Seismic Design of Intze Water Tank

BY

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Seismic Design of Intze Water Tank

Major Project

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Civil Engineering
(Computer Aided Structural Analysis & Design)

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Declaration

This is to certify that

a. The thesis comprises my original work towards the Degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) at Nirma University and has not been submitted elsewhere for a degree.

b. Due acknowledgement has been made in the text to all other material used.

Rahul I. Shah

Certificate

This is to certify that the Major Project entitled **"Seismic Design of Intze Water Tank"** submitted by **Mr. Rahul I. Shah (11MCLC52)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) of Nirma University, Ahmedabad, is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

Earthquake is a natural hazard that causes damage to the structures. The damage may be in terms of lives or economy which always affects country's national growth. As Earthquake can not be predicted accurately the structural design of any structure should be such that it must resist the earthquake forces effectively.

Water tanks are considered most important structure for water distribution system. During past earthquakes the damages were observed which affected the entire water distribution network. After Bhuj earthquake more conciseness was developed which resulted in to more emphasize on seismic design approach to the water tanks. Present study focuses on seismic analysis of water tank considering frame staging.The results were compared with different parameters.The results obtaied with indian code is compared with Eurocode criteria. The design is carried out by Working Stress and Limit State approach.The Qauntity comparison is made for two methods.

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I would like to thank my guide **Prof. Jahanvi Suthar**, whose keen interest and excellent knowledge base helped me to carry out the major project work. His constant support and interest during my project equipped me with a great understanding of different aspects of the project work. He has shown keen interest in this work right from beginning and has been a great motivating factor in outlining the flow of my work.

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Abbreviation Notation and Nomenclature

WSM .... Working Stress Method

LSM .... Limit State Method

T_i .... Time period for impulsive mode

T_c .... Time period for convective mode

m_i .... Impulsive mass

m_c .... Convective mass

Z .... Zone factor

R .... Response reduction factor

V_i .... Base shear for impulsive mode

V_c .... Base shear for convective mode

A_{st} .... Area of steel

ϕ .... diameter of reinforcement

f_y .... Grade of steel

f_{ck} .... Grade of concrete

E_s .... Modulus of elasticity of steel

d .... Effective depth

D .... Overall depth

w .... Crackwidth

e_2 .... Strain due to stiffening effect

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Chapter 1

Introduction

1.1 General

Water is considered as one of the prime necessity for the survival. Water tank is a structure which is designed to store water. The water tank is considered as very important part of the water distribution system in which suitable pressure head is obtained by elevated water tank which is used in water distribution system.

The water tanks can be classified based on different parameters like type of staging, shape of container and placement of the tank.The selection of any specific type is based on site location,specific requirement, capacity of the tank and aesthetic requirements etc.

The following figures 1.1 to 1.11 shows classification of tanks based on placement,staging and shape of container.

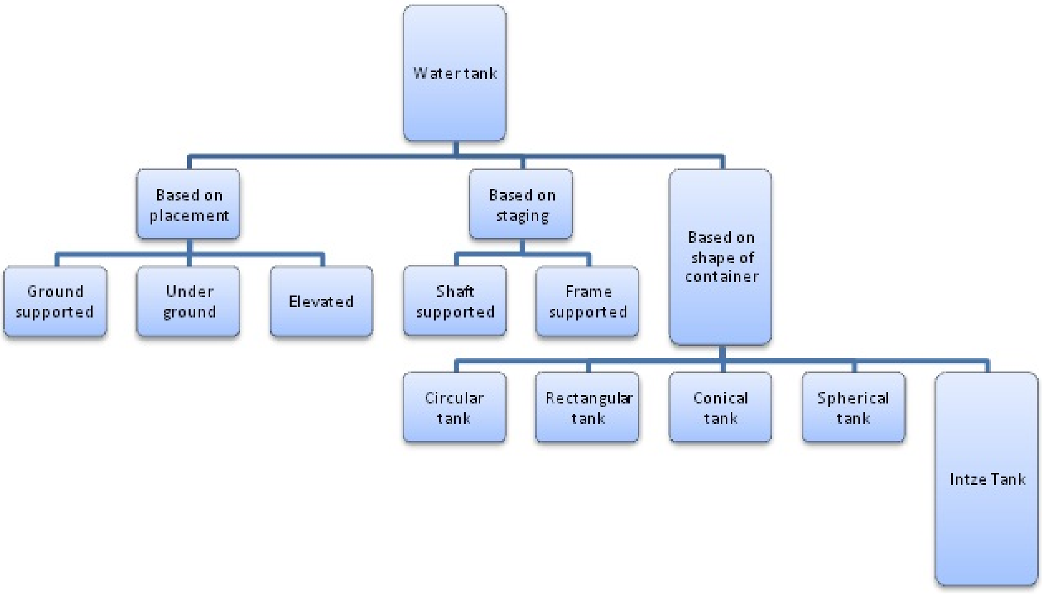

Figure 1.1: classification of tanks

- Based on Placement

Figure 1.2: Ground supported tanks

Figure 1.3: Under Ground tank

Figure 1.4: Elevated tank

- Based on Staging

Figure 1.5: Shaft Supported tank

Figure 1.6: Frame Supported tank

- Based on shape of container

Figure 1.7: Circular tank

Figure 1.8: Rectangular tank

Figure 1.9: Conical tank

Figure 1.10: Spherical tank

Figure 1.11: Intze tank

1.2 Need of the study

Water tanks are considered as very important element in the water distribution system. The entire community of the area is directly depends on it for the water requirement. At time of earthquake it is most important to have surety about the safe behavior of the water tank. The damage of the water tank affects water supply, economical loss and fails to provide water at the time of fire if any.

Due to such reasons it is very important to design the water tank considering the effects of earthquake so that desired performance under the seismic loadings can be achieved. Although it is very difficult to predict the intensity of the earthquake but based on available guidelines from different research and codal provisions the attempt is required to be made for seismic design of the water tanks.

1.3 Objective of Study

- To design the components of water tank considering the seismic approach as per IS 1893 (draft) /IIT GSDMA [5] guidelines.
- To compare the results obtained with Euro code criteria
- To Design the water tank as per Working Stress Method and Limit State Method

1.4 Scope of the work

To achieve above mentioned objectives, following scope of work is proposed.

- Study of various codes/guidelines related to seismic design approach
- Calculation of forces as per IIT GSDMA [5] guide lines (IS 1893 part II Draft code)for intze type of tank
- Comparison of results with different parameters

- Comparison of available results with Euro code criteria
- Design the components of Frame supported Intze Tank as per Limit State Method and Working Stress Method
- Computation of quantity of steel as per Limit State Method and Working Stress Method
- Computation of quantity of concrete as per Limit State Method and Working Stress Method

1.5 Organization of Report

The Major Project-I is divided into seven chapters. They are as follows:

Chapter 2 comprises of literature review covering various research papers, report etc. It focuses on various studies carried out to analyze the water tank considering seismic approach. It also includes papers discussing importance of response reduction factor in design of water tank.

Chapter 3 gives steps of analysis of the elevated intze tank as per Indian and European guidelines.Based on the worksheet prepared, comparison of results are made with different parameters.

Chapter 4 covers the design of tank as per Working Stress Method. The component design of water tank is carried out for different capacity of the tank.The structural details are provided based on the design.

Chapter 5 covers the design of tank as per Limit Stress method. The component design of water tank is carried out for different capacity of the tank.The structural details are provided based on the design.

Chapter 6 gives the comparison of the material quantity based on Limit State method and Working Stress method design of tank as per Limit Stress method.

Chapter 7 includes the summary of the study, conclusions and future scope of work.

Chapter 2

Literature Survey

2.1 General

Literature survey is carried out to be familiar with the amount of work done in the area throughout the world. The survey gives ideas about the extent of work to be carried out during project. It helps in framing the scope of work. It also helps in deciding the line of action of work. It generates the clear vision of the work and gives the overall scenario of it. During this survey many new things, concepts, and ideas will emerge which improve the clarity of the topic.

