भारतीय मानक
Indian Standard

IS 1893 (Part 2) : 2014

संरचनाओं के भूकम्परोधी डिजाइन के मानदंड

भाग 2 द्रव धारित टैंक

(पाँचवाँ पुनरीक्षण)

Criteria for Earthquake Resistant Design of Structures

Part 2 Liquid Retaining Tanks

(Fifth Revision)

ICS 91.120.25

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FOREWORD

This Indian Standard (Part 2) (Fifth Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Earthquake Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

In the fifth revision IS 1893 has been split into five parts. The other parts in the series are:

Part 1	General provisions and buildings
Part 3	Bridges and retaining walls
Part 4	Industrial structures including stack like structures
Part 5	Dams and embankments

Part 1 contains provisions that are general in nature and applicable to all types of structures. It also contains provisions that are specific to buildings only. Unless stated otherwise, the provisions in Part 2 to Part 5 shall be read in conjunction with the general provisions in Part 1.

This standard (Part 2) contains provisions for liquid retaining tanks. Unless otherwise stated, this standard shall be read necessarily in conjunction with IS 1893 (Part 1) : 2002.

As compared to provisions of IS 1893 : 1984, in this standard following important provisions and changes have been incorporated:

a) Analysis of ground supported tanks is included.
b) For elevated tanks, the single degree of freedom idealization of tank is done away with; instead a two-degree of freedom idealization is used for analysis.
c) Bracing beam flexibility is explicitly included in the calculation of lateral stiffness of tank staging.
d) The effect of convective hydrodynamic pressure is included in the analysis.
e) The distribution of impulsive and convective hydrodynamic pressure is represented graphically for convenience in analysis; a simplified hydrodynamic pressure distribution is also suggested for stress analysis of the tank wall.
f) Effect of vertical ground acceleration on hydrodynamic pressure is considered.
g) Quality control measures considered necessary in deign and construction of reinforced concrete tanks for achieving safe performance under normal as well as seismic conditions are also included.

The units used with the items covered by the symbols shall be consistent throughout this standard, unless specifically noted otherwise.

In the formulation of this standard due weightage has been given to international coordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field of this country.

In the formulation of this standard considerable help has been taken by the Indian Institute of Technology Kanpur, Institute of Technology Roorkee, Visvesvaraya National Institute of Technology, Nagpur and several other organizations including Guidelines prepared by IIT, Kanpur for GSDMA.

Reference has been made to the following documents in the formulation of this standard:

a) ACI 350.3, 2001, 'Seismic design of liquid containing concrete structures', American Concrete Institute, Farmington Hill, MI, USA.
b) Eurocode 8, 1998, 'Design provisions for earthquake resistance of structures, Part 1 General rules and Part 4 – Silos, tanks and pipelines', European Committee for Standardization, Brussels.

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Indian Standard

CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES

PART 2 LIQUID RETAINING TANKS

(Fifth Revision)

1 SCOPE

This standard (Part 2) covers ground supported liquid retaining tanks and elevated tanks supported on staging. Guidance is also provided on seismic design of buried tanks.

2 REFERENCES

The following standards contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
456 : 2000	Code of Practice for plain and Reinforced Concrete (*fourth revision*)
1893 (Part 1) : 2002	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*fifth revision*)
3370	Code of Practice for concrete structures for the storage of liquids
(Part 1) : 2009	General requirements (*first revision*)
(Part 2) : 2009	Reinforced concrete structures (*first revision*)
(Part 3) : 1967	Prestressed concrete structures
(Part 4) : 1967	Design tables
4326 : 2013	Code of Practice for earthquake resistant design and construction of buildings (*third revision*)
11682 : 1985	Criteria for design of RCC staging for overhead water tanks
13920 : 1993	Ductile detailing of reinforced concrete structures subjected to seismic sorces — Code of Practice

3 SYMBOLS

The symbols and notations given below apply to the provisions of this standard:

A_h = Design horizontal seismic coefficient

$(A_h)_c$ = Design horizontal seismic coefficient for convective mode

$(A_h)_i$ = Design horizontal seismic coefficient for impulsive mode

A_v = Design vertical seismic coefficient

B = Inside width of rectangular tank perpendicular to the direction of seismic force

C_c = Coefficient of time period for convective mode

C_i = Coefficient of time period for impulsive mode

d = Deflection of wall of rectangular tank, on the vertical centre line at a height h, when loaded by a uniformly distributed pressure q, in the direction of seismic force

d_{max} = Maximum sloshing wave height

D = Inner diameter of circular tank

E = Modulus of elasticity of tank wall

EL_x = Response quantity due to earthquake load applied in x - direction

EL_y = Response quantity due to earthquake load applied in y - direction

g = Acceleration due to gravity

h = Maximum depth of liquid

$\bar{h}$ = Height of combined centre of gravity of half impulsive mass of liquid ($m_i/2$) and mass of one wall ($\overline{m_w}$)

h_c = Height of convective mass above bottom of tank wall (without considering base pressure)

h_i = Height of impulsive mass above bottom of tank wall (without considering base pressure)

h_s = Structural height of staging, measured from top of foundation to the bottom of container wall

h_t = Height of centre of gravity of roof mass above bottom of tank wall

h_w = Height of centre of gravity of wall mass above bottom of tank wall

h_c^* = Height of convective mass above bottom of tank wall (considering base pressure)

h_i^* = Height of impulsive mass above bottom of tank wall (considering base pressure)

h_{cg} = Height of centre of gravity of the empty container of elevated tank, measured from the top of footing

I = Importance factor given in Table 1

K_c = Spring stiffness of convective mode

K_s = Lateral stiffness of elevated tank staging

l = Length of a strip at the base of circular tank, along the direction of seismic force

L = Inside length of rectangular tank parallel to the direction of seismic force

m = Total mass of liquid in tank

m_b = Mass of base slab or plate

m_c = Convective mass of liquid

m_i = Impulsive mass of liquid

m_s = Mass of empty container (includes mass of members like roof, wall, tank floor, floor beams, etc) of elevated tank and one-third mass of staging (mass of tower excluding container and foundation. Mass of columns, braces and any other mass attached to staging shall be included in mass of staging. Mass of pedestal above foundation can be assumed to be attached to foundation)

m_t = Mass of roof slab

m_w = Mass of tank wall

$\bar{m}_w$ = Mass of one wall of rectangular tank perpendicular to the direction of loading

M = Total bending moment at the bottom of tank wall

M^* = Total overturning moment at base

M_c = Bending moment in convective mode at the bottom of tank wall

M_c^* = *Overturning* moment in convective mode at the base

M_i = Bending moment in impulsive mode at the bottom of tank wall

M_i^* = Overturning moment in impulsive mode at the base

p = Maximum hydrodynamic pressure on wall

p_{cb} = Convective hydrodynamic pressure on tank base

p_{cw} = Convective hydrodynamic pressure on tank wall

p_{ib} = Impulsive hydrodynamic pressure on tank base

p_{iw} = Impulsive hydrodynamic pressure on tank wall

p_v = Hydrodynamic pressure on tank wall due to vertical ground acceleration

p_{ww} = Pressure on wall due to its inertia

q = Uniformly distributed pressure on one wall of rectangular tank in the direction of ground motion

Q_{cb} = Coefficient of convective pressure on tank base

Q_{cw} = Coefficient of convective pressure on tank wall

Q_{ib} = Coefficient of impulsive pressure on tank base

Q_{iw} = Coefficient of impulsive pressure on tank wall

R = Response reduction factor given in Table 2

(S_a/g) = Average response acceleration coefficient as per IS 1893 (Part 1) and **4.5**

t = Thickness of tank wall

t_b = Thickness of base slab

T_c = Time period of convective mode (in s)

T_i = Time period of impulsive mode (in s)

V = Total base shear

V_c = Base shear in convective mode

V_i = Base shear in impulsive mode

x = Horizontal distance in the direction of seismic force, of a point on base slab from the reference axis at the centre of tank

y = Vertical distance of a point on tank wall from the bottom of tank wall

Z = Seismic zone factor as per Table 2 of IS 1893 (Part 1)

ρ = Mass density of liquid

ρ_w = Mass density of tank wall

ϕ = Circumferential angle

4 PROVISIONS FOR SEISMIC ANALYSIS

4.1 General

Hydrodynamic forces exerted by liquid on tank wall shall be considered in the analysis in addition to hydrostatic forces. These hydrodynamic forces are evaluated with the help of spring mass model of tanks.

For tank full as well as empty conditions, tank shall be analysed for all the load combinations as per IS 1893 (Part 1). For load combination with seismic load, the amount of liquid considered in the tank shall be normal liquid level under service condition only.

