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TIME PERIODS OF OVERHEAD WATER TANKS

by

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ABSTRACT

This paper deals with the analysis of time periods of overhead water tanks for use in the earthquake resistant design. An interactive software INTZE has been developed in FORTRAN 77 to carry out complete analysis and design of water tanks on an IBM PC/XT. The code does not give any expression for computing the lateral stiffness of the tank. Different authors use different empirical expressions assuming a tank to be equivalent cantilever beam. It is observed that these expressions do not give satisfactory results. In this paper, an equation is proposed to determine the lateral stiffness of the tanks based on the results of dynamic analysis and theory of curve fitting.

INTRODUCTION

Overhead water tanks form the most important component of water distribution system. An enormous amount is being invested on water supply schemes in the country by various government, semi-government and private agencies. A water tank is essential to maintain a balance water supply due to acute power shortage in the country. The capacity of tank and height of its staging depend upon the water and pressure requirements. A number of papers dealing with the design of container have appeared in the past (1,2,3,4). However, few papers have discussed the design of staging (5,6). The staging or supporting tower of the tank is required to be designed for gravity loads, and lateral loads due to wind and earthquake. This paper deals with the analysis of time periods of overhead water tanks for use in the earthquake analysis. However, it does not account for sloshing of water in the container.

An interactive software INTZE has been developed in FORTRAN 77 to carry out the complete analysis and design of water tank on an IBM compatible PC/XT. The lateral load analysis for earthquake is based on IS:1893-1984 (8) and wind is based on the draft code IS:875 (9). The different parameters considered in the present analysis are shown in Table 1.

ANALYSIS FOR TIME PERIOD

The earthquake force can be computed if the period of natural vibration of the tank is known. IS:1893-1984 (8) gives the following equation for computing the time period based on the behaviour of a single degree of freedom system :

$$T = 2\pi\sqrt{\Delta/g} \qquad (1)$$

$$= \quad 2\pi\sqrt{W_e/K\,g} \tag{2}$$

The code (7,8) does not give any expression for computing the lateral stiffness of the water tank. Different authors, have stated different expressions to compute lateral stiffness of water tanks assuming them to be equivalent cantilever beams. These expressions are as follows :

Dayaratnam (4) $$K = \frac{12\,E_1\,I_c\,n}{(N+1)\,L_c^3} \tag{3a}$$

Rao (6) use L in place of L_c in Eq. 3a (3b)

Prem Chand (3) $$K = \frac{12\,E_2\,I_c\,n}{2(N+1)\,L^3} \tag{4}$$

Jain & Chube (5) $$K = \frac{12\,E_2\,I_c\,n}{(N+1)\,L^3} \tag{5}$$

The confusion is further compounded by the modulus of elasticity of concrete. The new code IS:456-1978 (10) gives the modulus of elasticity as :

$$E_1 = 5700\sqrt{f_{ck}}\ \text{MPa} \tag{6a}$$

$$E_{ce} = E_1\,/\,(1+\theta) \tag{6b}$$

where, E_{ce} = effective modulus of elasticity; θ = creep coefficient.

The old IS:456-1964 (11) gives the modulus of elasticity as :

$$E_2 = \frac{3\,\sigma_{cbc}\,E_s'}{280}\ \text{MPa} \tag{7}$$

The value of E varies with the stress in concrete. In the present code the value E_1 is specified for zero stress level, that is, initial tangent modulus (12). The value of E_1 is almost twice the value E_2. However, E_{ce} is the long term modulus of elasticity & should be used in the analysis instead of E_1.

In the present study, a comparison is made among the stiffness and time period values obtained by using different expressions given by Eqs. 2 to 5. A static three dimensional space frame analysis is carried out to determine the stiffness of staging and, hence, time period. An eigen value analysis of the space frame is also carried out to determine the exact time period of the tank. These analyses were based on E_{ce} with θ = 1.1. The results are shown in Tables 2,3 and 4 for different heights of staging. It can be seen that none of the three equations give acceptable results. The periods obtained using the 3-D space frame static analyses are very close to those obtained using the eigen value analyses.