2.2 Lateral Strength assessment and provisions for seismic design of tank

Rai[3] carried out study for the lateral strength assessment of the damaged shaft supported water tanks past Bhuj Earthquake in design point of view. Lateral strength analyses of a few damaged shaft type stagings clearly show that all of them either met or exceeded the requirements of IS:1893-1984, however, they were all found deficient when compared with requirements of International Building Code in similar seismic exposure conditions. IS:1893-1984 design forces are unjustifiably low for these systems which do not have advantage of ductility and redundancy. The code's much higher degree of reliance on ductility to reduce design forces does not yield satisfactory performance; these forces are currently being grossly underestimated. A response reduction factor equal to 2 is proposed to be used with the revised code IS:1893-2002 for such structures, which provides reasonably safe design forces.

Jain and Jaiswal[1] recognized the limitations and shortcomings in the provision of IS 1893:1984; authors had suggested a set of provisions on aseismic design of liquid storage tanks.In this paper, which is in two parts, a set of modified provisions on aseismic design of liquid storage tanks are proposed. The major modifications are: (i) Design horizontal seismic coefficient given in revised IS 1893 (Part 1): 2002 is used and values of response reduction factor for different types of tanks are proposed. (ii) Different spring-mass models for tanks with rigid and flexible walls are done away with; instead, a single spring-mass model for both types of tank is proposed. (iii) Expressions for convective hydrodynamic pressure are corrected. (iv) Simple expression for sloshing wave height is used. (v) New provisions are included to consider the effect of vertical excitation and to describe critical direction of earthquake loading for elevated tanks with frame type staging.

Jaiswal, Rai and Jain[4] has stated that Liquid storage tanks generally possess lower energy-dissipating capacity than conventional buildings. During lateral seismic excitation, tanks are subjected to hydrodynamic forces. These two aspects are recognized by most seismic codes on liquid storage tanks and, accordingly, provisions specify higher seismic forces than buildings and require modeling of hydrodynamic forces in analysis. In this paper, provisions of ten seismic codes on tanks are reviewed and compared. This review has revealed that there are significant differences among these codes on design seismic forces for various types of tanks. Reasons for these differences are critically examined and the need for a unified approach for seismic design of tanks is highlighted.

2.3 Codal provisions

2.3.1 ACI COMMITTEE 350(ACI350.3R-01)

ACI COMMITTEE 350(ACI350.3R-01)[12] has made following recommendations

- Instead of assuming a rigid tank directly accelerated by ground acceleration, this documents assumes amplification of response due to natural frequency of the tank
- To includes the response modification factor;
- Rather than combining impulsive and convective modes by algebraic sum, this document combines these nodes by squareroot-sum-of-the-squares
- Inclusion of the effects of vertical acceleration and an effective mass coefficient, applicable to the mass of the walls.

2.3.2 NICEE,IIT Kanpur (IITK GSDMA guidelines)

NICEE,IIT Kanpur (IITK GSDMA guidelines)[5]contains provisions on liquid retaining tanks. This standard incorporates the following important provisions and changes for elevated water tanks

- For elevated tanks, the single degree of freedom idealization of tank is replaced by a two-degree of freedom idealization and is used for analysis.
- The effect of convective hydrodynamic pressure is included in the analysis.
- 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.

The above criteria are supported by Explanatory Examples for different types of tanks and conditions.

2.4 Summary

In this chapter, review of relevant literature is carried out. The review of literature includes study of Seismic provisions,lateral strength assessment, seismic parameters and codal guidelines for analysis of the tank.

Chapter 3

Analysis of tank

3.1 Introduction

Seismic activity prone countries across the world rely on "codes of practice" to mandate that all constructions fulfill at least a minimum level of safety requirements against future earthquakes. As the subject of earthquake engineering has evolved over the years, the codes have continued to grow more sophisticated.

After Bhuj earthquake GSDMA and IIT Kanpur had took up the task to formulate the design guidelines for the water tanks as there is no separate code for the same and water tanks were also suffered huge damage during earthquake.

The document has been prepared considering various countries' code of practices for seismic design of water tanks. After the effort the team ,NICEE has published document called "IITK-GSDMA GUIDELINES for SEISMIC DESIGN OF LIQUID STORAGE TANKS Provisions with Commentary and Explanatory Examples"[5].

3.1.1 Provisions in IIT GSDMA guidelines

As compared to provisions of IS 1893:1984, in this Guidelines following important provisions and changes have been incorporated in IIT GSDMA guidelines[5]:

- Analysis of ground supported tanks is included.
- 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.
- Bracing beam flexibility is explicitly included in the calculation of lateral stiffness of tank staging.
- The effect of convective hydrodynamic pressure is included in the analysis.
- 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.
- Effect of vertical ground acceleration on hydrodynamic pressure is considered.

After the commentary part six solved examples are given as per the provisions in document.

3.2 Geometry of tank

Intze shape of the container is most common type for storing water for municipal water distribution system.The following are major parts of the container and staging for Intze tank.

- Top Dome
- Top Ring Beam
- Cylindrical Wall
- Bottom Ring Beam
- Circular Ring Beam
- Bottom Dome
- Conical Dome

- Staging
- Braces
- Columns

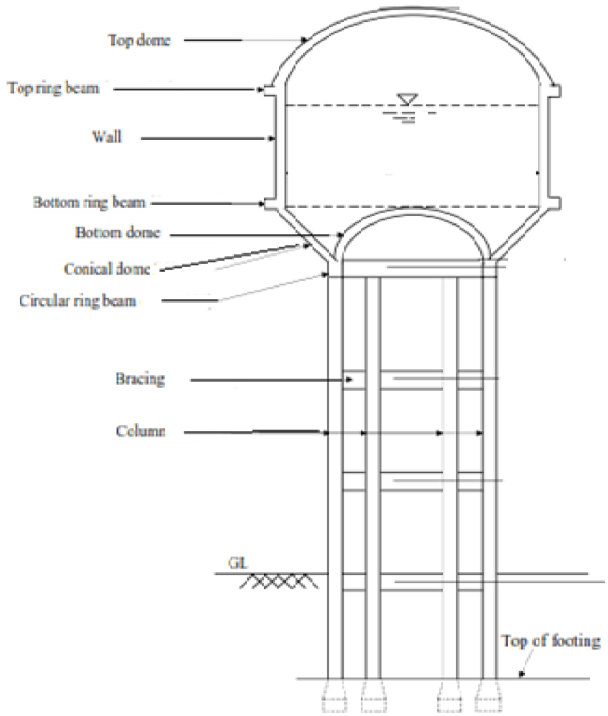

Figure 3.1: Components of Intze tank

3.3 Problem Formulation

Problem Data

Capacity: 250 m^3

Seismic zone: IV

Soil type: Hard

Height of staging from GL 15.7 m

3.4 Steps for analysis of intze tank

Following are the steps for analysis of intze tank consisting frame staging

- Step 1 Requirement of Preliminary Data (size of various members of the tank considering capacity of the tank)
- Step 2 Weight calculations of the various members (weight of staging, weight of container)
- Step 3 Center of Gravity of Empty Container
- Step 4 Parameters of Spring Mass Model (impulsive mass and convective mass)
- Step 5 Lateral Stiffness of Staging
- Step 6 Time Period (impulsive mode and convective mode)
- Step 7 Design Horizontal Seismic Coefficient (impulsive mode and convective mode)
- Step 8 Base shear calculations
- Step 9 Base moment calculations
- Step 10 Sloshing wave height

3.4.1 As per IS 1893:Part II (Draft)

- Step 1 Requirement of Preliminary Data (size of various members of the tank considering capacity of the tank)

Problem Data

Capacity: 250 m^3

Seismic zone: IV

Soil type: Hard

Height of staging from GL 15.7 m

Components Size

Table 3.1: Sizes of components of container and staging

Component	Size
Top dome	120 mm thick
Top ring beam	250 mm x 300 mm
Cylindrical wall	200 mm thick
Bottom ring beam	500 mm x 300 mm
Circular ring beam	500 mm x 600 mm
Bottom dome	200 mm thick
conical dome	250 mm thick
Column Braces	300 mm x 600 mm
Column	650 mm diameter

