Journal of Structural Engineering
Vol 20 No. 3 October 1993 pp.119–128

Proposed provisions for aseismic design of liquid storage tanks: Part I - Codal provisions

Sudhir K. Jain* and M.S. Medhekar**

The provisions of IS: 1893-1984 on the aseismic design of liquid storage tanks need revision. This paper in two parts, brings out clearly the necessity for the revision. The significant modifications and revisions proposed are (i) the scope of provisions may be extended to include ground supported tanks with rigid and flexible walls, (ii) the tank is to be idealized by a two-mass or three-mass model instead of the present one-mass model, (iii) the bracing girder flexibility is to be included in calculation of lateral stiffness of elevated tank staging, (iv) use of performance factor (*K*) of 3.0 is suggested for all types of tank, (v) convective hydrodynamic pressure effects are included in analysis, and (vi) a simplified equivalent hydrodynamic pressure distribution may be suggested for design. Part I of the paper brings out the necessity of the proposed modifications and revisions. Part II contains a commentary and worked out examples.

Liquid storage tanks are used extensively by municipalities and industries for storing water, inflammable liquids and other chemicals. They must remain functional even after an earthquake. Elevated tanks, which typically consist of a large mass supported on the top of a slender staging, are particularly susceptible to earthquake damage. Thus, design of such structures against earthquake effects is of considerable importance.

In India, the criteria (recommendations) for aseismic design of elevated tower supported tanks are given in IS: 1893-1984[1]. However, no provisions are available for seismic design of ground supported liquid storage tanks. The criteria for the design of R.C. staging of elevated tanks are given in IS: 11682-1985[2]. Provisions for ductile design and detailing of R.C. building frames are given in IS: 4326-1976[3]. As per IS: 11682-1985, the provisions of IS: 4326 are also to be used for detailing of R.C. tank stagings when the design horizontal seismic coefficient, α_h exceeds 0.05.

In recent years, considerable research has been carried out on aseismic design of ground supported and elevated liquid storage tanks. Therefore, the provisions of IS: 1893-1984 need to be revised to take advantage of the latest advances in research and design practice. The major points that need revision are summarized below:

(i) As per IS: 1893-1984, an elevated tank may be modelled by a single degree of freedom system. However, research indicates that the single degree of freedom idealization is appropriate only for closed tanks which are completely filled with liquid.

(ii) IS: 1893-1984 does not explicitly state that flexural stiffness of bracing girders should be considered while calculating lateral stiffness of tank staging. In the design example in SP: 22 (S & T)[4] and also in many text books, bracing girders are assumed to be infinitely rigid. This leads to a substantial overestima-

* Associate Professor, ** Senior Project Associate, Department of Civil Engineering, Indian Institute of Technology, Kanpur, U.P. 208 016.

tion of the staging stiffness and hence a low natural period[5,6].

(iii) IS: 1893-1984 does not specify any performance factor (K) for elevated tanks; this amounts to assuming K as 1.0. This value of K is the same as that for buildings with ductile moment resisting frames. However, this ignores the fact that the elevated tanks have less energy absorbing capacity and ductility as compared to buildings with ductile moment resisting frames.

(iv) IS: 1893-1984 states explicitly that convective hydrodynamic pressure may be neglected in analysis. On the contrary, IS: 11682-1985 states that such pressure should be considered. Recent studies indicate that convective pressure may form a significant part of the total hydrodynamic pressure, depending on the tank geometry and proportions[6]. Hence, its effects should be considered.

(v) Hydrodynamic pressure varies along the tank perimeter. This makes rigorous stress analysis of the tank shell a tedious process. Moreover, the algebraic expressions for hydrodynamic impulsive pressure given in IS: 1893-1984 are rather complicated and it is difficult to get a physical picture of the pressure distribution in the tank wall and base. Hence, many engineers design the staging for seismic effects only and neglect the effect of hydrodynamic pressure on the tank walls. This could cause problems related to serviceability of the tank, for instance due to formation of cracks. Hence, the hydrodynamic pressure distribution should be given in a simpler form so that its effects can be considered conveniently in design.

In this paper, modifications to the existing design provisions for liquid storage tanks are proposed for the future revision of IS: 1893. Provisions are given for aseismic design of ground supported tanks with rigid and flexible walls and also for elevated tanks, supported on a staging. These provisions are based on research results and design practices followed in other countries. A commentary explaining the rationale of these provisions is also given. Two worked out examples are included to illustrate application of the proposed provisions. A comparison is also made between the results obtained by applying the proposed modifications and the existing provisions to the same design problem, in order to get an idea of the implications of the proposed modifications.

SUGGESTED MODIFICATIONS

The provisions of this section apply to tanks resting on the ground and elevated tanks that are supported on a staging.

Wall flexibility of ground supported steel tanks shall be considered in analysis. The wall of concrete tanks may be considered as rigid. In elevated tanks, the tank shell may be considered as rigid.

Spring-Mass Model for Seismic Analysis

When a tank containing liquid vibrates, the liquid exerts impulsive and convective hydrodynamic pressure on the tank walls and on the tank base, in addition to the hydrostatic pressure. In order to include the effect of hydrodynamic pressure in the analysis, the tank shall be idealized by an equivalent spring mass model which includes the interaction effects of tank wall and liquid. The parameters of this model depend on geometry and flexibility of the tank wall.