4.2 Spring Mass Model for Seismic Analysis

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

4.2.1 *Ground Supported Tank*

4.2.1.1 Ground supported tanks can be idealized as spring-mass model shown in Fig. 1. The impulsive mass of liquid, m_i is rigidly attached to tank wall at height h_i (or h_i^*). Similarly, convective mass, m_c is attached to the tank wall at height h_c (or h_c^*) by a spring of stiffness K_c.

4.2.1.2 *Circular and rectangular tank*

For circular tanks, parameters m_i, m_c, h_i, h_i^*, h_c, h_c^* and K_c shall be obtained from Fig. 2 and for rectangular tanks these parameters shall be obtained from Fig. 3. h_i and h_c account for hydrodynamic pressure on the tank wall only and the tank base. Hence, the value of h_i and h_c shall be used to calculate moment due to hydrodynamic pressure at the bottom of the tank wall. The value of h_i^* and h_c^* shall be used to calculate overturning moment at the base of tank.

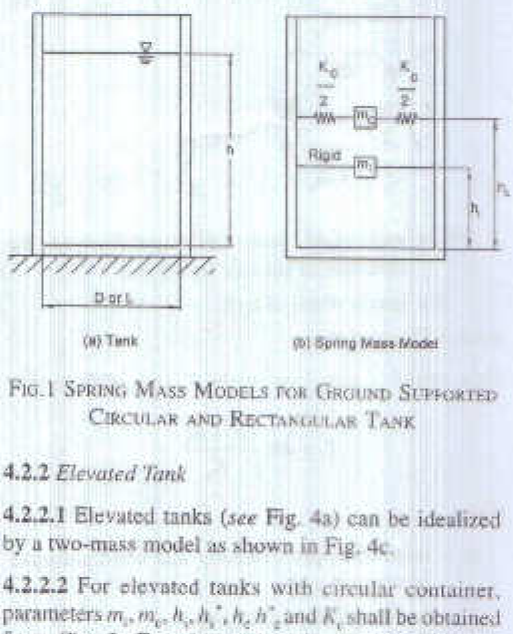


FIG. 1 SPRING MASS MODELS FOR GROUND SUPPORTED CIRCULAR AND RECTANGULAR TANK

4.2.2 *Elevated Tank*

4.2.2.1 Elevated tanks (*see* Fig. 4a) can be idealized by a two-mass model as shown in Fig. 4c.

4.2.2.2 For elevated tanks with circular container, parameters m_i, m_c, h_i, h_i^*, h_c h_c^* and K_c shall be obtained from Fig. 2. For elevated tanks with rectangular container, these parameters shall be obtained from Fig. 3.

4.2.2.3 In Fig. 4c, m_s is the structural mass and shall comprise of mass of tank container and one-third mass of staging.

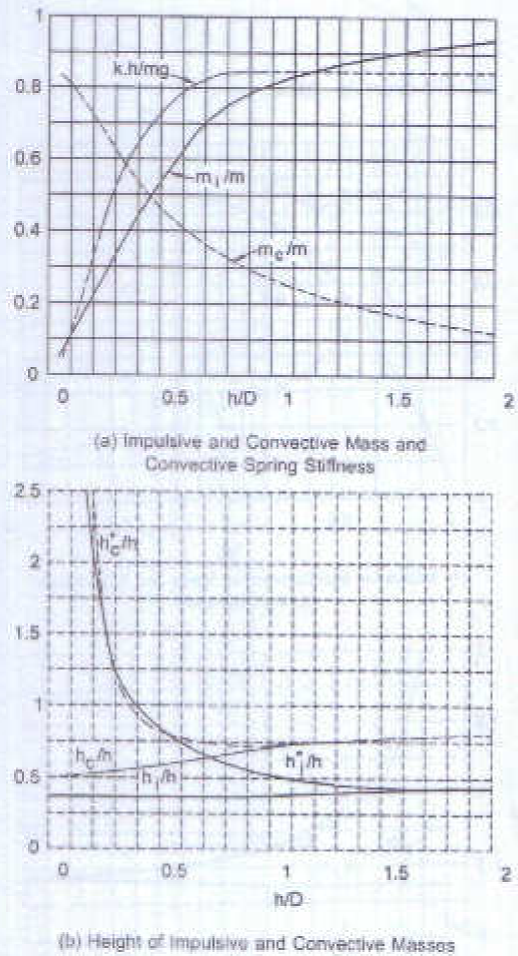
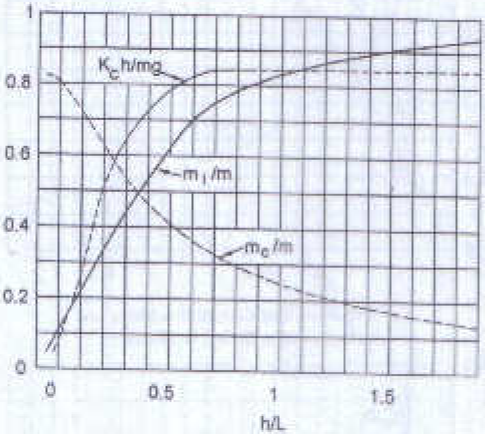


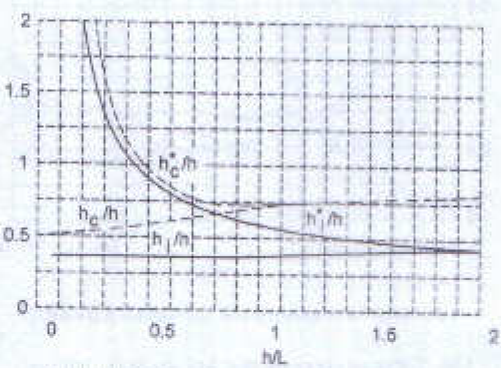
FIG. 2 PARAMETERS OF THE SPRING MASS MODEL FOR CIRCULAR TANK

4.2.2.4 For elevated tanks, the two degree of freedom system of Fig. 4c can be treated as two uncoupled single degree of freedom systems (*see* Fig. 4d), one representing the impulsive plus structural mass behaving as an inverted pendulum with lateral stiffness equal to that of the staging, K_s and the other representing the convective mass with a spring of stiffness, K_c.

4.2.3 For tank shapes other than circular (like intze, truncated conical shape), the value of h/D shall correspond to that of an equivalent circular tank of same volume and diameter equal to diameter of tank at top level of liquid; and m_i, m_c, h_i, h_i^*, h_c h_c^* and K_c of equivalent circular tank shall be used. The equivalent cylindrical tank should be assumed to be located such that top level of the liquid in equivalent tank is same as in actual tank.



(a) Impulsive and Convective Mass and Convective Spring Stiffness



(b) Height of Impulsive and Convective Masses

FIG. 3 PARAMETERS OF THE SPRING MASS MODEL FOR RECTANGULAR TANK

4.3 Time Period

4.3.1 *Impulsive Mode*

4.3.1.1 *Ground supported circular tank*

For a ground supported circular tank, wherein wall is rigidly connected with the base slab (*see* Fig. 6a, 6b and 6c), time period of impulsive mode of vibration T_i, in second, is given by:

$$T_i = C_i \frac{h\sqrt{\rho}}{\sqrt{t/D}\sqrt{E}}$$

where

C_i = coefficient of time period for impulsive mode. Value of C_i can be obtained from Fig. 5;

h = maximum depth of liquid;

D = inner diameter of circular tank;

t = thickness of tank wall;

E = modulus of elasticity of tank wall; and

ρ = mass density of liquid.

NOTE — In some circular tanks, wall may have flexible connection with the base slab (Different types of wall to base slab connections are described in Fig. 6). For tanks with flexible connections with base slab, time period evaluation may properly account for the flexibility of wall to base connection.

4.3.1.2 *Ground supported rectangular tank*

For a ground supported rectangular tank, wherein wall is rigidly connected with the base slab, time period of impulsive mode of vibration, T_i in s, is given by:

$$T_i = 2\pi\sqrt{d/g}$$

where

d = deflection of the tank wall on the vertical center-line at a height of $\bar{h}$, when loaded by uniformly distributed pressure of intensity q.

$$q = \frac{\left(\frac{m_i}{2} + \bar{m}_w\right)g}{Bh}$$

$$\bar{h} = \frac{\frac{m_i}{2}h_i + \bar{m}_w\frac{h}{2}}{\frac{m_i}{2} + \bar{m}_w}$$

$\bar{m}_w$ = mass of one tank wall perpendicular to the direction of seismic force; and

B = inside width of tank.

4.3.1.3 *Elevated tank*

Time period of impulsive mode, T_i, in s, is given by:

$$T_i = 2\pi\sqrt{\frac{m_i + m_s}{K_s}}$$

where

m_s = mass of empty container and one-third mass of staging; and

K_s = lateral stiffness of staging.

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

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

4.3.2 *Convective Mode*

Time period of convective mode can be calculated using **4.3.2.1** and **4.3.2.2**. However, shorter time period shall be used for design purposes.

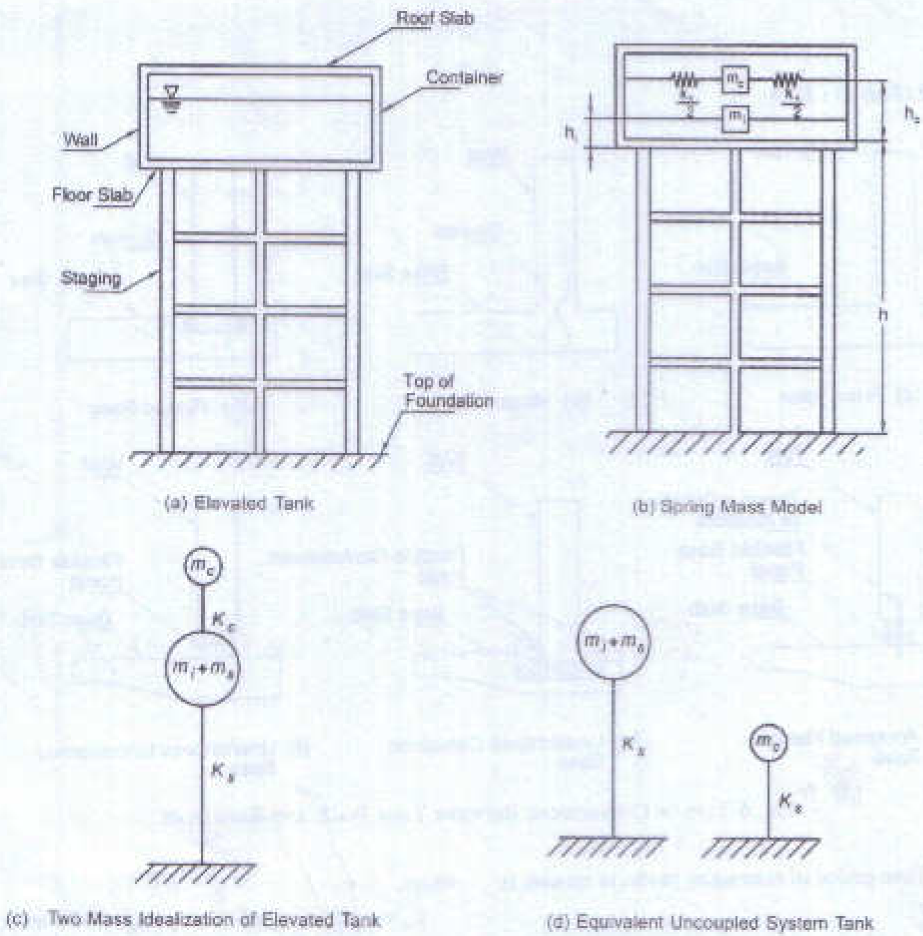


FIG. 4 TWO MASS IDEALIZATION FOR ELEVATED TANK

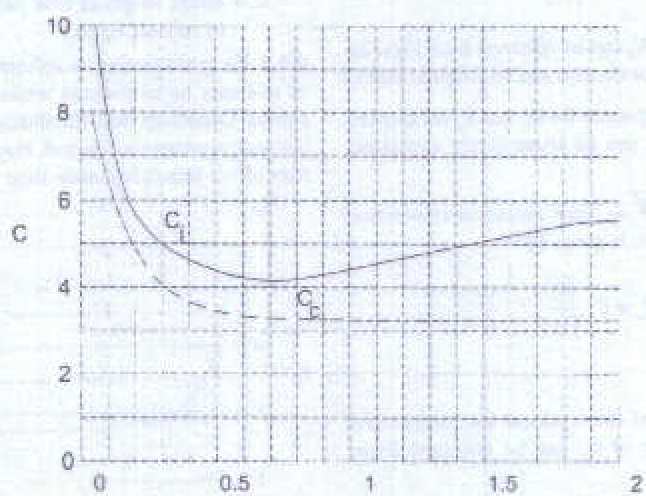


FIG. 5 COEFFICIENT OF IMPULSIVE AND CONVECTIVE MODE TIME PERIOD FOR CIRCULAR TANK

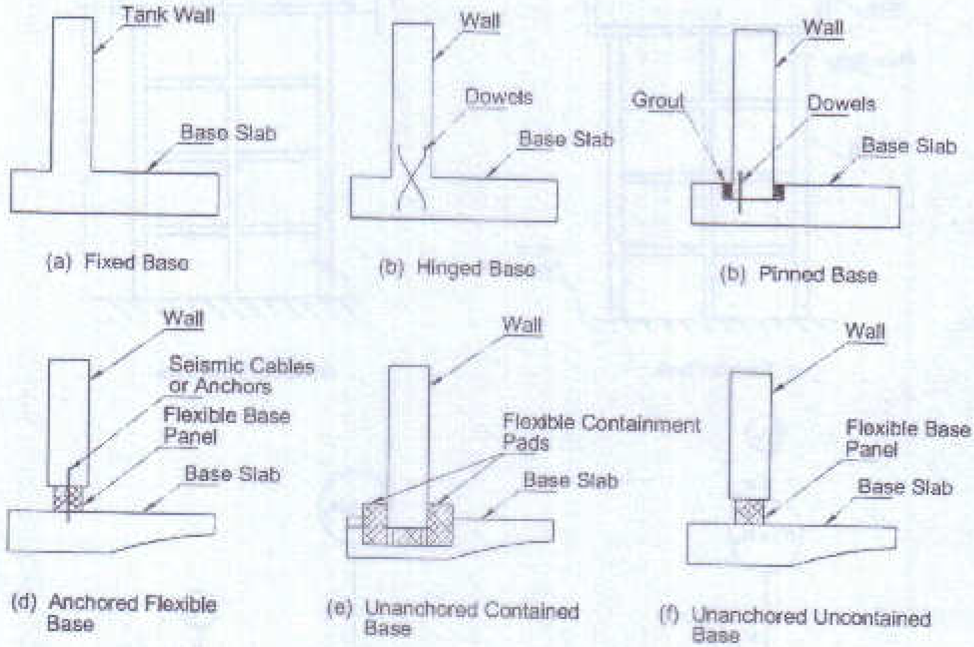


FIG. 6 TYPE OF CONNECTIONS BETWEEN TANK WALL AND BASE SLAB

4.3.2.1 Time period of convective mode, in second, is given by:

$$T_1 = 2\pi\sqrt{\frac{m_c}{K_c}}$$

The values of m_c and K_c can be obtained from Figs. 2a and 3a respectively, for circular and rectangular tanks.

4.3.2.2 Since the expressions for m_c and K_c are known, the expression for T_c can be alternatively expressed as:

a) *Circular tank* — Time period of convective mode, T_c, in s, is given by:

$$T_c = C_c\sqrt{\frac{D}{g}}$$

where

C_c = coefficient of time period for convective mode. Value of C_c can be obtained from Fig. 5; and

D = inner diameter of tank.

b) *Rectangular tank* — Time period of convective mode of vibration, T_c, in second, is given by:

$$T_c = C_c\sqrt{\frac{L}{g}}$$

where

C_c = coefficient of time period for convective mode. Value of C_c can be obtained from Fig. 7; and

L = inside length of tank parallel to the direction of seismic force.

4.3.3 For tanks resting on soft soil, effect of flexibility of soil may be considered while evaluating the time period. Generally, soil flexibility does not affect the convective mode time period. However, soil flexibility may affect impulsive mode time period.

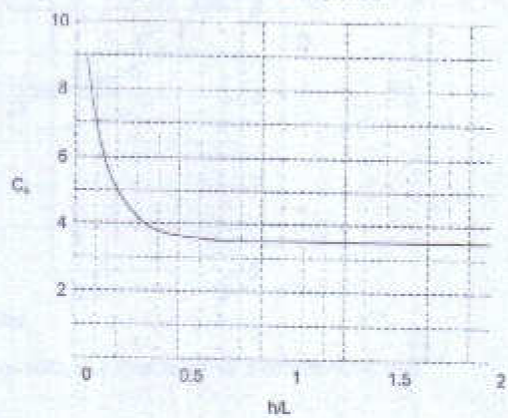


FIG. 7 COEFFICIENT OF CONVECTIVE MODE TIME PERIOD (C_c) FOR RECTANGULAR TANK

4.4 Damping

Damping in the convective mode for all types of liquids and for all types of tanks shall be taken as 0.5 percent of the critical.