Proportioning of tank

Table 3.2: Proportioning of tank

Component	Size in m
D	7.52
H	5.01
h0	1.41
h1	1.25
D0	4.70
h2	0.78

Capacity = 257.23 m^3 ....ok

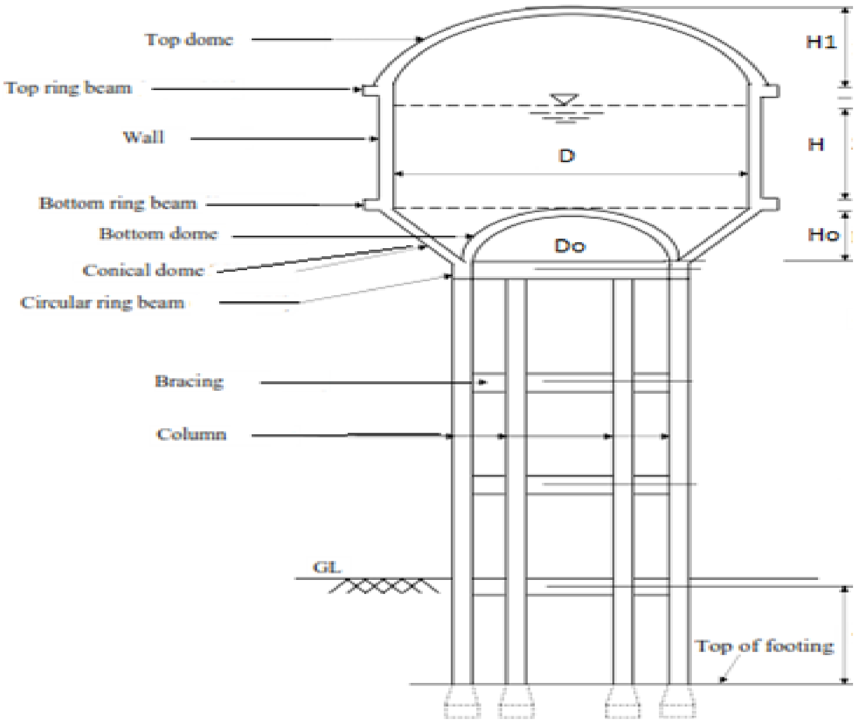

Figure 3.2: Intze tank

- Step 2 Weight calculations of the various members (weight of staging, weight of container)

Weight Calculations

Weight of Empty container = 1311.331 kN

Weight of staging = 1035.801 kN

Weight of Empty container + 1/3 weight of staging = 1656.598 kN

Table 3.3: Weight calculations

Component	Weight in kN
Top dome	118.053
Top ring beam	45.742
Cylindrical wall	607.224
Bottom ring beam	94.430
Bottom dome	96.270
Circular ring beam	110.675
conical dome	238.94
Water	2523.427
Braces	254.34
Column	781.461

- Step 3 Center of Gravity of Empty Container

Centre of Gravity for empty container above top of circular ring beam = 3.292

- Step 4 Parameters of Spring Mass Model (impulsive mass and convective mass)

mi = 185266.4 kg

mc = 76158.66 kg

mi+mc = 261425.1 kg

Total mass = 257230.1 kg

Difference in % = 1.6% less than 2%

- Step 5 Lateral Stiffness of Staging

Stiffness from stadd model = 1.92E07 N/m

- Step 6 Time Period (impulsive mode and convective mode)

Full tank condition

Time period for impulsive mode

$$T_i = 2\pi\sqrt{\frac{m_i + m_s}{K_s}} \tag{3.1}$$

$T_i = 0.8531 seconds$

Time period for convective mode

$$T_c = C_c\sqrt{\frac{D}{g}} \tag{3.2}$$

$C_c = 3.2865$

$T_c = 2.8766 seconds$

- Step 7 Design Horizontal Seismic Coefficient (impulsive mode and convective mode)

For impulsive mode

$$(A_h)_i = \frac{Z}{2}\frac{S_a}{g}\frac{I}{R} \tag{3.3}$$

Z = 0.24

I = 1.5

R = 2.25

Sa/g = 1.16 (Damping 5%)

Ti = 0.8531 seconds

For Convective mode

$$(A_h)_c = \frac{Z}{2}\frac{S_a}{g}\frac{I}{R} \tag{3.4}$$

Z = 0.24

I = 1.5

R = 2.25

Sa/g = 1.16 (Damping 0.5%)

Tc = 2.8766 seconds

- Step 8 Base shear calculations

Base shear at bottom of staging

$$V_i = (A_h)_i(m_i + m_s)g \tag{3.5}$$

Vi = 322.392 kN

$$V_c = (A_h)_c m_c g \tag{3.6}$$

Vc = 36.360 kN

$$V = \sqrt{(V_i^2 + V_c^2)} \tag{3.7}$$

V = 324.436 kN

- Step 9 Base moment calculations

Base Moment calculations

$$M_i^* = (A_h)_i[m_i(h_i^* + h_s) + m_s h_{cg}]g \tag{3.8}$$

M_i^* = 6225.59 kN-m

$$M_c^* = (A_h)_c m_c(h_c^* + h_s)g \tag{3.9}$$

M_c^* = 746.263 kN-m

$$M = \sqrt{(M_i^*)^2 + (M_c^*)^2} \tag{3.10}$$

M = 6270.16 kN-m

- Step 10 Sloshing wave height

$$d_{max} = (A_h)_c RD/2 \tag{3.11}$$

$d_{max} = 0.411$ m

All above steps are repeated for tank empty condition.

- Result table

The following table shows the base shear and base moment comparison for tank empty and tank full condition.

Table 3.4: Result table

Condition	Tank Full	Tank empty	Remark
shear force in kN	324.436	224.942	Tank full critical
Base moment in kN-m	6270.16	4272.19	Tank full critical

3.4.2 As per EC 8 (Part IV)

The tank liquid system is modeled by two singled degree of freedom systems one corresponding to the impulsive component, involving together with the flexible wall, and the other corresponding to the convective component. The impulsive and convective responses are combined by taking their numerical sum.

In this analysis the above steps up to 5 remain same while time periods for convective and impulsive mass is calculated from below formula

$$T_{imp} = C_i \frac{\sqrt{\rho}H}{\sqrt{S/R}\sqrt{E}} \tag{3.12}$$

$$T_{con} = C_c \sqrt{R} \tag{3.13}$$

where: H = height to the free surface of the liquid

R= tank's radius

S = equivalent uniform thickness of the tank wall

ρ = mass density of liquid.

E = Modulus of elasticity of tank material.

The C_i and C_c can be obtained depending upon the H/R ratio while the m_i and m_c can also be evaluated from linear interpolation from the table A2 of the EC 8 part IV.

The base shear can be calculated from the formula given below.

$$Q = (m_i + m_w + m_r)S_c T_{imp} + m_c s_c T_{con} \tag{3.14}$$

Where

m_w=mass of tank wall

m_r= mass of tank roof

T_{imp}= Time period for Impulsive mode

T_{con} =Time period for convective mode

S_c = Spectral acceleration

The base moment can be calculated from the formula given below.

$$M = (m_i h_i + mwh_w + mrh_r)S_c T_{imp} + m_c h_c s_c T_{con} \tag{3.15}$$

where,

h_w= height of the centre of gravity of the tank wall

h_r= height of the centre of gravity of the tank roof

h_c= height of the centre of gravity of the convective mass

3.5 Result comparison for different parameters

The results obtained from above method are compared for different variables like,

- Seismic Zone
- Capacity
- Response reduction factor

The base shear and base moment are compared with above parameters.

- Seismic Zone

Figure 3.3 shows relationship between seismic zone and base shear.

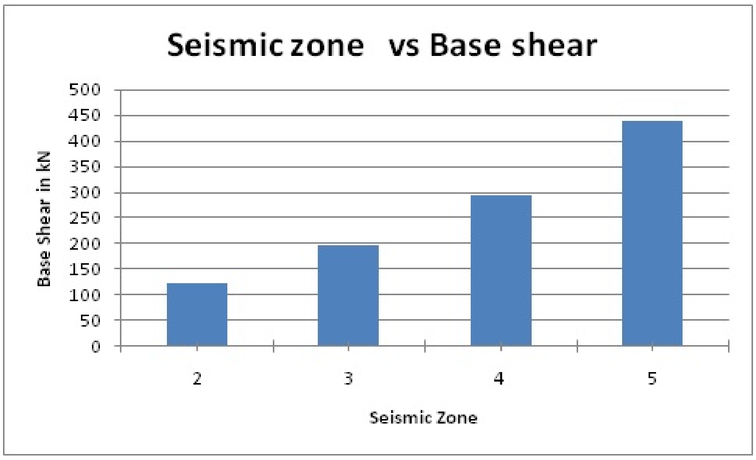

Figure 3.3: Seismic zone Vs Base shear of tank

Figure 3.4 shows relationship between seismic zone and overturning moment.