Ground Supported Tank with Rigid Walls

Circular and rectangular tanks shall be idealized by a two-mass model as per Fig. 1. The impulsive mass m_0 is rigidly attached to the tank wall at height h_0 (h'_0). The convective mass m_1 is attached to the tank wall at height h_1 (h'_1) by a spring of stiffness K_1. The parameters m_0, m_1, h_0, h'_0, h_1, h'_1 and K_1 depend on tank geometry and shall be obtained from Fig. 2. h_0 and h_1 account for hydrodynamic pressure on the tank wall only. h'_0 and h'_1 account for hydrodynamic pressure on the tank wall and the tank base. Hence, the value of h_0 and h_1 shall be used to calculate moment due to hydrodynamic pressure at the base of the tank wall. The value of h'_0 and h'_1 shall be used to calculate overturning moment on the tank due to hydrodynamic pressure.

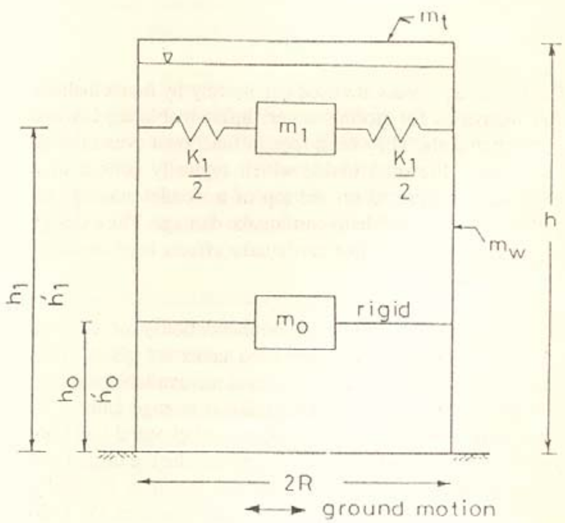


FIG.1 SPRING-MASS MODEL FOR GROUND SUPPORTED TANK WITH RIGID WALLS

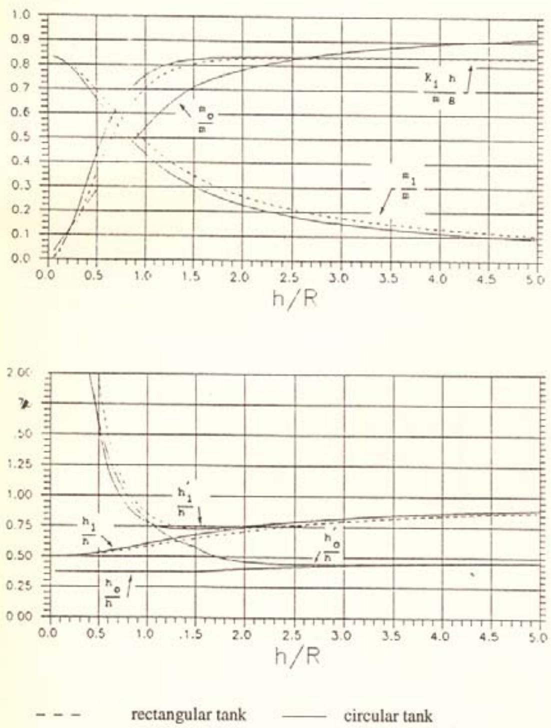
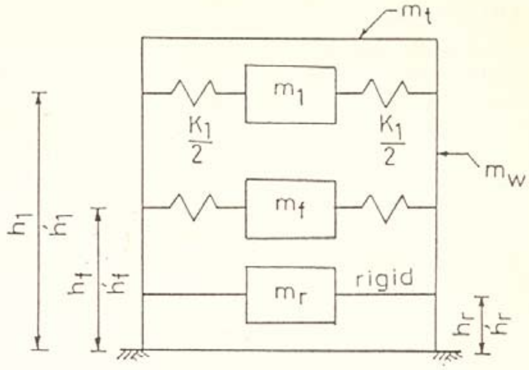
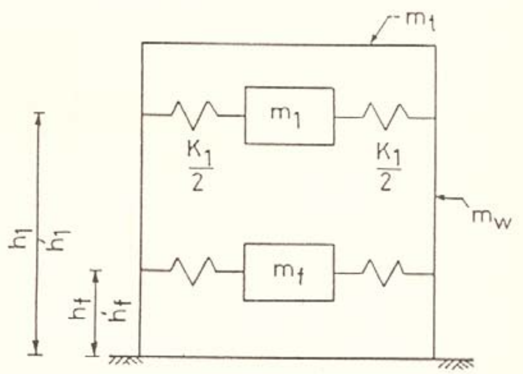


FIG.2 PARAMETERS OF THE SPRING-MASS MODEL FOR A TANK WITH RIGID WALLS



(a) Three-mass model for circular tank with flexible walls



(b) Two-mass model for rectangular tank with flexible walls

FIG.3 SPRING-MASS MODEL FOR GROUND SUPPORTED TANK WITH FLEXIBLE WALLS

Ground Supported Tank with Flexible Walls

Circular Tank: A three-mass model shall be used as per Fig. 3 (a). The mass m_1 at height h_1 (h'_1) represents the convective mass. The masses m_r and m_f correspond to two separate impulsive modes of vibration. The mass m_r is rigidly attached to the tank wall at height h_r (h'_r). The mass m_f is attached to the tank wall at height h_f (h'_f) by a spring which represents the flexibility of the tank wall. The mass m_r is given by:

$$m_r = m_o - m_f \tag{1}$$

Values of m_o, m_1, h_o, h'_o, h_1, h'_1 and K_1 shall be obtained from Fig. 2, assuming the tank walls as rigid. m_f, h_f and h'_f shall be obtained from Fig. 4.

Rectangular Tank: A two-mass model shall be used as per Fig. 3 (b). The mass m_f shall be taken equal to m_o, where m_o is the rigid tank impulsive mass. m_o, m_1, h_1, h'_1 and K_1 shall be obtained from Fig. 2, assuming the tank walls as rigid. h_f and h'_f shall be obtained from Fig. 4 with dimension L being used instead of R, where $2L$ is the length of tank in the direction of seismic exitation under consideration.

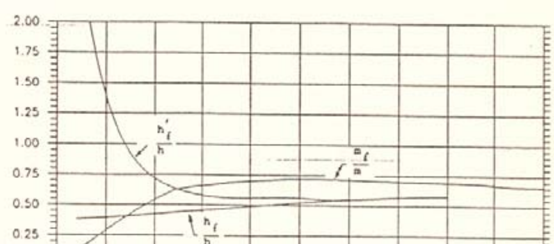


FIG.4 PARAMETERS OF THE SPRING-MASS MODEL FOR A CIRCULAR TANK WITH FLEXIBLE WALL

Elevated Tank

An elevated tank (Fig. 5) shall be idealized by a two-mass model as shown in Fig. 5(c). The tank shell is assumed rigid; hence m_o, m_1, h_o, h'_o, h_1, h'_1 and K_1 shall be obtained from Fig. 2. m_s is the structural mass and shall comprise of mass of tank shell and one-third that of staging.

Rectangular tanks shall be analyzed for horizontal earthquake force acting non-concurrently along each of the main axes of the tank.

For elevated tanks of usual proportions, the two degrees of freedom system of Fig. 5(c) can be treated as two uncoupled single degree of freedom systems (Fig. 5(d)), one representing the impulsive plus structural mass behaving as an inverted pendulum with lateral stiffness equal to that of the staging, and the other representing the convective mass that is assumed to be connected to the ground by a spring of appropriate stiffness.

Damping in the convective mode may be taken as 0.5 per cent of the critical value for all types of tank. Damping in the impulsive mode may be taken as 2 per cent of the critical value for steel tanks, and 5 per cent of the critical value for concrete and masonry tanks.

TIME PERIOD

Impulsive mode

Ground Supported Tank with Rigid Walls: The period of the impulsive mode of vibration, T_o, of a tank on a rigid foundation may be taken to be equal to zero.

