

Analysis and design of elevated water tank for different seismic zones

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Abstract

Water tanks are widely used for storing potable water. Large capacity elevated circular tanks are used to store a variety of liquids, e.g. water for drinking and fire fighting, petroleum, chemicals, and liquefied natural gas. A water tank is used to store to tide over the daily requirements. Due to lack of water around the world, importance is given more on the water storage project. So water storage is very important as it plays a vital role in everyday life. The recent edition for the design concerning towards liquid retaining structure have been revised. Elevated water tanks are one of the most lifeline structures in earthquake prone regions. They are critical elements in municipal water supply, firefighting systems and in many industrial facilities for storage of water. Hence elevated water tanks must remain functional even after the earthquake.

The main aim of this study is to analyze and design the circular elevated water tank in different seismic zones due to earthquake using ETABS software. Any Civil Engineering structures are conceived keeping in mind its intended use, the materials available, cost and aseptic considerations..

Key Words: Elevated circular water tank, ETABS.

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I. INTRODUCTION

Water plays very important role in everyday life, so water storage is very important. In general, depending upon the location tanks are classified as tank resting on ground, underground water tank, and overhead or elevated water tank. Depending upon their shape, water tanks are further classified as rectangular tanks, circular tanks and intze tanks. An elevated water tank is a large water storage container constructed for the purpose of holding water supply at certain height to provide sufficient pressure in the water distribution system. Elevated water tanks consists of huge water mass at the top of the slender staging which are most critical consideration for the failure of the tank during earthquakes.

Elevated water tanks are critical and strategic structures and the damage of these structures during earthquakes may endanger drinking water supply, cause to fail in preventing large files and substantial economic loss. The elevated water tanks are frequently used in seismic active regions. Due to the lack of knowledge of supporting system some of the water tanks were collapsed or heavily damaged. So there is need to focus on seismic safety of lifeline structures with respect to alternate supporting system which are safe during earthquake and also to withstand more design forces.

Circular water tank

The circular over head tanks are used to store water up to 7, 50,000 liters. The diameter varies from 5 to 15m m. The water tank is the container to store water for purposes of distribution, irrigation, fire extinguish, or future use. Water can be of any shape and size as per requirement. The design of circular water tank is necessary for the economical and safe use of tanks.

[Document title]

Static earthquake method:

Static analysis is a design approach where equivalent static story forces, due to wind or earthquakes, are applied to the structure. The computation of story forces is prescriptive, and formulations for calculating these forces are provided within the applicable building code. Linear static analysis is typically restricted to use in regular structures, where dynamic behavior is dominated by the fundamental mode of vibration, without significant higher modes and torsion effects and in regions of low seismicity.

Since tall buildings often exhibit significant higher mode effects and the effects of torsion are important, linear dynamic analysis, instead of linear static analysis, is typically conducted for the seismic design of tall buildings, even in regions of low seismicity.

Seismic zone:

The varying geology at different locations in the country implies that the likelihood of damaging earthquakes taking place at different locations is different. Thus, a seismic zone map is required to identify these regions. Based on the levels of intensities sustained during damaging past earthquakes, the 1970 version of the zone map subdivided India into four zones – II, III, IV and V (Figure 3). The maximum Modified Mercalli (MM) intensity of seismic shaking expected in these zones were V or less, VI, VII, VIII, and IX and higher, respectively. Parts of Himalayan boundary in the north and northeast, and the Kachchh area in the west were classified as zone V.

II. OBJECTIVES:

- To study about the analysis and design of water tank.
- Comparing the structural responses of tanks for different seismic zones.
- To know about the design philosophy for the safe and economical design of water tank.
- To optimize the shape, size and number of columns to resist the forces in critical zone.

III. METHODOLOGY:

In this present study, the behaviors of the structure due to different seismic zones were studied. Plans of water tanks are analyzed using ETABS 18.0.0 software. ETABS is one of the most useful and friendly software which is developed by Computers and Structural Engineers of U.S.A. In this project static loads are considered for the study. i.e. (Earthquake loads in x and y direction and Wind loads). Analysis is carryout through Static Earthquake Method and subjected to Diaphragm, mass sources, and load combinations. Extracting the results for different seismic zones of water tank from the ETABS software and comparing it with each other. Extracted analysis result are mainly focused on different parameters like Average drift, Storey displacement, