio, convective mass of liquid m_c decreases while impulsive mass of liquid m_i increases.
- Convective component of base shear is much less than impulsive component. Also, convective component's contribution decreases with increase in h/l whereas, the impulsive component increases both with h/l and also with volume.

- Impulsive component of base moment is observed to increase sharply with h/l, also its value is higher for larger volume of liquid stored. Convective component of base moment is much smaller when compared with impulsive component and its value increases at a very small rate.
- Impulsive component of overturning moment increases sharply with h/l ratio and its value is much higher compared to convective component which decreases with h/l with the effect more pronounced at higher volume of liquid.
- Maximum sloshing height decreases with h/l. The rate of decrease being large initially decreases gradually in case of lower volume of liquid whereas the rate of decrease is small initially and increases gradually in case of higher volume of liquid.
- Convective time period T_c decreases while impulsive time period T_i exhibits very little increment by increasing h/l ratio.

5. Concluding Remarks

In this study, analysis of liquid domain has been carried out along with structural interaction for various geometries of rectangular tanks considering seismic effects. An attempt has been made to determine hydrodynamic pressure distribution on the tank wall considering impulsive and convective components of liquid mass. Design charts have also been developed to help design engineers in quick dynamic analysis of liquid filled storage tanks. With the help of these design charts, the effect of geometry of tank on design seismic forces and sloshing has been studied. A comparative study of Draft IS 1893 Part 2, ACI 350.3 and Eurocode 8 for Rectangular Shaped Tank has been performed. Further, it has been observed that the values obtained as per Draft IS 1893 Part 2 are considerably higher than those obtained by IS 3370 IV -1967 highlighting the need for us to revise the old code to a newer code which is more accurate and reliable.

References

[1] O.R. Jaiswal, D.C. Rai, S.K. Jain, Review of code provisions on seismic analysis of liquid storage tanks: a review, Report No. IITKGSDMA-EQ-04-V1.0, Indian Institute of Technology, Kanpur (2004).

[2] Eurocode 8, Design provisions for earthquake resistance of structures, Part 1- General rules and Part 4 – Silos, tanks and pipelines, European Committee for Standardization, Brussels, 1998.

[3] Housner, The Dynamic Behaviour of Water Tanks, Bulletin of Seismological Society of America, 1963, Vol. 53, No. 2, pp. 381-387.

[4] NZS 3106, Code of practice for concrete structures for the storage of liquids, Association of New Zealand, Wellington, 1986.

[5] R.C. Barros, Seismic analysis and design of bottom supported anchored metallic tanks, Edicoes INEGI, ISBN: 978-972-8826-18-5, Porto, Portugal, 2008, pp. 1-160.

[6] IITK-GSDMA: Guidelines for Seismic Design of Liquid Storage Tanks, Provisions with Commentary on the Indian seismic code, Indian Standard IS 1893 (Part 1): 2002, Indian Institute of Technology Kanpur, Gujarat State Disaster Management Authority, 2005.

[7] R.C. Barros, On the Seismic Response of Anchored Tanks: Methodologies for Finite Element Analysis and Parametric Study for Design Codes, in Civil Engineering Computations: Tools and Techniques‖, Ed.: B.H.V. Topping, Chapter 17, 391-447, Saxe-Coburg Publications, Stirlingshire, UK, 2007.

[8] A.S. Veletsos, Seismic response and design of liquid storage tanks, Standards for the seismic design of oil and gas pipeline systems, Technical Council on Lifeline Earthquake Engineering, ASCE, NewYork, 1984, pp. 443-461.

[9] P.K. Malhotra, T. Wenk, M. Wieland, Simple procedure for seismic analysis of liquid storage tanks, Structural Engineering, IABSE, 2000, Vol. 10, No. 3, pp. 197-201.

[10] ACI 350.3, Seismic design of liquid containing concrete structures, An Americian Concrete Institute Standard, 2001.