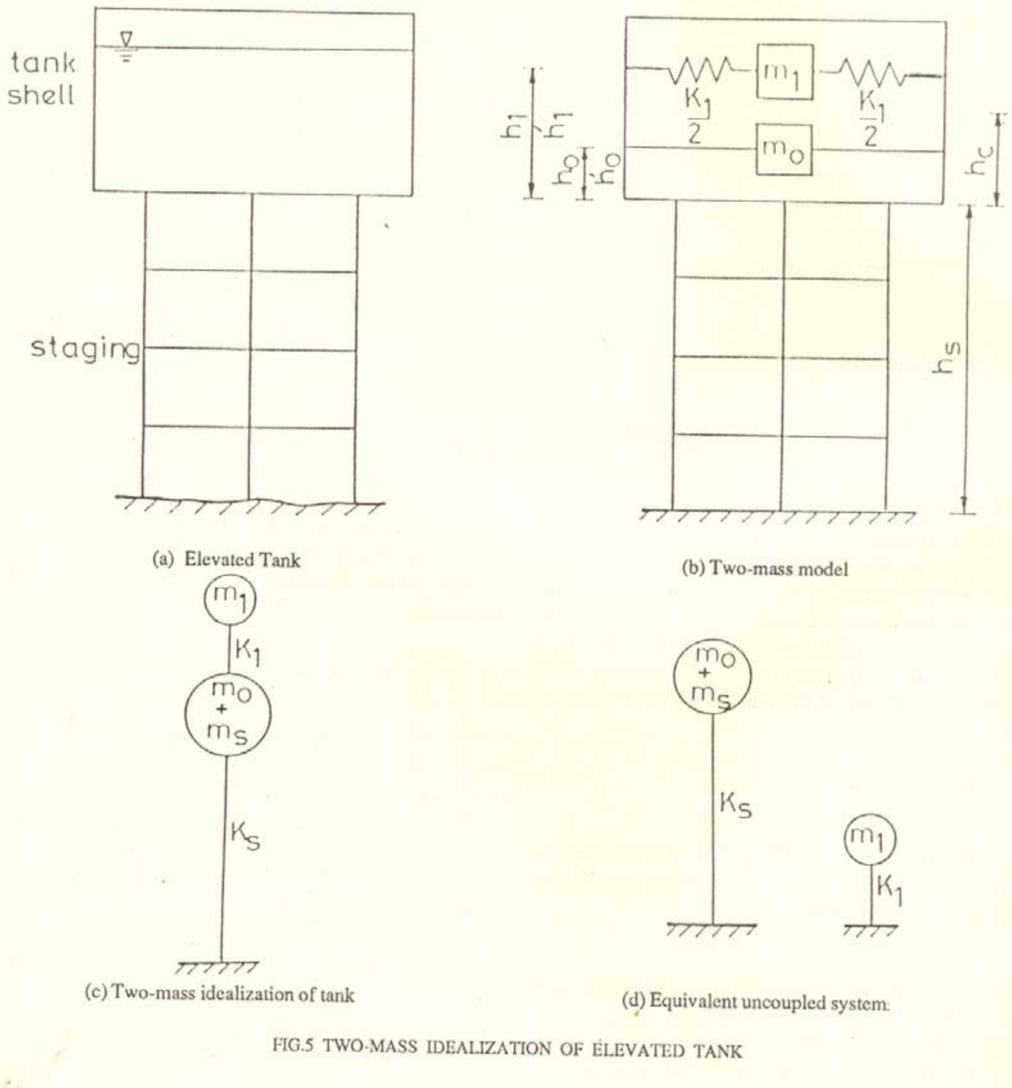


FIG.5 TWO-MASS IDEALIZATION OF ELEVATED TANK

Ground Supported Tank with Flexible Walls

Circular Tank: There are two impulsive mode periods denoted by T_0 and T_f.

For a tank on a rigid foundation, the period T_0 may be taken to be equal to zero.

The period T_f is given by:

$$T_f = \frac{5.61 \; \pi \; h}{K_h} \sqrt{\frac{w}{E_t \; g}} \qquad (2)$$

where K_h = period coefficient to be obtained from Fig. 6.

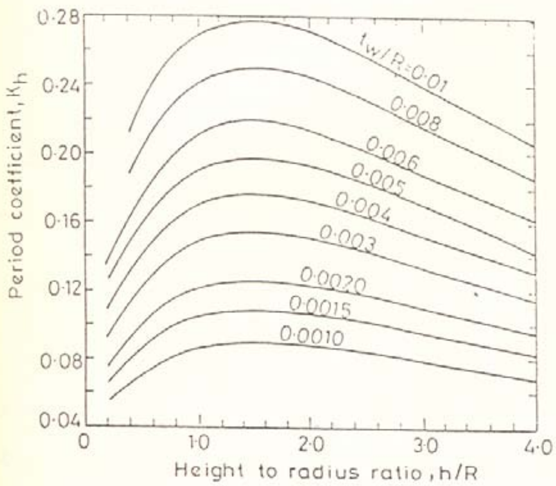


FIG.6 PERIOD CO-EFFICIENT K_h FOR CIRCULAR TANK WITH FLEXIBLE WALL

Rectangular Tank: The period of the impulsive mode is given by:

$$T_f = 2 \; \pi \sqrt{\frac{d}{g}} \qquad (3)$$

The uniformly distributed load (q) in the direction of ground motion is given by:

$$q = (m_f + m_w) \; g \, / \, (4 \; B \; h) \qquad (4)$$

For elevated tanks, the period of the impulsive mode, T_0, is given by:

$$T_0 = 2 \; \pi \sqrt{\frac{m_o + m_s}{K_s}} \qquad (5)$$

Lateral stiffness of the staging, K_s, is the horizontal force required to be applied at the center of gravity of the tank to cause a corresponding unit horizontal displacement.

Convective Mode

The time period of the convective mode, T_1, for all types of tanks is given by:

$$T_1 = 2 \; \pi \sqrt{\frac{m_1}{K_1}} \qquad (6)$$

The flexibility of bracing girders shall be considered in calculating the lateral stiffness, K_s, of elevated moment-resisting frame type tank staging.

For elevated tanks, the design shall be worked out both when the tank is empty and full. Using the time period and appropriate damping, the spectral acceleration shall be read from the design spectra given in Fig. 2 of IS: 1893-1984[1].

The design horizontal seismic coefficient, α_h, shall be calculated as

$$\alpha_h = K \; \beta \; I \; F_o \; S_a / g \qquad (7)$$

where β, I, F_o and S_a / g are as per clause 3.4.2.3 (b) of IS: 1893-1984[1]. The value of K may be taken as 3.0 for all types of tank.