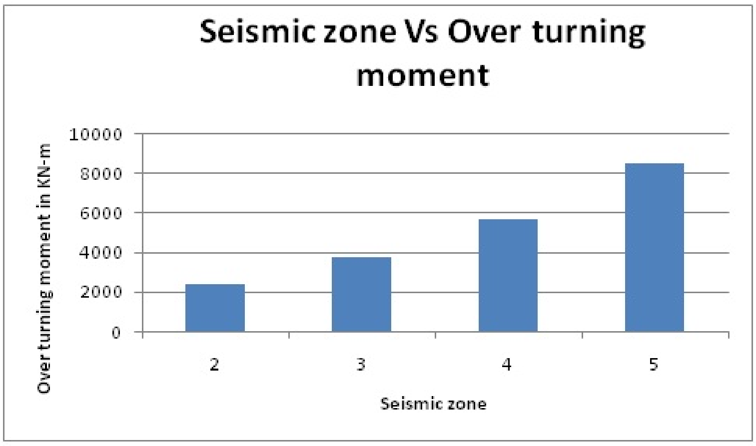

Figure 3.4: Seismic zone Vs overturning moment

- Capacity

Figure 3.5 shows relationship between capacity and base shear.

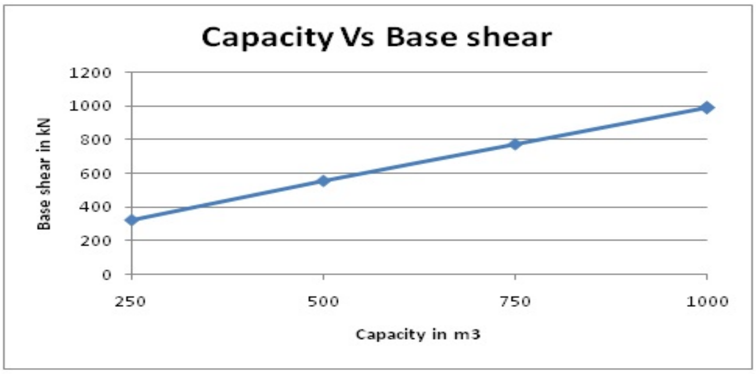

Figure 3.5: Capacity Vs Base shear

Figure 3.6 shows relationship between capacity and over turning moment.

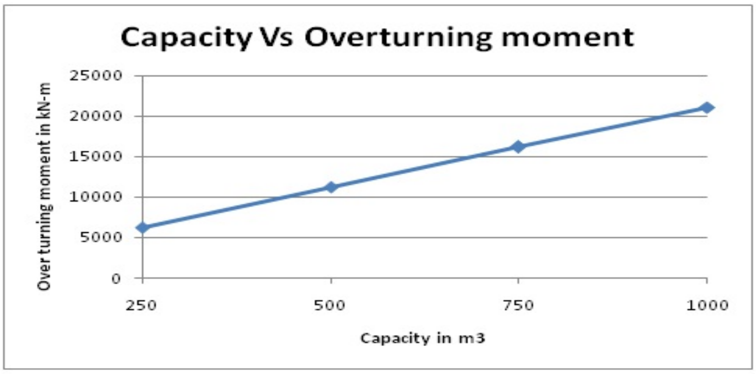

Figure 3.6: Capacity Vs overturning moment

- Response reduction factor

Figure 3.7 shows relationship between response reduction factor and base shear.

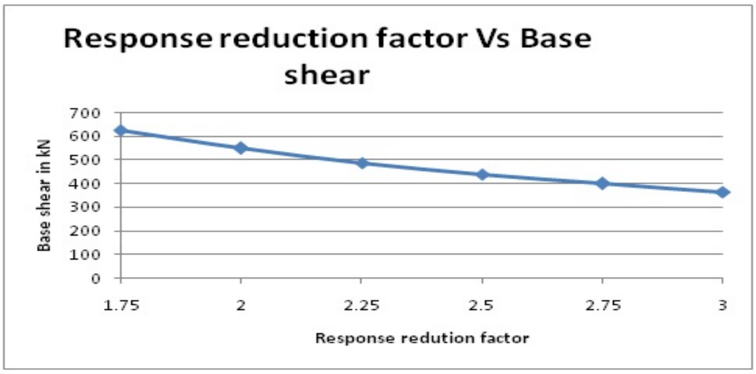

Figure 3.7: Response reduction factor Vs Base shear

Figure 3.8 shows relationship between response reduction factor and overturning moment.

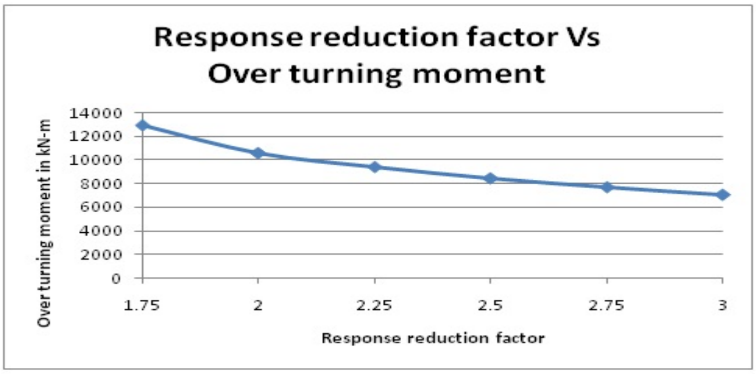

Figure 3.8: Response reduction factor Vs overturning moment

3.5.1 Comparison with Indian and Euro code criteria

The results obtained with both codal criteria are tabulated below.The base shear and base moment results are compared for both guidelines.

Table 3.5: Comparison of base moment and base shear

Capacity	Indian	Guidelines	Eurocode	
	Base shear	Base moment	Base shear	Base moment
	kN	kN-m	kN	kN-m
250	324	6270.14	292	5594
500	554.46	11199.96	483.36	10208.23
750	773.43	16094.02	641.62	14953.23
1000	986.42	21002.84	858.36	19228.23

Figure 3.9 shows comparison between Indian and Eurocode for base shear.

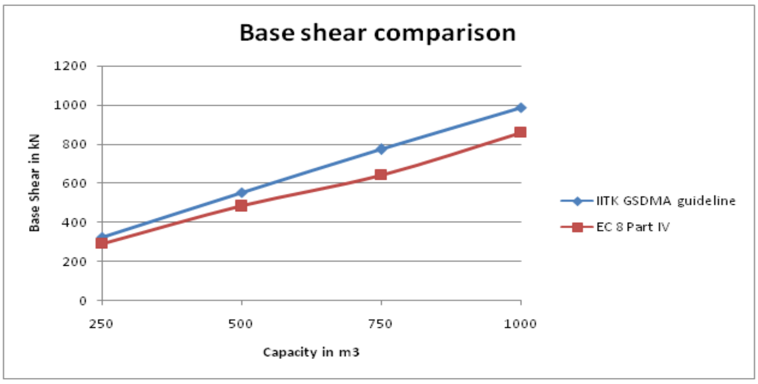

Figure 3.9: Base Shear comparison

Figure 3.10 shows comparison between Indian and Eurocode for base moment.

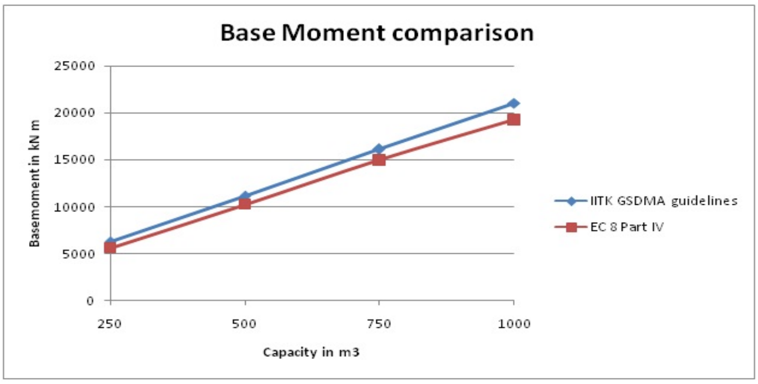

Figure 3.10: Base Moment comparison

3.6 Results and Discussion

From the analysis the base shear and base moment calculated from IITK GSDMA which is compared with various parameters. The seismic zone V exhibits 3.6 times more value than Zone II. While response reduction factor shows linear behavior which is one of the governing parameter of the analysis. Indian guidelines provide higher results of Base moment and base shear by 7% to 11% as compared with EC8.