Damping in the impulsive mode shall be taken as 2 percent of the critical for steel tanks and 5 percent of the critical for concrete or masonry tanks.

4.5 Design Horizontal Seismic Coefficient

Design horizontal seismic coefficient, A_h shall be obtained by the following expression, subject to **4.5.1** and **4.5.2**:

$$A_h = \frac{Z}{2} \times \frac{I}{R} \times \frac{S_a}{g}$$

where

Z = zone factor given in Table 2 of IS 1893 (Part 1);

I = importance factor given in Table 1;

R = response reduction factor given in Table 2 and Table 3; and

S_a/g = average response acceleration coefficient as given by Fig. 2 and multiplying factors for obtaining values for other damping as given in Table 3 of IS 1893(Part 1) and subject to **4.5.1** and **4.5.2**.

Table 1 Importance Factor, *I*
(*Clause* 4.5)

Sl No. (1)	Type of Liquid Storage Tank (2)	*I* (3)
i)	Tanks used for storing drinking water, non-volatile material, low inflammable, etc. and intended for emergency services such as fire fighting services. Tanks of post earthquake importance	1.5
ii)	All other tanks with no risk to life and with negligible consequences to environment, society and economy	1.0

NOTE — Higher values of importance factor, I given in IS 1893 (Part 4) may be used where appropriate.

4.5.1 Design horizontal seismic coefficient, A_h shall be calculated separately for impulsive $(A_h)_i$, and convective $(A_h)_c$ modes.

4.5.2 Value of multiplying factor shall be taken as 1.0 for 5 percent, 1.4 for 2 percent and 1.75 for 0.5 percent damping.

4.6 Base Shear

4.6.1 *Ground Supported Tank*

Base shear in impulsive mode, at the bottom of tank wall is given by:

$$V_i = (A_h)_i\ (m_i + m_w + m_t)\ g$$

Table 2 Suggested Values of 'R' for Elevated Tanks
(*Clause* 4.5)

Sl No. (1)	Type of Elevated Tank (2)	'R' (3)
i)	Tank supported on masonry shaft (*Not permitted in zones IV and V*):	
	a) Masonry shaft reinforced with horizontal bands	2
	b) Masonry shaft reinforced with horizontal bands and vertical bars	3
ii)	Tank supported on RC shaft:	
	a) RC shaft with reinforcement in one curtain (in both directions) at center of shaft thickness	2.5
	b) RC shaft with reinforcement in two curtains (in both directions)	3.5
	c) RC shaft with reinforcement in two curtains (in both directions) and with stiffened openings and bracings	4
iii)	Tank supported on RC frame[1]:	
	a) Ordinary moment resisting frame (OMRF) type staging	2.5
	b) Special moment resisting frame (SMRF) conforming ductility requirements of IS 13920	4
iv)	Tank supported on steel frame[1]:	
	a) Special moment resistant frame (SMRF) without diagonal bracing	3.5
	b) Special moment resistant frame (SMRF) with diagonal bracing	4

[1] These R values are meant for liquid retaining tanks on frame type staging which are inverted pendulum type structures. These R values shall not be misunderstood for those given in other parts of IS 1893 for building and industrial frames.

NOTE — P – Δ effect should be considered in the design of the staging.

Table 3 Suggested Values of 'R' for Ground Supported Tanks
(*Clause* 4.5)

Sl No. (1)	Type of Ground Supported Tank (2)	R (3)
i)	Masonry tank:	
	a) Masonry wall reinforced with horizontal bands (*Not permitted in zones IV and V*)	2.0
	b) Masonry wall reinforced with horizontal bands and vertical bars at corners and jambs of openings	3.0
ii)	RC / prestressed tank:	
	a) Fixed or hinged/pinned base tank (*see* Figs. 6a, 6b, 6c)	2.5
	b) Anchored flexible base tank (*see* Fig. 6d)	3.0
	c) Unanchored contained or uncontained tank (*see* Figs. 6e, 6f)	2.5
iii)	Steel tank:	
	a) Unanchored base	2.5
	b) Anchored base	3.0
iv)	Underground RC and steel tank (*see* Note)	4.0

NOTE — For partially buried tanks, values of R can be interpolated between ground supported and underground tanks based on depth of embedment.

and base shear in convective mode is given by:

$$V_c = (A_h)_c \, m_c \, g$$

where

$(A_h)_i$ = design horizontal seismic coefficient for impulsive mode;

$(A_h)_c$ = design horizontal seismic coefficient or convective mode;

m_i = impulsive mass of water;

m_w = mass of tank wall;

m_t = mass of roof slab; and

g = acceleration due to gravity.

4.6.2 *Elevated Tank*

Base shear in impulsive mode, just above the base of staging (that is, at the top of footing of staging) is given by:

$$V_i = (A_h)_i \, (m_i + m_s) \, g$$

and base shear in convective mode is given by:

$$V_c = (A_h)_c \, m_c \, g$$

where

m_s = mass of container and one-third mass of staging.

4.6.3 Total base shear V can be obtained by combining the base shear in impulsive and convective mode through square root of sum of squares (SRSS) rule and is given as follows:

$$V = \sqrt{V_i^2 + V_c^2}$$

4.7 Base Moment

4.7.1 *Ground Supported Tank*

4.7.1.1 Bending moment in impulsive mode, at the bottom of wall is given by:

$$M_i = (A_h)_i \, (m_i h_i + m_w h_w + m_t h_t) g$$

and bending moment in convective mode is given by:

$$M_c = (A_h)_c \, m_c \, h_c \, g$$

where

h_w = height of centre of gravity of wall mass; and

h_t = height of centre of gravity of roof mass.

4.7.1.2 Overturning moment in impulsive mode to be used for checking the tank stability at the bottom of base slab/plate is given by:

$$M_i^* = (A_h)_i \, [m_i(h_i^* + t_b) + m_w(h_w + t_b) + m_t(h_t + t_b) + m_b t_b/2] \, g$$

and overturning moment in convective mode is given by:

$$M_c^* = (A_h)_c \, m_c \, (h_c^* + t_b) \, g$$

where

M_b = mass of base slab/plate; and

t_b = thickness of base slab/plate.

4.7.2 *Elevated Tank*

Overturning moment in impulsive mode, at the base of the staging is given by:

$$M_i^* = (A_h)_i \left[m_i(h_i^* + h_s) + m_s \, h_{cg} \right] g$$

and overturning moment in convective mode is given by:

$$M_c^* = (A_h)_c \, m_c \, (h_{cg} + h_s) \, g$$

where

h_s = structural height of staging, measured from top of footing of staging to the bottom of tank wall; and

h_{cg} = height of centre of gravity of the empty container of elevated tank, measured from the top of footing.

4.7.3 Total moment shall be obtained by combining the moment in impulsive and convective modes under **4.7.1** and **4.7.2** through square of sum of squares (SRSS) and is given as follows:

$$M = \sqrt{\left(M_i^2 + M_c^2\right)} \quad \text{and}$$

$$M^* = \sqrt{\left(M_i^{*2} + M_c^{*2}\right)}$$

4.7.4 For elevated tanks, the design shall be worked out for tank empty and tank full conditions.

4.8 Direction of Seismic Force

4.8.1 Ground supported rectangular tanks shall be analyzed for horizontal earthquake force acting non-concurrently along each of the horizontal axis of the tank for evaluating forces on tank walls.

4.8.2 For elevated tanks, staging components should be designed for the critical direction of seismic force. Different components of staging may have different critical directions.

4.8.3 As an alternative to **4.8.2**, staging components can be designed for either of the following load combination rules:

a) 100 percent + 30 percent rule:
   $\pm EL_x \pm 0.3 \, EL_y$ and $\pm 0.3 \, EL_x \pm EL_y$

b) SRSS Rule:
   $\sqrt{EL_x^2 + EL_y^2}$

where

EL_x = response quantity due to earthquake load applied in x-direction; and

EL_y = response quantity due to earthquake load applied in y-direction.

4.9 Hydrodynamic Pressure

During lateral base excitation, tank wall is subjected to lateral hydrodynamic pressure and tank base is subjected to hydrodynamic pressure in vertical direction.

4.9.1 *Impulsive Hydrodynamic Pressure*

The impulsive hydrodynamic pressure exerted by the liquid on the tank wall and base is given by:

a) For Circular Tank (*see* Fig. 8a):

Lateral hydrodynamic impulsive pressure on the wall, p_{iw}, is given by:

$$p_{iw} = Q_{iw}(y)\,(A_h)_i\,\rho\,g\,h\cos\phi$$

$$Q_{iw}(y) = 0.866\left[1-(y/h)^2\right]\tanh\left(0.866\frac{D}{h}\right)$$

where

ρ = mass density of liquid;

ϕ = circumferential angle; and

y = vertical distance of a point on tank wall from the bottom of tank wall.