The reason for the inability of the empirical equations 3 to 5 to predict the lateral stiffness is their simplicity. Such equations should be a function of capacity of the tank as well as height of staging. Accordingly, the following equation is proposed based on the results of dynamic analyses and theory of curve fitting :

$$\text{Stiffness of water tank} = \frac{J_{ms}\ E_{ce}\ I_c\ n}{(N+1)\ L^3} \tag{8}$$

Note : 1. For 10 m Height of staging

$$J_{ms} = -5.11\ E-5(Q/L^3)^3 + 5.95\ E-3(Q/L^3)^2 - 2.66\ E-1(Q/L^3) + 6.82 \tag{9a}$$

2. For 20 m Height of staging

$$J_{ms} = -1.97E-4\ (Q/L^3)^3 + 6.97\ E-3\ (Q/L^3)^2 - 1.85\ E-1(Q/L^3) + 5.60 \tag{9b}$$

3. For 30 m Height of staging

$$J_{ms} = -3.10\ E-4(Q/L^3)^3 + 1.39\ E-2(Q/L^3)^2 - 1.45\ E-1(Q/L^3) + 4.10 \tag{9c}$$

Where Q is capacity of water tank

4. E_{ce} - Effective modulus of elasticity of concrete

The periods obtained using the above equations under full and empty tank conditions have been compared with those obtained using the space frame analysis and are shown in Fig. 1, it can be seen that the comparison is quite satisfactory.

GOVERNING CRITERIA

The analysis of tank staging was also carried out in accordance with the latest specifications on wind loads (9). Its purpose was to determine the governing loads for a given site. The wind loads in the proposed draft code are based on two criteria :

a) The statistical and probabilistic approach to the evaluation of wind loads.

b) Due recognition to the dynamic component of wind loading and its interaction with the dynamic characteristics of the structure.

These revisions are consistent with the philosophy of limit state design (12). The design wind speed V_d at a given site is expressed as a product of four parameters :

$$V_d = V_b\ K_1\ K_2\ K_3\ K_4 \tag{10}$$

The design wind pressure p_d is given by the relation :

$$p_d = 0.0047\ V_d^2 \tag{11}$$

The wind force on the structure can be computed as follows :

$$F = C_f\ A_e\ p_d \tag{12}$$

Using Eqs. 10 to 12, wind loads can be computed on the tank container, columns and braces. In the present case, the following values were used :

$$V_b = 170 \text{ kmph}, \quad K_1 = 1.0, \quad K_3 = 1.0, \quad K_4 = 1.0 \tag{13}$$

The terrain factor K_2 also depends up on the height of staging. Its value varied from 1.037 to 1.129 in the present study.

The forces in critical columns and braces due to wind and earthquake loads are shown in Table 5. It is assumed that the water tanks are located in Roorkee. The earthquake forces were computed using the following values :

Earthquake zone = 4, Zone factor = 0.25,
Soil foundation factor = 1.0, Importance factor = 1.5 (14)

It can be seen that for 10 m staging, the design is governed by earthquake; for 20 m staging, the design is governed by wind for 200 kL and 500 kL water tanks, and by earthquake in rest of the cases. For 30 m staging, the design is governed by wind. A detailed analyses of more results is published elsewhere (13).

CONCLUSIONS

The results presented in this paper indicate that none of the empirical expressions in use give accurate time periods. The values obtained are very much conservative and results in higher earthquake forces. The latest code IS:11682-1985 on the design of staging is also silent in this regard. The empirical equation based on the wide spectrum of results of 3D static and dynamic analyses presented in this paper will help the designers to arrive at a reasonable estimate of the time period for a given capacity and staging height of the water tank.

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NOTATION

A_e	effective projected area
C_f	force coefficient for the structure
E_1	modulus of elasticity of concrete as per IS:456-1978
E_2	modulus of elasticity of concrete as per IS:456-1964
E_s	modulus of elasticity of steel in MPa
f_{ck}	characteristic strength of concrete at 28 days in MPa
g	acceleration due to gravity
I_c	moment of inertia of a column
K	lateral stiffness of the water tank
K_1	risk factor
K_2	terrain and height factor
K_3	local topography factor
K_4	gust factor
L	effective panel height
L_c	clear panel height
N	number of braces
n	number of columns in the staging

P_d	design wind pressure in kg/m^2
Q	capacity of water tank in m^3
T_1	period of the tank when empty
T_2	period of the tank when full of water
V_b	basic wind speed in kmph
V_d	design wind speed in kmph
W_e	effective weight of tank for earthquake loads
σ_{cbc}	permissible stress in concrete in bending compression in MPa
Δ	lateral displacement at the centre of gravity of container