Base Shear Calculation

(a) The base shear components for a ground supported tank with rigid walls are given by:

$$V_r = \alpha_{h_r} \; (m_o + m_w + m_t) \; g$$
$$V_1 = \alpha_{h_1} \; m_1 \; g \qquad (8)$$

(b) The base shear components for a ground supported tank with flexible walls are as follows:

(i) Circular Tank

$$V_r = \alpha_{h_r} \; m_r \; g$$
$$V_f = \alpha_{h_f} \; (m_f + m_w + m_t) \; g \qquad (9)$$
$$V_1 = \alpha_{h_1} \; m_1 \; g$$

(ii) Rectangular Tank

$$V_f = \alpha_{h_f} \; (m_f + m_w + m_t) \; g$$
$$V_1 = \alpha_{h_1} \; m_1 \; g \qquad (10)$$

(c) The base shear components for an elevated tank are given by

$$V_r = \alpha_{h_r} \ (m_o + m_s)\, g$$
$$V_1 = \alpha_{h_1} \ m_1 \ g \qquad (11)$$

The design base shear, V, shall be the square root of sum of squares (SRSS) combination of the impulsive and convective components and is given by

$$V = \sqrt{(V_r + V_f)^2 + V_1^{\,2}} \qquad (12)$$

Base Moment Calculation

The components of overturning moment at a section just above the base of the tank wall may be calculated as follows:

(a) Ground Supported Tank with Rigid Walls

$$M_r = \alpha_{h_r} \cdot (m_o \, h_o + m_w \, h_w + m_t \, h_t)\, g$$
$$M_1 = \alpha_{h_1} \ m_1 \, h_1 \, g \qquad (13)$$

(b) Ground Supported Tank with Flexible Walls

(i) Circular Tank

$$M_r = \alpha_{h_r} \, (m_o \, h_o - m_f \, h_f) \ g$$
$$M_f = \alpha_{h_f} \, (m_f \, h_f + m_w \, h_w + m_t \, h_t)\, g$$
$$M_1 = \alpha_{h_1} \ m_1 \, h_1 \, g \qquad (14)$$

(ii) Rectangular tank

$$M_f = \alpha_{h_f} \ (m_f \, h_f + m_w \, h_w + m_t \, h_t) \ g$$
$$M_I = \alpha_{h_I} \ m_1 \, h_1 \ g \qquad (15)$$

(c) Elevated Tank: The components of overturning moment at a section just above the base of the tank may be calculated as per Eq. (13).

The moment to be used for stress analysis of the tank wall shall be the SRSS combination of the impulsive and convective components and is given by

$$M = \sqrt{(M_r + M_f)^2 + M_1^{\,2}} \qquad (16)$$

The overturning moment to be used for checking the tank stability, design of the tank foundation and for the purpose of anchoring the tank shall be obtained using the above equations, except that h'_o, h'_f and h'_1 shall be used in place of h_o, h_f and h_1 respectively. For elevated tanks, the components of the overturning moment at the base of the staging are given by:

$$M_r = \alpha_{h_r} \ [\, m_o \, (h'_o + h_s) + m_s \, (h_c + h_s)\,]\, g$$
$$M_1 = \alpha_{h_1} \ m_1 \, (h'_1 + h_s) \ g \qquad (17)$$

Hydrodynamic pressure on tank wall

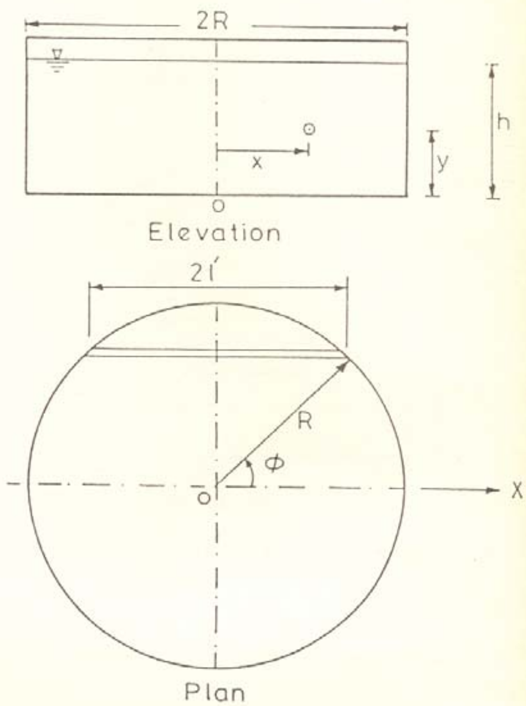
The impulsive hydrodynamic pressure exerted by the liquid on the tank wall and base may be calculated as follows:

(a) Circular tank with rigid wall (Fig. 7(a)): The pressure on the wall, p_w, is given by

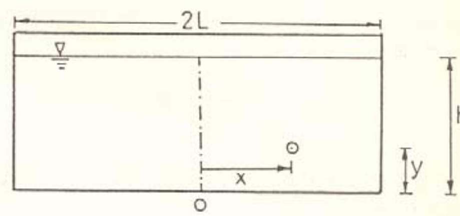
$$p_w = Q_{iw}(y)\, \alpha_{h_r} \ w \ h \ \cos\phi \qquad (18)$$

where

$$Q_{iw}(y) = 0.866 \left[1 - \left(\frac{y}{h} \right)^2 \right] \tanh \left(1.732 \, \frac{R}{h} \right) \qquad (19)$$



(a) Vertical circular tank



(b) Rectangular tank

FIG.7 CIRCULAR AND RECTANGULAR TANKS

The value of $Q_{iw}(y)$ may be read from Fig. 8(a).