Coefficient of impulsive hydrodynamic pressure on wall, $Q_{iw}(y)$ can also be obtained from Fig. 9a.

Impulsive hydrodynamic pressure in vertical direction, on base slab ($y = 0$) on a strip of length l', is given by:

$$p_{ib} = 0.866(A_h)_i\rho g h\frac{\sinh\left(1.732\frac{x}{h}\right)}{\cosh\left(0.866\frac{l'}{h}\right)}$$

x = horizontal distance of a point on base of tank in the direction of seismic force, from the centre of tank.

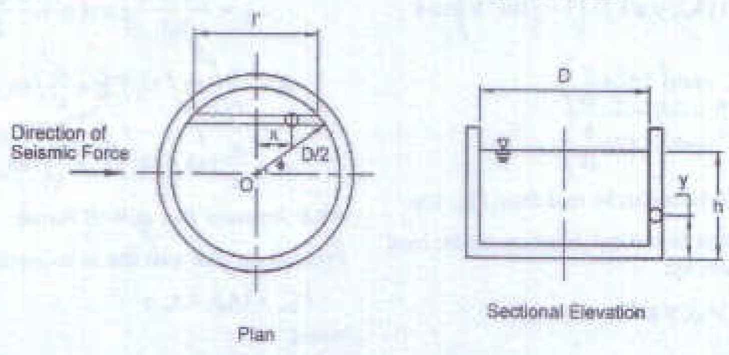
b) For Rectangular Tank (*see* Fig. 8b):

Lateral hydrodynamic impulsive pressure on wall p_{iw}, is given by:

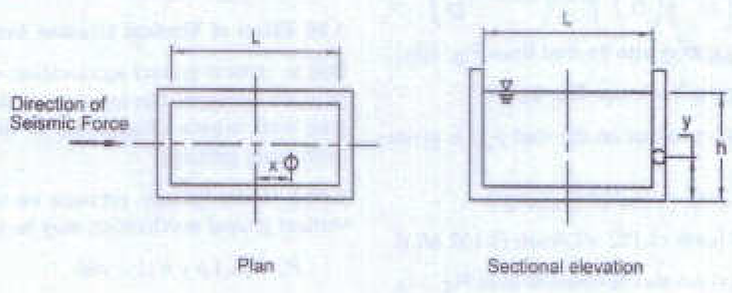
$$p_{iw} = Q_{iw}(y)\,(A_h)_i\,\rho\,g\,h$$

where

$Q_{iw}(y)$ is same as that for a circular tank and can be read from Fig. 9a, with h/L being used in place of h/D.



(a) Circular Tank



(b) Rectangular Tank

FIG. 8 GEOMETRY OF (a) CIRCULAR TANK AND (b) RECTANGULAR TANK

Impulsive hydrodynamic pressure in vertical direction, on the base slab ($y = 0$), is given by:

$$P_{ib} = Q_{ib}(x)\,(A_h)_i\,\rho\,g\,h$$

$$Q_{ib}(x) = \frac{\sinh\left(1.732\frac{x}{h}\right)}{\cosh\left(0.866\frac{L}{h}\right)}$$

The value of coefficient of impulsive hydrodynamic pressure on base $Q_{ib}(x)$, can also be read from Fig. 9b.

4.9.2 *Convective Hydrodynamic Pressure*

The convective pressure exerted by the oscillating liquid on the tank wall and base shall be calculated as follows:

a) Circular Tank (*see* Fig. 8a)

Lateral convective pressure on the wall p_{cw}, is given by:

$$P_{cw} = Q_{cw}(y)\,(A_h)_c\,\rho\,g\,h\,D\left(1-\frac{1}{3}\cos^2\phi\right)\cos\phi$$

$$Q_{cw}(y) = 0.5625\frac{\cosh\left(3.674\frac{y}{D}\right)}{\cosh\left(3.674\frac{h}{D}\right)}$$

The value of $Q_{cw}(y)$ can also be read from Fig. 10a.

Convective pressure in vertical direction, on the base slab ($y = 0$) is given by:

$$P_{cb} = Q_{cb}(x)\,(A_h)_c\,\rho\,g\,D$$

where

$$Q_{cb}(x) = 1.125\left(\frac{x}{D}-\frac{4}{3}\left(\frac{x}{D}\right)^3\right)\mathrm{sech}\left(0.3674\frac{h}{D}\right)$$

The value of $Q_{cb}(x)$ may also be read from Fig. 10b.

b) Rectangular Tank (*see* Fig. 8b):

The hydrodynamic pressure on the wall p_{cw}, is given by:

$$p_{cw} = Q_{cw}(y)\,(A_h)_c\,\rho\,g\,L$$

$$Q_{cw}(y) = 0.4165\,[\cosh(3.162\,y/L)/\cosh(3.162\,h/L)]$$

The value of $Q_{cw}(y)$ can also be obtained from Fig. 11a.

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

$$P_{cb} = Q_{cb}(x)\,(A_h)_c\,\rho\,g\,L$$

$$Q_{cb}(x) = 1.125\left(\frac{x}{L}-\frac{4}{3}\left(\frac{x}{L}\right)^3\right)\mathrm{sech}\left(3.162\frac{h}{L}\right)$$

where

The value of $Q_{cb}(x)$ can also be obtained from Fig. 11b.

4.9.3 In circular tanks, hydrodynamic pressure due to horizontal excitation varies around the circumference of the tank. However, for convenience in stress analysis of the tank wall, 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 (*see* Fig. 12a).

4.9.4 Hydrodynamic pressure due to horizontal excitation has curvilinear variation along wall height. 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 bending moment at the bottom of tank wall (*see* Figs. 12b and 12c). The following expressions shall be used to linearise the pressure distribution:

For circular tanks : $q_i = \frac{(A_h)_i\,m_i}{\pi D/2}\,g$ and $q_c = \frac{(A_h)_c\,m_c}{\pi D/2}\,g$

For rectangular tanks :

$$q_i = \frac{(A_h)_i\,m_i}{2B}\,g \text{ and } q_c = \frac{(A_h)_c\,m_c}{2B}\,g$$

$$a_i = \frac{q_i}{h^2}(4h-6h_i),\ b_i = \frac{q_i}{h^2}(6h_i-2h) \text{ and}$$

$$a_c = \frac{q_c}{h^2}(4h-6h_c),\ b_c = \frac{q_c}{h^2}(6h_c-2h)$$

4.9.5 *Pressure Due to Wall Inertia*

Pressure on tank wall due to its inertia is given by:

$$P_{ww} = (A_h)_i\,t\,\rho_m\,g$$

where

ρ_m = mass density of tank wall; and

t = wall thickness.

4.10 Effect of Vertical Ground Acceleration

Due to vertical ground acceleration, effective weight of liquid increases, this induces additional pressure on tank wall, whose distribution is similar to that of hydrostatic pressure.

4.10.1 Hydrodynamic pressure on tank wall due to vertical ground acceleration may be taken as:

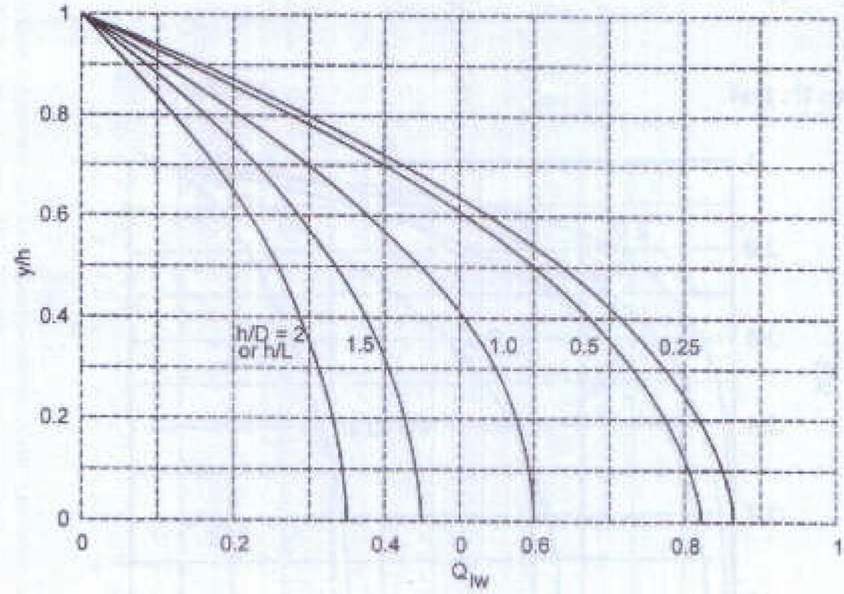
$$P_v = (A_v)\,\rho\,g\,h\,(1-y/h)$$

$$A_v = \frac{2}{3}\left(\frac{Z}{2}\times\frac{I}{R}\times\frac{S_a}{g}\right)$$