TABLE 1
PARAMETERS

Particulars	Capacity of tank in m^3					
	200	500	1000	1500	2000	2500
Dia of staging (m)	4.75	7.30	9.00	10.30	11.30	12.00
Number of columns	6	8	10	12	16	18
Dia of columns (cm)	40/45*	45/50*	50/55*	50	50	50
No of braces for 10m height of staging	2	2	2	2	2	2
No of braces for 20m height of staging	4	4	4	4	4	4
No of braces for 30m height of staging	6	6	6	6	6	6

Note : *Dia used for 30m staging height

TABLE 2

COMPARISON OF STIFFNESS AND TIME PERIODS OF WATER TANKS FOR 10 m HEIGHT OF STAGING

Capacity (K.L)		200	500	1000	1500	2000	2500
K (kN/cm)	Eq. 3(a)	240	536	1150	1594	2162	2708
	Eq. 3(b)	153	336	650	827	1119	1259
	Eq. 4	37	92	158	243	329	370
	Eq. 5	79	174	336	370	500	563
	Static	37	60	84	90	93	89
T_1 (Sec) Empty Tank	Eq. 3(a)	0.367	0.368	0.363	0.376	0.382	0.385
	Eq. 3(b)	0.461	0.464	0.483	0.428	0.531	0.565
	Eq. 4	0.937	0.942	0.980	0.962	0.978	1.041
	Eq. 5	0.642	0.646	0.672	0.780	0.793	0.845
	Static	0.936	1.090	1.350	1.570	1.837	2.115
	Dynamic	0.921	0.991	1.210	1.411	1.652	2.002
T_2 (Sec) Full Tank	Eq. 3(a)	0.687	0.720	0.700	0.729	0.727	0.730
	Eq. 3(b)	0.865	0.909	0.931	0.826	1.011	1.070
	Eq. 4	1.755	1.845	1.891	1.864	1.864	1.973
	Eq. 5	1.203	1.265	1.296	1.512	1.512	1.601
	Static	1.754	2.143	2.605	3.049	3.502	4.015
	Dynamic	1.714	2.115	2.551	3.010	3.415	3.853

TABLE 3

COMPARISON OF STIFFNESS AND TIME PERIODS OF WATER TANKS FOR 20 m HEIGHT OF STAGING

Capacity (K.L)		200	500	1000	1500	2000	2500
K (kN/cm)	Eq. 3(a)	95	184	396	553	744	915
	Eq. 3(b)	58	125	239	317	426	480
	Eq. 4	14	30	59	93	126	141
	Eq. 5	30	64	124	142	191	215
	Static	13	24	40	52	60	61
T_1 (Sec) Empty Tank	Eq. 3(a)	0.665	0.659	0.650	0.660	0.669	0.683
	Eq. 3(b)	0.808	0.802	0.826	0.871	0.885	0.944
	Eq. 4	1.641	1.628	1.676	1.606	1.631	1.740
	Eq. 5	1.125	1.116	1.149	1.303	1.323	1.411
	Static	1.735	1.851	2.010	2.134	2.356	2.626
	Dynamic	1.689	1.841	1.921	2.065	2.260	2.591
T_2 (Sec) Full Tank	Eq. 3(a)	1.185	1.245	1.222	1.248	1.251	1.266
	Eq. 3(b)	1.440	1.513	1.551	1.648	1.653	1.749
	Eq. 4	2.922	3.072	3.149	3.038	3.047	3.224
	Eq. 5	2.003	2.106	2.159	2.464	2.471	2.615
	Static	3.091	3.496	3.774	4.038	4.400	4.868
	Dynamic	2.062	3.511	3.784	4.052	4.321	4.818

TABLE 4

COMPARISON OF STIFFNESS AND TIME PERIODS OF WATER TANKS FOR 30 m HEIGHT OF STAGING

Capacity (K.L)		200	500	1000	1500	2000	2500
K (kN/cm)	Eq. 3(a)	79	163	324	321	431	527
	Eq. 3(b)	55	113	208	191	256	288
	Eq. 4	13	27	50	56	75	85
	Eq. 5	28	58	107	85	114	129
	Static	9	18	30	36	43	47
T_1 (Sec) Empty Tank	Eq. 3(a)	0.755	0.750	0.744	0.894	0.905	0.926
	Eq. 3(b)	0.906	0.900	0.929	1.160	1.175	1.253
	Eq. 4	1.839	1.827	1.887	2.139	2.167	2.310
	Eq. 5	1.261	1.253	1.293	1.735	1.757	1.873
	Static	2.284	2.288	2.429	2.667	2.851	3.088
	Dynamic	2.154	2.144	2.305	2.601	2.866	3.020
T_2 (Sec) Full Tank	Eq. 3(a)	1.266	1.351	1.352	1.653	1.658	1.685
	Eq. 3(b)	1.519	1.622	1.689	2.146	2.153	2.280
	Eq. 4	3.084	3.293	3.429	3.956	3.970	4.204
	Eq. 5	2.114	2.257	2.351	3.209	2.219	3.410
	Static	3.829	4.120	4.413	4.935	5.224	5.620
	Dynamic	3.845	4.150	4.300	4.752	5.200	5.525