3.7 Summary

The chapter deals with seismic analysis of Intze tank with frame staging. The result comparison is made for tank empty and full condition.The results are studied with different parameters. The analysis is also carried out as per Eurocode 8 criteria and results obtaied are compared with Indian guidelines.

Chapter 4

Design of Tank using Working Stress Method

4.1 Introduction

This chapter presents the design of different components of the tank using the Working Stress Method.The tank of different capacity are designed as per WSM concept. In this method of design, stresses acting on structural members are calculated based on elastic method and they are designed not to exceed certain allowable values. In fact, the whole structure during the lifespan may only experience loading stresses far below the ultimate state and that is the reason why this method is called working stress approach.

4.2 Problem Formulation

Problem Data

Capacity: 1000 m^3

Seismic zone: IV

Soil type: Hard

Height of staging from GL 15.7 m

Components Size

Table 4.1: Sizes of components of container and staging

Component	Size
Top dome	120 mm thick
Top ring beam	250 mm x 300 mm
Cylindrical wall	350 mm thick
Bottom ring beam	1200 mm x 600 mm
Circular ring beam	600 mm x 900 mm
Bottom dome	300 mm thick
conical dome	500 mm thick
Column Braces	500 mm x 500 mm
Column	800 mm diameter

4.3 Design of components for different capacity

Proportioning of tank

The following dimensions are adopted for required capacity

Table 4.2: Proportioning of tank

Component	Size in m
D	11.93
H	7.95
h0	2.24
h1	1.99
D0	7.46
h2	1.24

Capacity = 1028.92 m^3 ....ok (Appendix B)

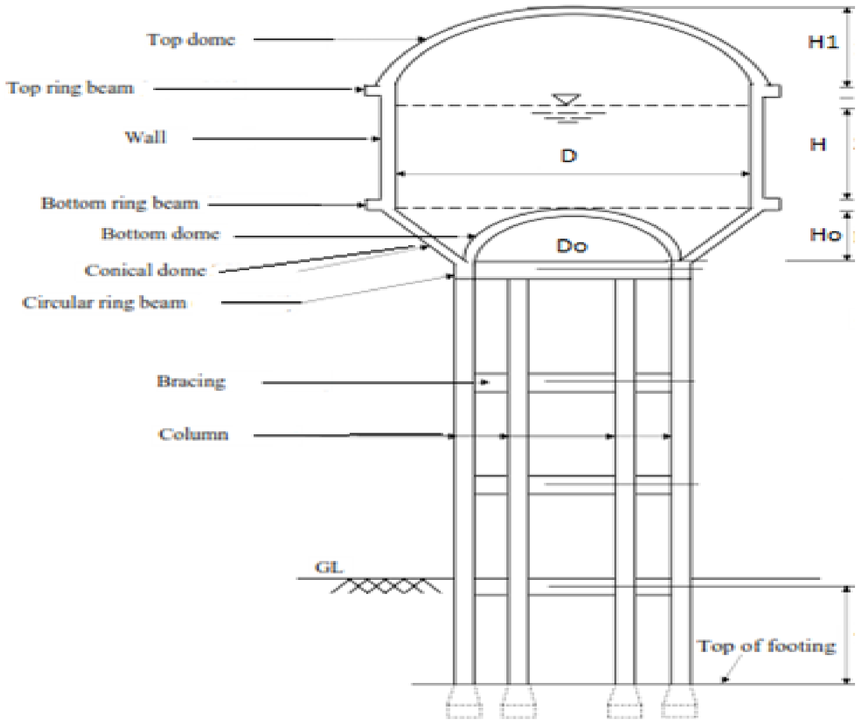

Figure 4.1: Intze tank

4.3.1 Effects of Continuity

Due to monolithic construction, the deformation of different element of the tank is restrained and results in to secondary forces.

The dotted line shows independent deformation behavior while the solid line shows the restrained behavior.

Continuity Analysis

- **Maximum deflection and stiffness at edges**

- Top dome

$$Slope\phi atedge = \frac{2qrsin\theta}{Et} \tag{4.1}$$

ϕ = 447.3/E radian

Moment Stiffness M = 1.525 E kN-m/m per radian

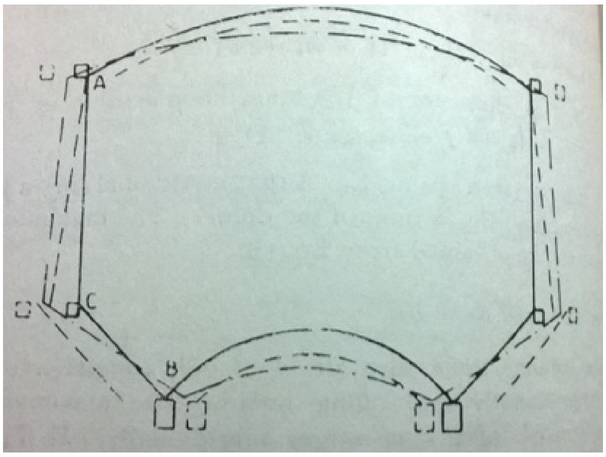

Figure 4.2: Effects of Continuity

Radial force H = 4.2x 10^{-4} E kN/m per radian

Thrust Stiffness = 2.22x10^{-3} E kN/m

Corresponding moment M = 4.2x10^{-4} kN-m/m

- Ring beam

Radial thrust to cause unit deflection = 0.015 E kN/m

Moment per unit circumference = 1.13 E kN m/m

- Wall

Maximum stiffness = 3.469 x 10^{-4}

Corresponding thrust = 8.36 x 10^{-4}

Clock wise slope of the wall = 2162/E radians

- Middle ring beam

Outward thrust to cause unit deflection = 0.162 E kN/m Radial moment to cause unit rotation = 2.36 E kN m

- Conical dome

Outward deflection at top = 1369.1/E in m

slope at edge = 628.92/E radians

Reactions due to continuity

Table 4.3: Reactions due to continuity

Element	Moment in kN-m	Thrust(Comp) in kN
Dome	21.56	5.28
Top ring beam	2.18	4.16
Wall	18.12	7.12

Component Design

- **Top Dome**

Meridional force = 24.85 kN/m

Circumferential force = 10.94 kN/m

- **Top Ring beam**

Hoop tension = 116.61 kN

- **Cylindrical wall**

Table 4.4: Forces in cylindrical wall

Height in m	Maximum Water Pressure kN/m2	Hoop Tension in kN
0 - 2	19.62	117.03
2 - 4	39.24	234.07
4 - 6	58.86	351.1
6 - 7.95	78.02	465.41

- **Middle ring beam**

Total Load V1 = 80.54 kN/m

T1 = 113.90kN/m

H1 = 313.25 kN

- **Conical dome**

Perimeter load V2 = 423.25 kN/m

Compression stress = 1.2 Mpa ....Ok

Hoop tension = 621.36 kN

- **Bottom spherical dome**

Weight of water above bottom spherical dome = 3625.23 kN Meridional force = 296.36 kN/m

Circumferential force = 105.59 kN

- **Bottom circular girder**

Hoop compression = 582.52 kN

Compressive stress = 0.97 Mpa ....Ok

Total load = 598.21 kN/m

Maximum negative bending moment = 775.69 kN-m

Maximum positive bending moment = 392.46 kN-m

Maximum torsion = 68.25 kN-m

Maximum Shear force = 1166 kN

Shear force at which the shear force is maximum = 596.36 kN

- **Column**

Total load on column = 3007.37 kN

Moment = 69.25 kN-m

diameter of column = 800 mm

$$\frac{\sigma_c}{\sigma_{cc}} + \frac{\sigma_{bc}}{\sigma_{cbc}} = 0.77 < 1...ok \tag{4.2}$$

- **Bracing**

Moment in brace = 178.38 kN-m

Shear in brace = 98.38 kN

- **Foundation - Annular Raft**

Vertical load at foundation level = 19846 kN

SBC = 250 kN/m^2

Area required = 79.38 m^2

Inner diameter D_i = 3.96 m

Outer diameter D_o = 10.96 m

Self weight + vertical loading = 862.2 kN-m

Maximum negative bending moment = 862 kN-m

Maximum positive bending moment = 512 kN-m

Maximum radial moment M_r = 432 kN-m

Maximum tangential moment M_t = 382 kN-m

4.4 Structural details for different capacity of tank

4.4.1 250m^3capacity tank

The following table shows the proposed structural details for 250 m^3 capacity tank.