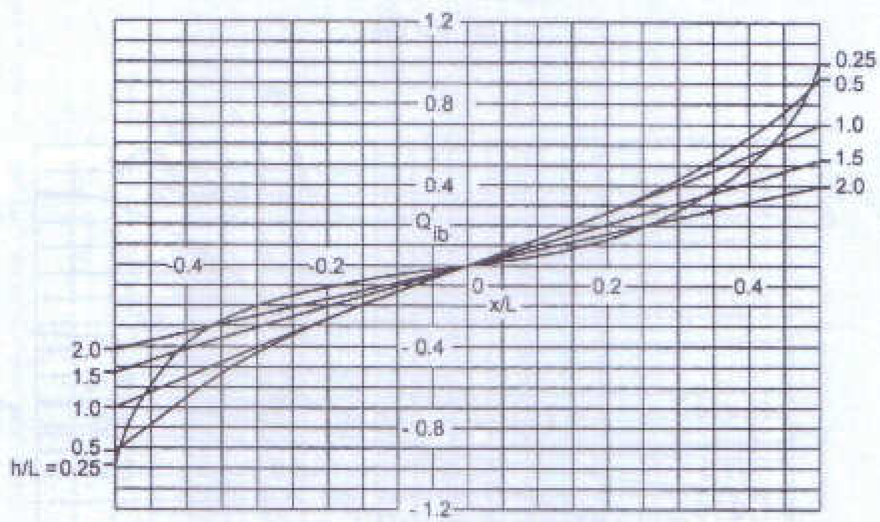
where

y = vertical distance of point under consideration from bottom of tank wall, and

(S_a/g) = Average response acceleration coefficient given by Fig. 2 and Table 3 of IS 1893 (Part 1) and subject to **4.5.2** and **4.5.3**.