TABLE 5

COMPARISON OF DESIGN MOMENTS IN COLUMNS AND BRACES UNDER FULL TANK CONDITION WITH RESPECT TO HEIGHT OF STAGING

Sl. No.	Ht. of staging m	Design moments in	Capacity of Tank in m^3					
			200	500	1000	1500	2000	2500
1.	10	Column in a panel (kN-cm)	2483	3953	4751	5630	7522	5258
			3477*	7375*	9375*	11150	10800*	11030*
		Brace at a level (kN-cm)	3686	4226	5415	6625	5920	7271
			5279*	7954*	11280*	13420*	12260*	13930*
2.	20	Column in a panel (kN-cm)	4535*	6780*	8080	9166	8688	8570
			2934	5601	8457*	9204*	9576*	10740*
		Brace at a level (kN-cm)	6953*	7665*	9211	10960	9750	12430
			4691	6571	10150*	11220*	11090*	14690*
3.	30	Column in a panel (kN-cm)	7166*	10180*	12160*	12690*	12060*	11790*
			2776	4743	7723	9477	9845	10830
		Brace at a level (kN-cm)	10040*	10720*	13590*	15180*	16610*	17280*
			4272	5358	9099	11600	14420	15300

Note : 1. Top row values obtained by wind analysis in each item

2. Bottom row values obtained by earthquake analysis in each item

3. * Represents design governs

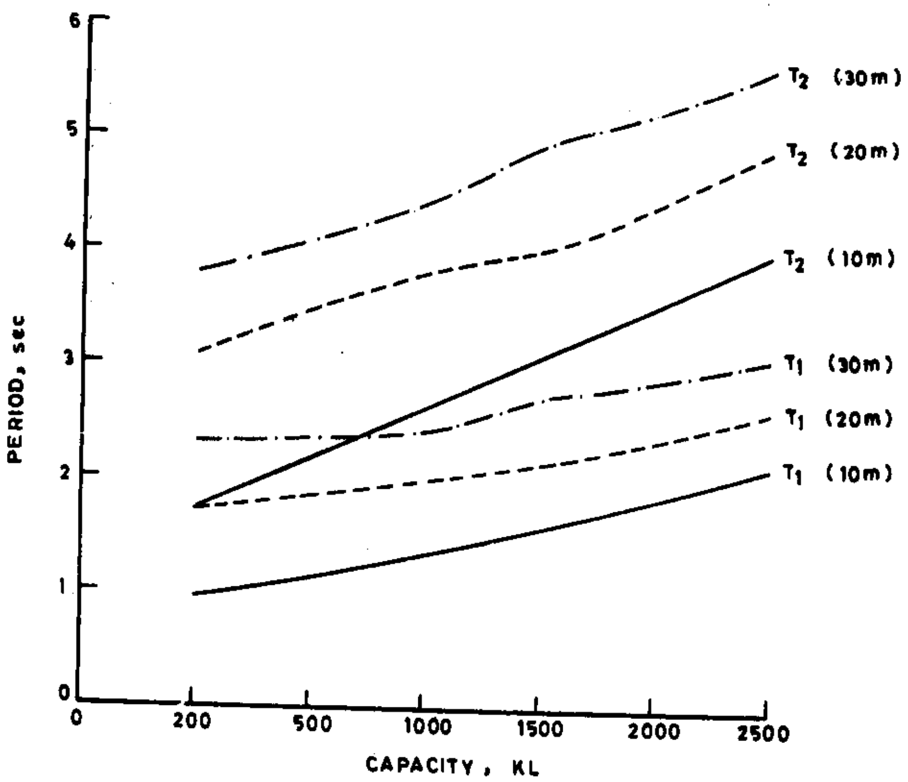

FIG.1. TIME PERIODS OF WATER TANKS USING THE PROPOSED EQUATION