Table 4.5: Structural details for 250 m^3 capacity

Component	Size	Ast in mm^2	Details
Top dome	120 mm thick	288	8ϕ @ 150 c/c
Top ring beam	250 mm x 300 mm	813	8 -12ϕ
Cylindrical wall	Tapered (200-300)mm	1129	20ϕ @ 180 c/c both face
Middle ring beam	400 mm x 800 mm	1325	8 -16ϕ
Conical wall	350 mm thick	3236	20ϕ @ 200 c/c both face
Bottom spherical dome	300 mm	600	10ϕ @ 220 c/c both face
Bottom circular girder	400 mm x 700 mm	2325	8-20ϕ bottom 8-20ϕ top
Column	650 mm dia	3015	10 -25ϕ
Brace	400 mm x 400 mm	1658	8 -16ϕ
Circular beam (Foundation)	600 mm x 800 mm	2455	8 -20ϕ
Raft	600 mm thick	1169	16ϕ @180c/c bothways

4.4.2 500m^3capacity tank

The following table shows the proposed structural details for 500 m^3 capacity tank.

Table 4.6: Structural details for 500 m^3 capacity

Component	Size	Ast in mm^2	Details
Top dome	120 mm thick	288	8ϕ @ 150 c/c
Top ring beam	250 mm x 300 mm	813	8 -12ϕ
Cylindrical wall	Tapered (300-350)mm	1689	20ϕ @ 160 c/c both face
Middle ring beam	500 mm x 900 mm	1672	10 -16ϕ
Conical wall	400 mm thick	3236	20ϕ @ 180 c/c both face
Bottom spherical dome	300 mm	600	10ϕ @ 220 c/c both face
Bottom circular girder	500 mm x 800 mm	2896	8-20ϕ bottom 10-20ϕ top
Column	700 mm dia	3698	10 -25ϕ
Brace	450 mm x 450 mm	2100	8 -16ϕ
Circular beam (Foundation)	750 mm x 900 mm	2980	10 -20ϕ
Raft	700 mm thick	1169	20ϕ @180c/c bothways

4.4.3 750m^3capacity tank

The following table shows the proposed structural details for 750 m^3 capacity tank.

Table 4.7: Structural details for 750 m^3 capacity

Component	Size	Ast in mm^2	Details
Top dome	120 mm thick	288	8ϕ @ 150 c/c
Top ring beam	250 mm x 300 mm	813	8ϕ -12
Cylindrical wall	Tapered (300-350)mm	1880	20ϕ @ 150 c/c both face
Middle ring beam	500 mm x 1000 mm	1982	10 - 20ϕ
Conical wall	450 mm thick	3789	20ϕ @ 160 c/c both face
Bottom spherical dome	300 mm	600	10ϕ @ 220 c/c both face
Bottom circular girder	500 mm x 800 mm	3265	8-20ϕ bottom 10-20 top
Column	750 mm dia	4256	12 -25ϕ
Brace	500 mm x 500 mm	2100	8 -16ϕ
Circular beam (Foundation)	800 mm x 1000 mm	3456	10 -25ϕ
Raft	800 mm thick	1260	20ϕ @170c/c bothways

4.4.4 1000m^3capacity tank

The following table shows the proposed structural details for 1000 m^3 capacity tank.

Table 4.8: Structural details for 1000 m^3 capacity

Component	Size	Ast in mm^2	Details
Top dome	120 mm thick	288	8ϕ @ 150 c/c
Top ring beam	300 mm x 300 mm	813	8 -12ϕ
Cylindrical wall	Tapered (300-400)mm	2013	20ϕ @ 150 c/c both face
Middle ring beam	600 mm x 1200 mm	2088	10 - 20ϕ
Conical wall	500 mm thick	4142	20ϕ @ 140 c/c both face
Bottom spherical dome	300 mm	600	10ϕ @ 200 c/c both face
Bottom circular girder	600 mm x 900 mm	3528	8-25ϕ bottom 10-25ϕ top
Column	800 mm dia	4523	12 -25ϕ
Brace	500 mm x 500 mm	2100	8 -20ϕ
Circular beam (Foundation)	900 mm x 1200 mm	3693	10 -25ϕ
Raft	800 mm thick	1543	20ϕ @150c/c bothways

4.5 Summary

This chapter deals with the component design of Intze tank for different capacity.In analysis of tank container the concept of continuity is also considered.The Structural details are proposed for all components of the tank for different capacity based on working stress method.

Chapter 5

Design of tank using Limit State Method

5.1 Introduction

This chapter presents the design of different components of the tank using the Limit State Method.The tank of different capacity are designed as per LSM concept. The design is based upon the IS 3370 part II 2009 in which the limit state approach is discussed.The crack width calculations are carried out as per Annexure A and B of the said code.

5.1.1 IS 3370 Part II:2009 Codal provisions

The following criteria are discussed in the Annexure A in IS 3370 Part II:2009 [11] codal guidelines.

- **Assessment of crack widths in flexure**

The strain in the tension reinforcement is limited to 0.8 f_y/E_s and the stress in the concrete is limited to 0.45 f_cu.the design surface crack Width may be calculated from equation.

$$w = \frac{3a_{cr}e_m}{1 + \frac{2(a_{cr} - C_{Mean})}{D-x}} \tag{5.1}$$

Where

w =design surface crack width.

a_{cr} =distance from the point considered to the surface of the nearest longitudinal bar.

e_m = average strain at the level where the cracking is being considered.

C_{Mean} =minimum cover to the tension steel

D =overall depth of the members

x =depth of neutral axis

- **Average strain in flexure**

The average strain at the level where cracking is being considered. is assessed by calculating the apparent strain using characteristic loads and normal clastic theory . Where flexure is pre dominant hut some tension exists at the section. the depth of the neutral axis should be adjusted. The calculated apparent strain, e_1 is then adjusted to take into account the stiffening effect of the concrete between cracks e_1.

$$e_m = e_1 - e_2 \tag{5.2}$$

where

e_m = average strain at the level where cracking is being considered

e_1 = strain at the level considered

e_2 = strain due to stiffening effect of concrete between cracks.

- **Stiffening effect of concrete in flexure**

For a limiting design surface crack width of 0.2 mm,

$$e_2 = \frac{b_t(D-x)(a'-x)}{3E_sA_s(d-x)} \tag{5.3}$$

For a limiting design surface crack width of 0.1 mm,

$$e_2 = \frac{1.5b_t(D-x)(a'-x)}{3E_sA_s(d-x)} \tag{5.4}$$

where

e_1 = strain at the level considered

e_2 = strain due to the stiffening effect of concrete between cracks.

b_t = width of section at the centroid of the tension steel

D = overall depth of the member

x = depth of the neutral axis

E_s = modulus of elasticity of reinforcement

A_s = area of tension reinforcement

d = effective depth

a'= distance from the compression face to the point at which the crack width is being calculated.

- **Assessment of crack widths in direct tension**

The strain in the reinforcement is limited to 0.8 f_y/E_s.the design crack width may be calculated from equation,

$$w = 3a_{cr}e_m \tag{5.5}$$

- **Stiffening effect of concrete in direct tension**

For a limiting design surface crack width of 0.2 mm,

$$e_2 = \frac{2b_tD}{3E_sA_s} \tag{5.6}$$

For a limiting design surface crack width of 0.1 mm,

$$e_2 = \frac{b_tD}{E_sA_s} \tag{5.7}$$

where

b_t = Width of the: section at the centroid of the tension steel

D = Overall depth of the member

E_s = Modulus of elasticity of reinforcement

A_s = Area of tension reinforcement.