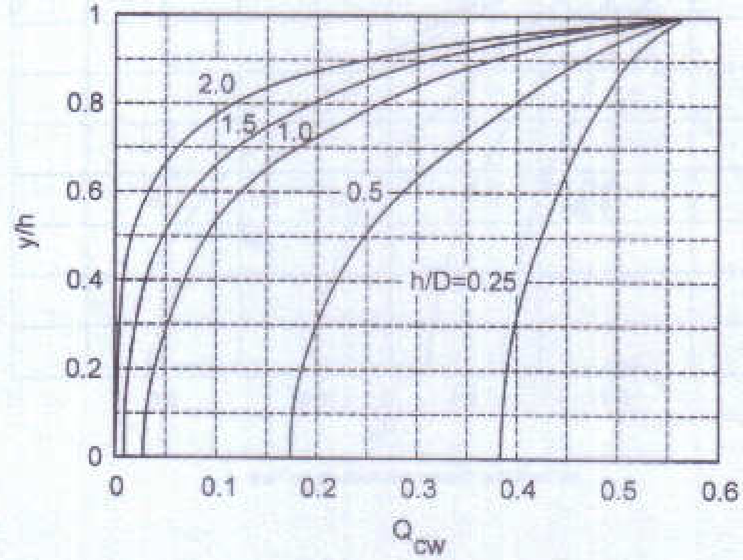


(a) On Wall of Circular and Rectangular Tank

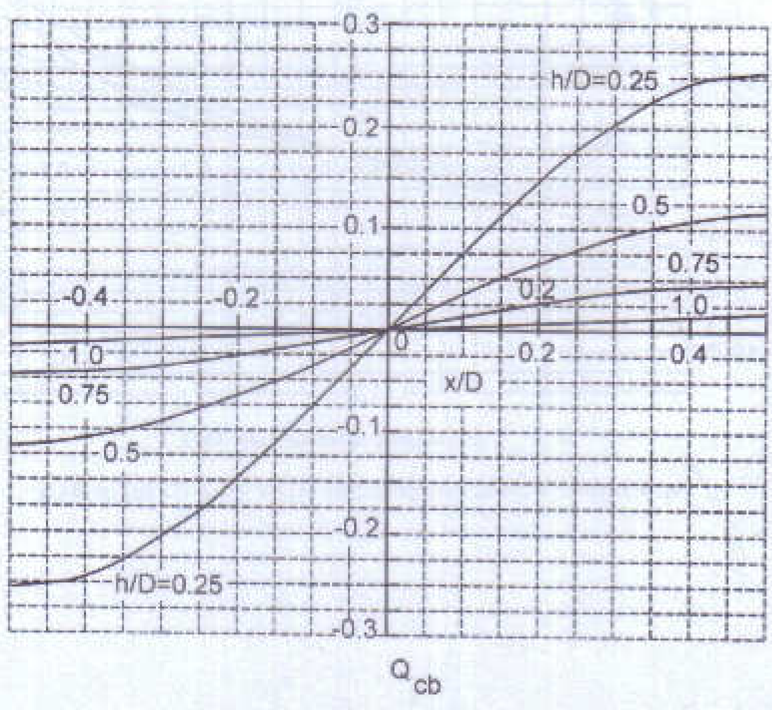


(b) On Base of Rectangular Tank

FIG. 9 IMPULSIVE PRESSURE COEFFICIENT (a) ON WALL (C) (b) ON BASE

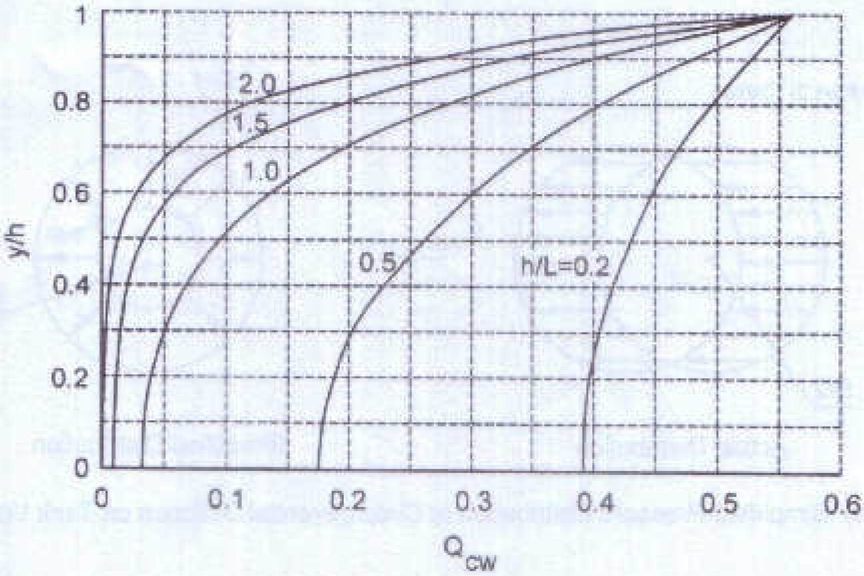


(a) On Wall

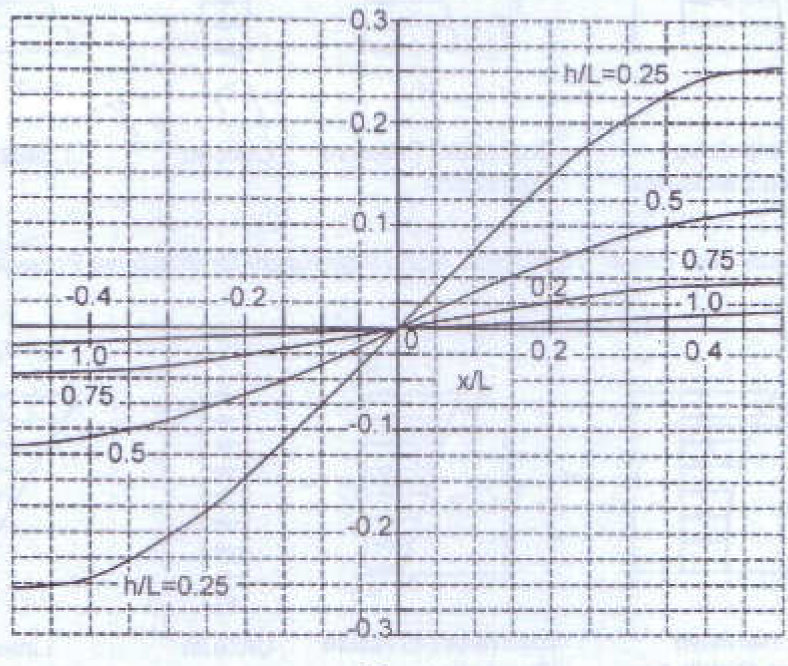


(b) On Base

FIG. 10 CONVECTIVE PRESSURE COEFFICIENT FOR CIRCULAR TANK
(a) ON WALL (b) ON BASE

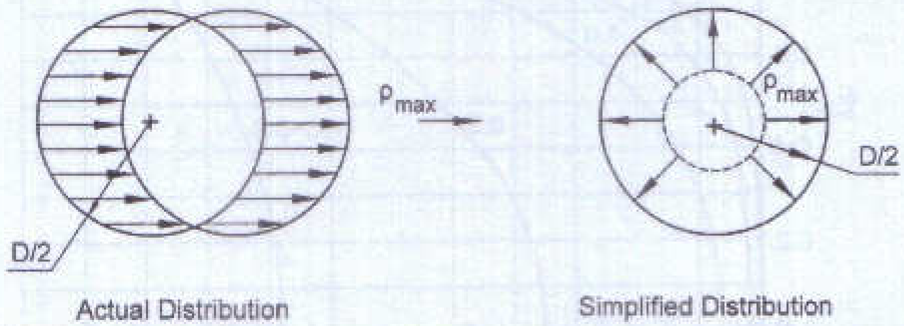


(a) On Wall

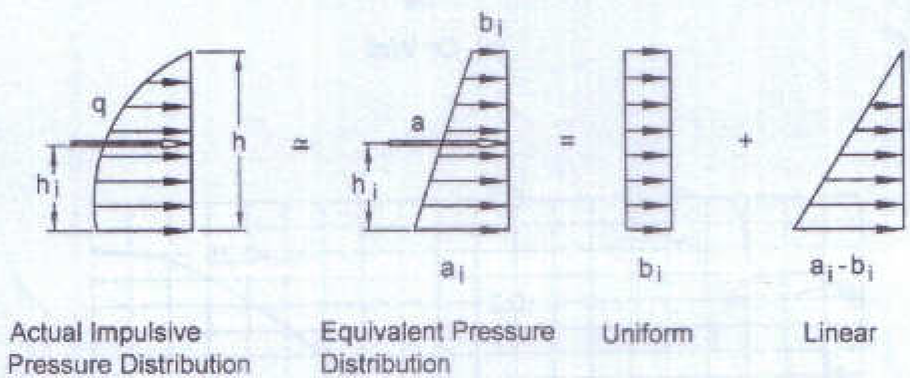


(b) On Base

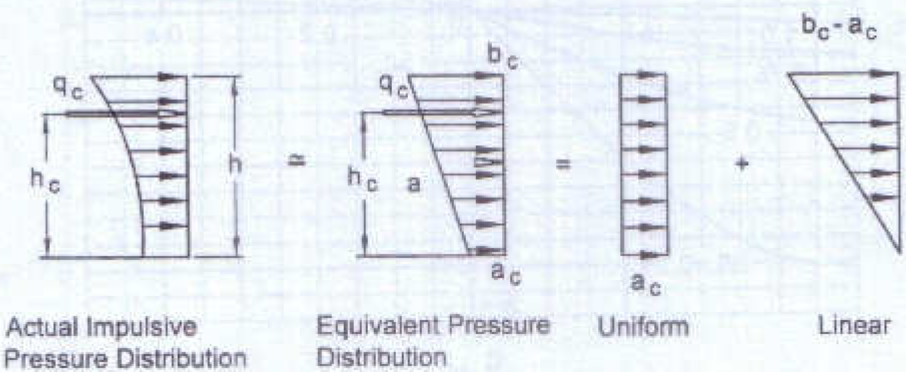
FIG. 11 CONVECTIVE PRESSURE COEFFICIENT FOR RECTANGULAR TANK
(a) ON WALL (b) ON BASE



(a) Simplified Pressure Distribution in Circumferential Direction on Tank Wall



(b) Equivalent Linear Distribution Along Wall Height for Impulsive Pressure



(c) Equivalent Linear Distribution Along Wall Height for Convective Pressure

FIG. 12 HYDRODYNAMIC PRESSURE DISTRIBUTION FOR WALL ANALYSIS
(a) ON WALL (b) ON BASE

In absence of more refined analysis, time period of vertical mode of vibration for all types of tank may be taken as 0.3 s.

4.10.2 The maximum value of hydrodynamic pressure should be obtained by combining pressure due to horizontal and vertical excitation through square root of sum of squares (SRSS) rule, which can be given as:

$$P = \sqrt{(P_{iw} + P_{ww})^2 + P_{cw}^2 + P_v^2}$$

4.11 Sloshing Wave Height

Maximum sloshing wave height is given by:

a) For circular tank:

$$d_{max} = (A_h)_c \ R\frac{D}{2}$$

b) For rectangular tank:

$$d_{max} = (A_h)_c \ R\frac{L}{2}$$

where

$(A_h)_c$ = design horizontal seismic coefficient corresponding to convective time period.

4.12 Anchorage Requirement

Circular ground supported tanks shall be anchored to their foundation (*see* Fig. 13) when

$$\frac{h}{D} > \frac{1}{(A_h)_i}$$

In case of rectangular tank, the same expression may be used with L instead of D.

5 SEISMIC DESIGN OF LIQUID RETAINING TANKS

5.1 Two Mass Idealization

The rational method of analysis using the two masses – impulsive and convective – as presented in **4.1** to **4.12** may be used for determining the seismic design forces on ground supported as well as elevated water tanks of any capacity and material of construction namely, reinforced concrete or steel.

5.2 One Mass Approximation

In the light of the on going practice for construction of large number of water tanks, it is considered expedient to permit the option of one mass idealization, in certain cases, as stated here below, in which the whole water mass is taken as if in impulsive mode.

5.2.1 Ground supported or elevated liquid retaining RC structure of up to and including 1 000 kl capacity, wall of the container if in concrete, which can be regarded as rigid.

5.2.2 Wall in steel may not be regarded as rigid, hence for design of steel tanks by one mass model, the capacity should not exceed 200 kl and h/D or h/L should be 0.4 or higher.

5.2.3 For one mass model, water mass in convective mode shall not be considered. Total water mass shall be assumed in impulsive mode and the impulsive force

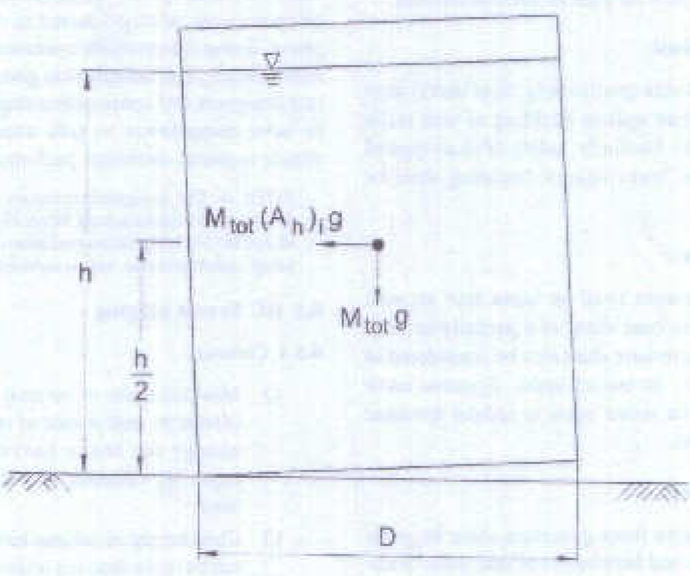


FIG. 13 INITIATION OF ROCKING OF TANK

shall be assumed to act at centre of gravity of the whole water mass.

5.2.4 The design shall be worked out both when the tank is full and when empty. When empty, the weight W used in the design shall consist of the dead load of the tank and one-third the weight of the staging lumped at the centre of gravity of the tank. When full, the weight of the fluid contents is to be added to the weight under empty conditions.

6 MISCELLANEOUS

6.1 Piping

Piping system connected to tanks should be given consideration of potential vibration and movement at the pipe joints during earthquakes, and sufficient flexibility should be introduced by proper detailing of pipe joints to avoid de-function. Piping system and its connection to the tank should be designed to comply with the assumptions made and the likely performance; merely neglecting the weight of piping system may not be adequate in all cases.

The piping system shall be designed so as not to impart significant mechanical loading on tank. Local loads at pipe connections can be considered in the design of the tank. Mechanical devices, which add flexibility to piping such as bellows, expansion joints and other special couplings, may be used in the connections.

6.2 Buckling of Shell

Ground supported tanks (particularly, steel tanks) shall be checked for failure against buckling of tank walls under vertical board. Similarly, safety of shaft type of staging of elevated tanks against buckling shall be ensured.

6.3 Buried Tanks

Dynamic earth pressure shall be taken into account while computing the base shear of a partially or fully buried tank. Earth pressure shall also be considered in the design of walls. In buried tanks, dynamic earth pressure shall not be relied upon to reduce dynamic effects due to liquid.