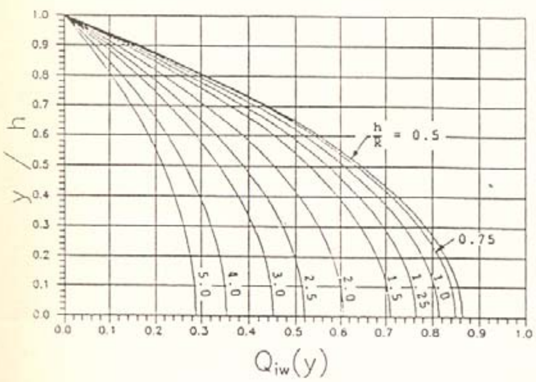
The pressure on the tank bottom (y = 0) is given by:

$$p_b + 0.866\ \alpha_{h_r}\ w\,h\ \frac{\sinh\left(1.732\ \dfrac{x}{h}\right)}{\cosh\left(1.732\ \dfrac{L}{h}\right)} \qquad (20)$$

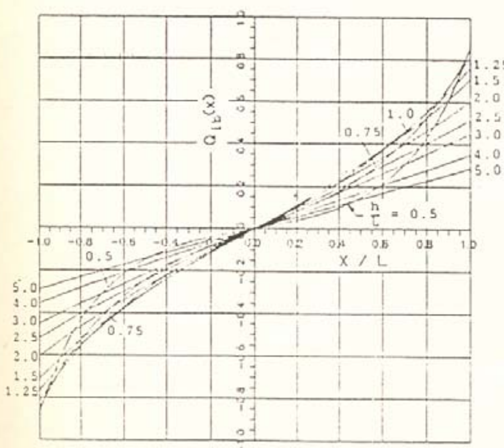
(b) Rectangular tank with rigid wall (Fig. 7(b)): The pressure on the wall, p_w, is given by:

$$p_w = Q_{iw}(y)\ \alpha_{h_r}\ \ w\ h \qquad (21)$$

where $Q_{iw}(y)$ is the same as that for a circular tank and may be read from Fig. 8(a), with *h/L* being used in place of *h/R*.



(a) On the wall – circular and rectangular tanks



(b) On the base – rectangular tank

FIG. 8 DISTRIBUTION OF NON-DIMENSIONAL IMPULSIVE PRESSURE

The pressure on the tank bottom (y = 0) is given by:

$$p_b = Q_{ib}(x)\ \alpha_{h_r}\ w\ h \qquad (22)$$

Where,

$$Q_{ib}(x) = \frac{\sinh\left(1.732\ \dfrac{x}{h}\right)}{\cosh\left(1.732\ \dfrac{L}{h}\right)} \qquad (23)$$

The value of $Q_{ib}(x)$ may be read from Fig. 8(b).

(c) For tanks with flexible walls, α_{h_f} shall be used instead of α_{h_r} in the above equations.

The convective pressure exerted by the oscillating liquid on the wall and base of tanks with rigid as well as flexible walls shall be calculated as follows:

(a) Circular tank (Fig. 7(a)): The pressure on the wall, p_w, is given by

$$p_w = Q_{cw}(y)\ \alpha_{h_1}\ w\ R\left[1 - \frac{1}{3}\cos^2\phi\right]\cos\phi\ \sin(\omega t) \qquad (24)$$

where,

$$Q_{cw}(y) = 0.844\ \frac{\cosh\left(1.837\ \dfrac{y}{R}\right)}{\cosh\left(1.837\ \dfrac{h}{R}\right)} \qquad (25)$$

The value of $Q_{cw}(y)$ may be read from Fig. 9(a).

The pressure on the base (y = 0) is given by :

$$p_b = Q_{cb}(x)\,\alpha_{h_1}\ w\ R\ \sin(\omega t) \qquad (26)$$

where,

$$Q_{cb}(x) = 0.844\left[\frac{x}{R} - \frac{1}{3}\left(\frac{x}{R}\right)^3\right] sech\left(1.837\ \frac{h}{R}\right) \qquad (27)$$

The value of $Q_{cb}(x)$ may be read from Fig. 9(b).

The maximum slashing height of the free liquid surface is given by $\theta_h R$ where

$$\theta_h = 1.378\ \frac{\overline{A}}{R}\ \tanh\left(1.837\frac{h}{R}\right) \qquad (28)$$

$\overline{A}$ is the maximum displacement of the convective mass due to ground excitation and is given by:

$$\overline{A} = \frac{\alpha_{h_1} \, g}{\omega^2} \tag{29}$$

where,

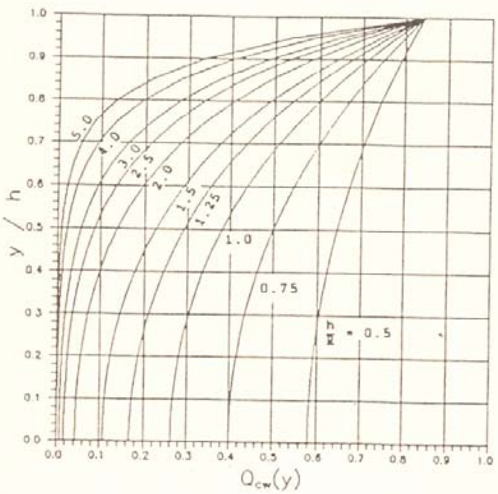
$\omega = 2 \; \pi / T_1$, and T_1 is as per Eq. (6)