5.2 Problem Formulation

The same data is considered as of Chapter 4,

Problem Data

Capacity: 1000 m^3

Seismic zone: IV

Soil type: Hard

Height of staging from GL 15.7 m

Apart from the analysis carried out in chapter 4, the following calculations as per IS 3370 patt IV is carried out for container.

- **Assessment of crack widths in direct tension - cylindrical wall**

Limiting Strain $e_1 = 0.00166$

Strain due to the stiffening effect $e_2 = 0.000326$

Average strain at the level $e_m = 0.001334$

Crack width w = 0.986 mm

- **Assessment of crack widths in flexure - Middle ring beam**

Limiting Strain $e_1 = 0.00166$

Strain due to the stiffening effect $e_2 = 0.000426$

Average strain at the level $e_m = 0.00123$

Crack width w = 0.1016 mm < 0.2 mm ... ok

5.3 Structural details for different capacity of tank

5.3.1 250m^3capacity tank

The following table shows the proposed structural details for 250 m^3 capacity tank.

Table 5.1: Structural details for 250 m^3 capacity

Component	Size	Ast in mm^2	Details
Top dome	120 mm thick	288	8ϕ @ 150 c/c
Top ring beam	250 mm x 300 mm	789	8 -12ϕ
Cylindrical wall	Tapered (200-300)mm	1056	20ϕ @ 200 c/c both face
Middle ring beam	400 mm x 700 mm	1325	8 -12ϕ
Conical wall	350 mm thick	3132	20ϕ @ 220 c/c both face
Bottom spherical dome	300 mm	600	10ϕ @ 220 c/c both face
Bottom circular girder	400 mm x 700 mm	2122	8-16ϕ bottom 8-20ϕ top
Column	600 mm dia	3015	10 -20ϕ
Brace	350 mm x 350 mm	1591	8 -12ϕ
Circular beam (Foundation)	600 mm x 800 mm	2069	10 -16ϕ
Raft	600 mm thick	1169	16ϕ @180c/c bothways

5.3.2 500m^3capacity tank

The following table shows the proposed structural details for 500 m^3 capacity tank.

Table 5.2: Structural details for 500 m^3 capacity

Component	Size	Ast in mm^2	Details
Top dome	120 mm thick	288	8ϕ @ 150 c/c
Top ring beam	250 mm x 300 mm	813	8 -12ϕ
Cylindrical wall	Tapered (300-350)mm	1149	20ϕ @ 190 c/c both face
Middle ring beam	500 mm x 800 mm	1362	8 -16ϕ
Conical wall	400 mm thick	3076	20ϕ @ 180 c/c both face
Bottom spherical dome	300 mm	600	10ϕ @ 220 c/c both face
Bottom circular girder	500 mm x 800 mm	2286	8-20ϕ bottom 10-20ϕ top
Column	650 mm dia	3436	10 -20ϕ
Brace	400 mm x 400 mm	1930	8 -16ϕ
Circular beam (Foundation)	700 mm x 800 mm	2670	10 -20ϕ
Raft	700 mm thick	1059	20ϕ @200c/c bothways

5.3.3 750m^3capacity tank

The following table shows the proposed structural details for 750 m^3 capacity tank.

Table 5.3: Structural details for 750 m^3 capacity

Component	Size	Ast in mm^2	Details
Top dome	120 mm thick	288	8ϕ @ 150 c/c
Top ring beam	250 mm x 300 mm	702	8 -12ϕ
Cylindrical wall	Tapered (300-350)mm	1236	20ϕ @ 180 c/c both face
Middle ring beam	500 mm x 900 mm	1689	10 - 16ϕ
Conical wall	450 mm thick	3132	20ϕ @ 200c/c both face
Bottom spherical dome	300 mm	600	10ϕ @ 220 c/c both face
Bottom circular girder	500 mm x 800 mm	2844	8-20ϕ bottom 10-20 top
Column	700 mm dia	3897	12 -20ϕ
Brace	500 mm x 500 mm	1656	8 -16ϕ
Circular beam (Foundation)	800 mm x 1000 mm	3456	10 -20ϕ
Raft	800 mm thick	1312	20ϕ @180c/c bothways

5.3.4 1000m^3capacity tank

The following table shows the proposed structural details for 1000 m^3 capacity tank.

Table 5.4: Structural details for 1000 m^3 capacity

Component	Size	Ast in mm^2	Details
Top dome	120 mm thick	288	8ϕ @ 150 c/c
Top ring beam	300 mm x 300 mm	813	8 -12ϕ
Cylindrical wall	Tapered (300-350)mm	1832	20ϕ @ 160 c/c both face
Middle ring beam	500 mm x 1000 mm	1922	10 - 20ϕ
Conical wall	500 mm thick	3869	20ϕ @ 160 c/c both face
Bottom spherical dome	300 mm	600	10ϕ @ 200 c/c both face
Bottom circular girder	500 mm x 800 mm	3168	8-20ϕ bottom 8-25ϕ top
Column	800 mm dia	4255	12 -25ϕ
Brace	500 mm x 500 mm	2100	8 -20ϕ
Circular beam (Foundation)	900 mm x 1200 mm	3493	10 -25ϕ
Raft	800 mm thick	1451	20ϕ @170c/c bothways

5.4 Summary

This chapter consists the component design of Intze tank for different capacity.The Limit state method is followed in the design.Codal provisions regarding effects of of strain and crack width calculation is also incorporated.The Structural details are proposed for all components of the tank for different capacity.

Chapter 6

Comparison of Quantity of materials

6.1 Introduction

The Working Stress Method and Limit State Method are used to design the structures. The quantity of the Steel and the Concrete vary with respect to the design methodology.As design should be carried out considering the safety and economy criteria simultaneously it is very important to study the variation in quantity of materials considering the both approach.

6.2 Quantity of concrete based on Working Stress Method

The following table shows the quantity of Concrete for different capacity of tank designed based on Working Stress Method.

Table 6.1: Quantity of concrete based on Working Stress Method

Component	Tank Capacity in m^3			
	250	500	750	1000
	Qty. of Concrete in m3			
Top dome	4.23	5.62	6.58	7.50
Top ring beam	2.23	2.52	2.69	2.87
Cylindrical wall	76.08	84.66	91.67	107.39
Middle ring beam	12.80	18.14	20.31	29.70
Conical wall	.33.72	38.53	43.35	48.17
Bottom spherical dome	9.23	10.23	12.68	14.56
Bottom circular girder	6.56	10.68	11.23	12.65
Column	31.26	36.25	41.52	47.35
Brace	9.04	11.45	12.68	14.13
Foundation	38.79	43.86	52.56	65.62
Total	223.94	261.94	295.15	349.93

6.3 Quantity of concrete based on Limit State Method

The following table shows the quantity of Concrete for different capacity of tank designed based on Limit State Method.

Table 6.2: Quantity of concrete based on Limit State Method

Component	Tank Capacity in m^3			
	250	500	750	1000
	Qty. of Concrete in m3			
Top dome	4.23	5.62	6.58	7.50
Top ring beam	2.23	2.52	2.69	2.87
Cylindrical wall	76.08	84.66	91.67	91.67
Middle ring beam	11.11	16	18.14	24.88
Conical wall	.33.72	38.53	38.53	48.17
Bottom spherical dome	9.23	10.23	12.68	14.56
Bottom circular girder	6.09	10.68	11.23	11.22
Column	26.63	31.26	36.25	47.35
Brace	6.92	9.04	12.68	14.13
Foundation	38.79	43.86	52.56	65.62
Total	215.02	252.39	282.89	341.17

6.4 Quantity of Steel based on Working Stress Method

The following table shows the quantity of Steel for different capacity of tank designed based on Working Stress Method Method.