6.4 Shear Transfer

The lateral earthquake force generates shear between wall and base slab and between roof and wall. Wall-to-base slab, wall-to-roof slab and wall-to-wall joints shall be suitably designed to transfer shear forces. Similarly in elevated tanks, connection between container and staging should be suitably designed to transfer the shear force.

6.5 P-Δ Effect

All staging of columns and braces (or beams) for elevated tanks shall be designed for P-Δ effect.

7 AESTHETICS

Elevated water tanks are prominently in public view and visible from near as well as long distances. They often become landmarks on the landscape. It is therefore important that the shape and form of the container and the supporting structure must receive due attention from the point of aesthetics. Innovations in the shape and form should be encouraged when they improve the ambience and enhance the quality of the environment.

Where unusual shapes and forms for supporting structures are used, the designer may use some discretion in choosing the value of response reduction factor R consistent with expected seismic performances and ductility. It will be incumbent on the designer, however, to justify the choice of R value *vis-à-vis* the seismic safety.

8 QUALITY CONTROL IN REINFORCED CONCRETE TANKS

Quality control in design and constructions are particularly important for elevated tanks in view of several collapses of water tanks during testing. It is necessary that quality of materials and construction tolerances are strictly adhered to during construction phase. Some construction tolerances and detailing are listed below. The information given is not exhaustive and designers and construction engineers are expected to have competence to take adequate measures to ensure required structural performance.

NOTE — The design/construction details for reinforced concrete tanks should strictly follow IS 456, IS 3370 (Parts 1 to 4), and IS 11682. The recommendations are made here to ensure safety under normal as well as service loads.

8.1 RC Frame Staging

8.1.1 *Columns*

a) Minimum size of column should be 400 mm (diameter and/or side of rectangular column) except for tanks having 200 m^3 or less capacity, columns of 300 mm size may be used.

b) Clear height of column between braces should not be more than ten times the size of column.

c) Reinforcement detailing including overlaps in longitudinal bars should follow as shown in IS 13920.

d) During construction and casting of columns, some eccentricity in the verticality of column may develop. Eccentricity up to 20 mm may be allowed in column between two brace levels. Additional moment due to this eccentricity should be considered in the analysis.

8.1.2 *Braces*

a) Minimum width of unflanged brace shall not be less than 1/30th of its clear length between junctions.

b) In Zones IV and V, use of diagonal bracings in vertical plane shall be encouraged. Information on detailing of RC and steel diagonal bracings is given in IS 11682.

8.1.3 *Foundation*

For isolated footings, tie beam near top of footing shall be provided as per IS 4326.

8.2. RC Shaft Staging

8.2.1 *Thickness of Shaft*

a) Minimum thickness of shaft shall be suitable for constructability which depends on height of formwork for one lift of concrete. Minimum thickness of shaft shall be 150 mm for shaft diameter up to 4 m. For larger diameter shafts, following equations shall be used to arrive at minimum thickness:

   1) For shafts with diameter less than 8 m,

   $$t_{min} = 150 + (D - 4\,000)/80 \text{ mm}$$

   2) For shafts with diameter equal to or greater than 8 m,

   $$t_{min} = 200 + (D - 8\,000)/120 \text{ mm}$$

   where

   D = diameter of shaft, in mm.

b) Additional thickening of shaft and extra vertical and circumferential reinforcement shall be provided at top and bottom level of shaft (that is, at junctions with foundation and with container). This is required to account for secondary moments and eccentricities. Additional vertical and circumferential reinforcement shall be same as that required as per design calculations.

8.2.2 *Reinforcement in Shaft*

a) Minimum vertical reinforcement shall be 0.25 percent of concrete area. The reinforcement shall be provided in two layers. The minimum diameter of vertical bars shall be 10 mm. Maximum centre-to-centre distance between vertical reinforcement in each layer shall not exceed 300 mm.

b) Circumferential reinforcement shall not be less than 0.2 percent of concrete area in vertical section. Since vertical reinforcement is provided in two layers, circumferential reinforcement shall be divided equally in two layers. The spacing of circumferential bars in each layer shall not be more than 300 mm or shell thickness, whichever is less. Circumferential reinforcement shall be placed nearer the faces of shell.

c) At horizontal construction joints in shaft, one additional layer of vertical bars projecting on either side of the joint with L_d anchorage length shall be provided. Continuity of concreting at construction joint shall be done with application of neat cement slurry.

d) *Openings in shaft* % Detailing of shaft at the opening shall take into consideration effective continuity of reinforcement at all sides. More information on detailing near openings is given in IS 11682. At vertical edges of door opening stiffeners may be required.

e) In the tank ring beams, reinforcement bars in direct tension shall have lap length twice the development length in tension. The spliced length of the ring beams in tension shall be enclosed in spirals made of bars not less than 6 mm dia with pitch not more than 100 mm, or enclosed in stirrups of 8 mm dia with pitch not more than 150 mm, the stirrups shall have 135° hooks bent into the core concrete with minimum 50 mm extension. If diameter is more than 22 mm, couplers may be used.

8.2.3 *Construction Control*

a) *Vertical Alignment* — The centre point of shaft shall not vary from its vertical axis by more than 0.2 percent of shaft height.

b) Over any height of 1.6 m, wall of shaft shall not be out of plumb by more than 10 mm.

c) *Shaft diameter* — The measured centerline diameter of shaft at any section shall not vary from the specified diameter by more than 20 mm plus 0.1 percent of the specified theoretical diameter.

d) *Shaft thickness* — The measured wall thickness shall not vary from the specified wall thickness by more than –5 mm or +10 mm.

8.2.4 *Mat Foundation*

In case of mat foundations, lifting of mat on tension side can be allowed at soil contact. The maximum eccentricity at base may be permitted up to 0.25 times the base diameter provided the maximum compression remains within permissible limits.

8.3 RC Tank and Shaft

a) In the tank ring beams, reinforcement bars in direct tension shall have lap length twice the development length in tension. The spliced length of the ring beams in tension shall be enclosed in spirals made of bars not less than 6 mm diameter with pitch not more than 100 mm, or enclosed in stirrups of 8 mm diameter with pitch not more than 150 mm, the stirrups shall have 135° hooks bent into the core concrete with minimum 50 mm extension.

b) In tank wall or shaft, not more than one-third of vertical bars shall be spliced at any section. For circumferential bars, lap length shall be 1.4 times development length in tension; the laps shall be staggered so that not more than one-third the bars shall be spliced at any one section.

8.4 Strong Column – Weak Beam

For column and beam type of staging of elevated tank, sum of moment of resistance of column at a junction should not be less than 1.1 times the sum of moment of resistance of beams in any one plane taken at a time. This check is to be applied by limit state method.

8.5 Staircase Design

Provisions of IS 11682 shall be followed for the staircase design.

(Continued from second cover)

c) Housner, G. W., 1963a, 'Dynamic analysis of fluids in containers subjected to acceleration', Nuclear Reactors and Earthquakes, Report No. TID 7024, U. S. Atomic Energy Commission, Washington D.C.

d) Housner, G. W., 1963b, 'The dynamic behavior of water tanks', Bulletin of Seismological Society of America, Vol. 53, No. 2, 381-387.

e) Jain, S. K. and Medhekar, M. S., 1993, 'Proposed provisions for aseismic design of liquid storage tanks: Part I – Codal provisions', Journal of Structural Engineering, Vol. 20, No. 3, 119-128.

f) Jain, S. K. and Medhekar, M. S., 1994, 'Proposed provisions for a seismic design of liquid storage tanks: Part II – Commentary and examples', Journal of Structural Engineering, Vol. 20, No. 4, 167-175.

g) Jaiswal, O. R. Rai, D. C. and Jain, S.K., 2004a, 'Codal provisions on design seismic forces for liquid storage tanks: a review', Report No. IITK-GSDMA-EQ-01-V1.0, Indian Institute of Technology, Kanpur.

h) Jaiswal, O. R., Rai, D. C. and Jain, S.K., 2004b, 'Codal provisions on seismic analysis of liquid storage tanks: a review' Report No. IITK-GSDMA-EQ-04-V1.0, Indian Institute of Technology, Kanpur.

i) Priestley, M. J. N., et al., 1986, 'Seismic design of storage tanks', Recommendations of a study group of the New Zealand National Society for Earthquake Engineering.

10. Veletsos, A. S., 1984, '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, N.Y., 255-370, 443-461.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value observed or calculated expressing the result of a test or analysis, shall be round off in the accordance with IS 2 : 1960 Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded value should be the same as that of the specified value in this Standard.

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Amendments Issued Since Publication

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