(b) Rectangular tank (Fig. 7(b)): The pressure on the wall, p_w, is given by:

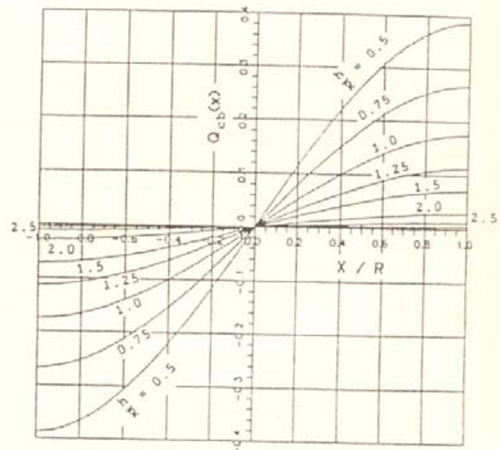
$$p_w = Q_{cw}(y) \, \alpha_{h_1} \; w \; L \; \sin(\omega t) \tag{30}$$

where,

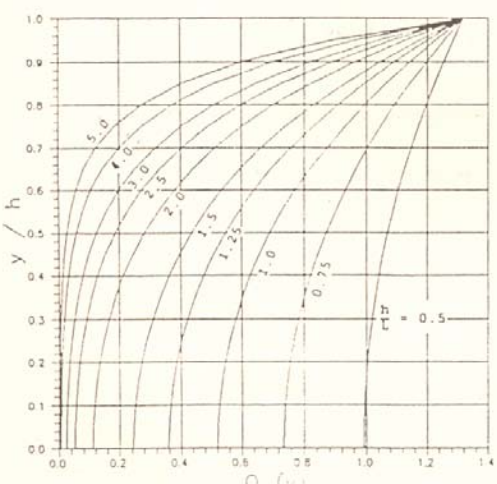
$$Q_{cw}(y) = 1.318 \; \frac{\cosh\left(1.581 \; \dfrac{y}{L}\right)}{\cosh\left(1.581 \dfrac{h}{L}\right)} \tag{31}$$



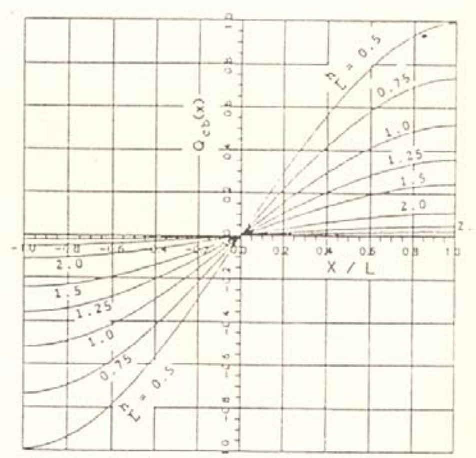
(a) On the wall – circular tank



(b) On the base – circular tank



(c) On the wall – rectangular tank



(d) On the base – rectangular tank

FIG.9 DISTRIBUTION OF NON-DIMENSIONAL CONVECTIVE PRESSURE

The value of $Q_{cw}(y)$ may also be read from Fig. 9(c) directly. The pressure on the base (y = 0) is given by:

$$p_b = Q_{cb}(x)\,\alpha_{h_1}\; w\; R\; \sin(\omega t) \qquad (32)$$

where,

$$Q_{cb}(x) = 1.976\left[\frac{x}{L}-\frac{1}{3}\left(\frac{x}{L}\right)^3\right] sech\left(1.581\,\frac{h}{L}\right) \qquad (33)$$

The value of $Q_{cb}(x)$ may also be read from Fig. 9(d) directly.

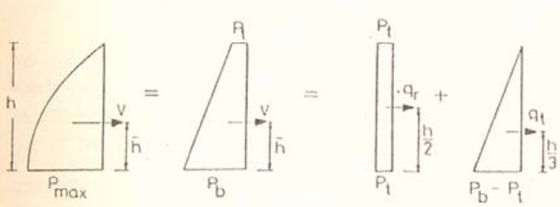
The maximum slashing height of the free liquid surface is given by $\theta_h L$ where

$$\theta_h = 2.5\,\frac{\overline{A}}{L}\,\tanh\left(1.581\,\frac{h}{L}\right) \qquad (34)$$

The hydrodynamic pressure varies around the circumference of the tank. However, for convenience of analysis of the tank shell, the hydrodynamic pressure on the tank wall may be approximated by an outward pressure distribution of intensity equal to that of the maximum hydrodynamic pressure (Fig. 10(a)).

The distribution of hydrodynamic pressure with height is curved. However, in the absence of more exact analysis, an equivalent linear pressure distribution may be assumed so as to give the same base shear and overturning moment (Fig. 10(b)).