Table 6.3: Quantity of Steel based on Working Stress Method

Component	Tank Capacity in m^3			
	250	500	750	1000
	Qty. of Steel in kg			
Top dome	112.17	131.26	140.23	158.88
Top ring beam	189.23	198.25	211.17	226.48
Cylindrical wall	6825.56	7125.23	7832.64	8946.84
Middle ring beam	1023.23	1156.23	1231.36	1390.30
Conical wall	956.23	982.23	1012.36	1128.44
Bottom spherical dome	237.54	252.23	268.12	298.97
Bottom circular girder	1098.14	1156.23	1236.23	1415.17
Column	4168.72	4896	5180	5910.93
Brace	1982.23	2213.23	2372.25	2485.51
Foundation	2956.23	3469.1	3832.12	4316.05
Total	19549.01	21655.48	23316.48	26777.56

6.5 Quantity of Steel based on Limit State Method

The following table shows the quantity of Steel for different capacity of tank designed based on Limit State Method.

Table 6.4: Quantity of Steel based on Limit State Method

Component	Tank Capacity in m^3			
	250	500	750	1000
	Qty. of Steel in kg			
Top dome	112.17	131.26	140.23	158.88
Top ring beam	189.23	198.25	211.17	226.48
Cylindrical wall	6317.82	6569	7413.09	7413.09
Middle ring beam	812.73	931.56	987.36	1001.75
Conical wall	798.63	812.22	865.32	1076.17
Bottom spherical dome	237.54	252.23	268.12	298.97
Bottom circular girder	1023.23	1156.23	1236.23	1279.3
Column	3687	3847.78	3932.22	4825.23
Brace	1982.23	1732.25	1856.2	1920.31
Foundation	2456.23	3469.1	3547.12	3647.23
Total	17714.76	18602.14	20457.06	21839.57

6.6 Results and Discussion

comparison result shows more variation of quantity of steel as compared to concrete quantity.Variation in range of 10 to 14% is observed in Steel whereas concrete has 3 to 4% variation.

Table 6.5: Comparison of Result

Capacity in m3	Quantity of Concrete in m^3			Quantity of Steel in kg		
	WSM	LSM	Difference in %	WSM	LSM	Difference in %
250	223.94	215.02	3.98	19549.01	17414.76	10.92
500	261.94	252.39	3.64	21655.48	18602.14	14.10
750	295.15	282.39	4.15	23316.48	20457.06	12.26
1000	349.93	341.17	2.5	26277.56	21839.57	16.89

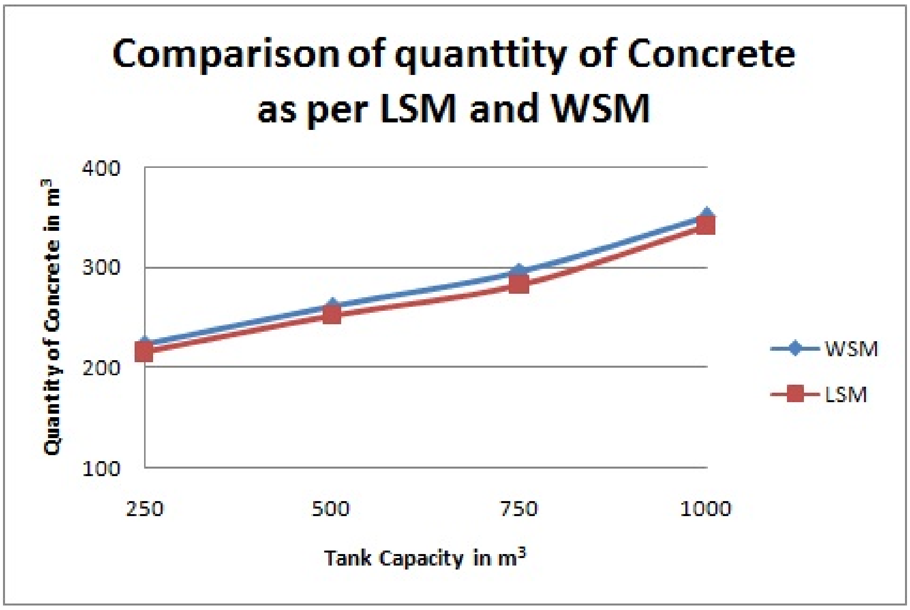

Figure 6.1: Concrete quantity comparison

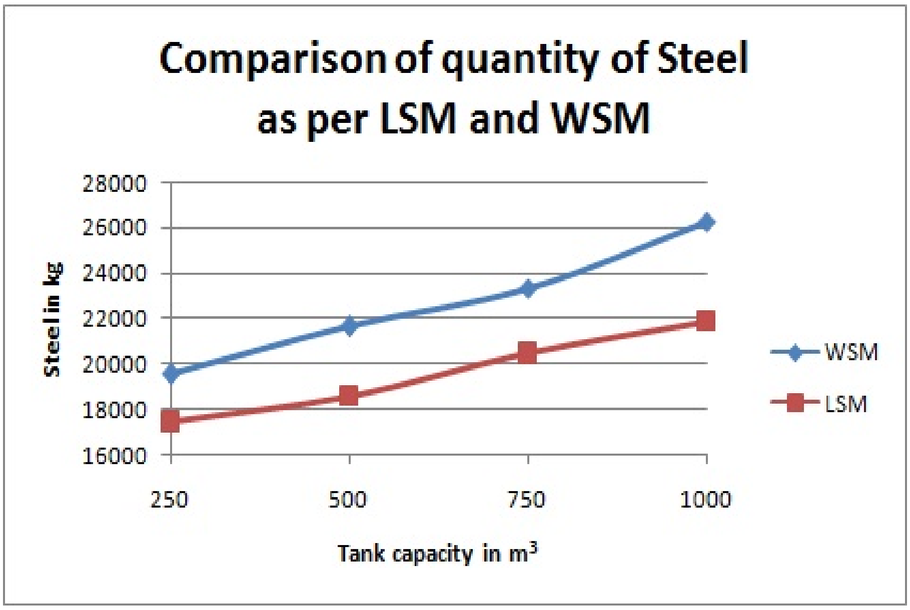

Figure 6.2: Steel quantity comparison

6.7 Summary

In this chapter the computation of quantity of the materials is carried out.The quantity of steel and concrete is calculated for different capacity of the tank which are designed as per Working Stress Method and Limit State Method.Comparison of the quantity for steel and concrete is also carried out in this chapter.

Chapter 7

Summary and Conclusions

7.1 Summary

This dissertation is an attempt to understand the seismic analysis and design of Intze type Elevated water tank. The analysis is carried out as per the Indian - IS 1893 II (Draft) code and is compared with the Euro code - EC 8 IV. The effects on Seismic forces by various parameters like response reduction factor, Seismic zone, capacity of the tank are considered. These parameters are compared for different capacities of 250 m_3,500 m_3,750 m_3 and 1000 m_3 in this study.

The Design of the water tank is carried out by Working Stress and Limit State Methods. The effects of continuity is also considered into account. The Limit state method takes care about the IS 3370 II (2009) regarding strain and crack width criteria. The quantity comparison is made for different capacity of the tank designed as per Limit State Method and Working Stress Method for steel and concrete.

7.2 Conclusions

Based on the study, the following conclusions are made.

- The base shear and base moment calculated from IS 1893 II (Draft) code shows that seismic zone V exhibits 3.6 times more value than Zone II.The base moment and base shear reduces linearly with respect to increase in Response reduction factor while base moment and base shear increases linearly with increase in capacity of tank

- Based on results available from Indian guidelines the Base moment and base shear is higher by 7% to 11% as compared with EC8.
- The quantity of concrete requirement is 3% to 4% more in WSM than LSM.
- The quantity of steel requirement is 10 % to 17% more in WSM than LSM

7.3 Future Scope of the Work

The present work can be extended as follows.

- The different shape of the container can be selected.
- The different staging pattern and foundation type can be adopted
- The different height of the staging can be selected.
- Indian guidelines can be compared with other code.
- Effects of soil structure interaction can be considered.
- Effects of hydro dynamic pressure on tank wall can be considered.

Appendix A

Structural Drawings

- Structural Drawings for various capacities of Intze tank for LSM and WSM are prepared.

Appendix B

Design Sheets

- Design Sheets for various capacities of Intze tank for LSM and WSM are prepared.

Appendix C

List of paper presented

- Shah Rahul and Suthar Jahanvi, "Seismic Analysis of frame supported Intze tank as per Indian and Eurocode criteria", International Civil Engineering Symposium, Vellore Institute of Technology, Tamil Nadu, March 2014.

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