(a) Simplified hydrodynamic pressure distribution on tank wall



$$V = (P_t + P_b)\,\frac{h}{2}$$

$$V\bar{h} = (2P_t + P_b)\,\frac{h^2}{6}$$

(b) Equivalent pressure distribution on tank wall

FIG.10 HYDRODYNAMIC PRESSURE DISTRIBUTION FOR ANALYSIS

Vertical circular ground supported tanks with flexible walls shall be anchored to their foundation when

$$\frac{h}{R} > \frac{2}{\alpha_{h_f}} \qquad (35)$$

For rigid tanks, α_{h_r} is to be used instead of α_{h_f}. In case of rectangular tank, the same expression may be used with L instead of R.

SUMMARY AND CONCLUSIONS

The provisions of IS:1893-1984 on the aseismic design of liquid storage tanks need to be revised in the light of extensive research results that have become available in recent years. Based on research results and design practice followed in other countries, a revised set of provisions is suggested for the future revision of IS: 1893-1984. The major revisions suggested are: (i) provisions are to be made to include the analysis of ground supported tanks with rigid and flexible walls, (ii) the single degree of freedom idealization of tank is to be replaced by a two or three degrees of freedom idealization, (iii) a performance factor (K) of 3.0 is suggested for all types of tank, (iv) IS: 1893 should state explicitly that bracing girder flexibility is to be included in the calculation of lateral stiffness of tank staging, (v) the effect of convective hydrodynamic pressure is to be included in the analysis, and (vi) a simplified hydrodynamic pressure distribution is also suggested for stress analysis of the tank wall. Procedures to carryout the analysis with the above suggested modifications are described alongwith graphs and charts for required design parameters.

NOTATION

A_c	Area of cross section of column
$\overline{A}$	Maximum displacement of convective mass
B	Half width of rectangular tank perpendicular to direction of loading
E_t	Elastic modulus of tank wall
F_o	Seismic zone factor
I	Importance factor for structure
K	Performance factor for tank
K_h	Period coefficient for a ground supported circular tank with flexible walls
K_s	Lateral stiffness of staging
K_1	Spring stiffness for convective mode
L	One-half of tank width; span of bracing girder
M	Design base moment
M_r, M_f	Base moment in impulsive mode

M_1	Base moment in convective mode
R	Radius of circular tank, half length of rectangular tank in the direction of motion; radius of staging
T_f, T_r	Impulsive mode periods for tank with flexible wall
T_o	Impulsive mode period for tank with rigid wall
T_1	Period of convective mode
V	Design base shear
V_f, V_r	Base shear in impulsive mode
V_1	Base shear in convective mode
d	Deflection of the rectangular tank wall due to a uniformly distributed load
g	Acceleration due to gravity
h	Depth of liquid in tank; height of column or panel
h_c	Height of center of gravity of tank shell above top of staging
h_f, h'_f	Height of mass m_f above tank base
h_r, h'_r	Height of the impulsive mass (m_r) above tank base
h_s	Height of staging
h_t	Height of center of gravity of roof mass above tank base
h_w	Height of center of gravity of wall mass above tank base
h_o, h'_o	Height of impulsive mass (m_o) above tank base
h_1, h'_1	Height of convective mass (m_1) above tank base
m	Total mass of liquid in tank
m_f	Impulsive mass for tank with flexible wall
m_o	Impulsive mass for tank with rigid wall
m_r	Impulsive mass for tank with flexible wall
m_s	Mass of tank shell + one-third mass of staging
m_t	Mass of tank roof
m_w	Mass of tank wall
m_1	Convective mass
p_b	Liquid pressure at tank base
p_w	Liquid pressure at tank wall
w	Unit weight of liquid
x	Co-ordinate along the radius of the tank base
y	Co-ordinate along the height of the tank
α_{h_r}	Design horizontal seismic coefficient (≅ period T_o)
α_{h_f}	Design horizontal seismic coefficient (≅ period T_f)
α_{h_1}	Design horizontal seismic coefficient (≅ period T_1)
β	Soil-foundation system coefficient
ω	$2\pi/T_1$
θ_h	Angle of oscillation of liquid surface

REFERENCES

1. IS:1893-1984: "*Indian Standard Criteria for Earthquake Resistant Design of Structures*", Bureau of Indian Standards, New Delhi., 1984.

2. IS:11682-1985: "*Indian Standard Criteria for Design of RCC Staging for Overhead Water Tanks*", Bureau of Indian Standards, New Delhi., 1985.

3. IS:4326-1976: "*Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings*," .Bureau of Indian Standards, New Delhi., 1976.

4. SP: 22 (S & T) - 1982: "*Explanatory Handbook on Codes for Earthquake Engineering: IS: 1893-1984 & IS: 4326-1976*", Bureau of Indian Standards, New Delhi., 1982.

5. Jain, S.K., and Sameer, S.U., "Seismic Design of Frame Stagings for Elevated Water Tanks", *Proc. the Ninth Symposium on Earthquake Engineering*, Roorkee, 1990.

6. Sameer, S.U., "A Study on Seismic Analysis and Design of Elevated Water Tank Stagings", *M. Tech Thesis*, Department of Civil Engineering, Indian Institute of Technology, Kanpur, 1990.

7. Fluid – Structure Interaction During Seismic Excitation, *A report by the Seismic Analysis Committee of the ASCE Nuclear Structures and Materials Committee*, American Society of Civil Engineers, New York., 1984.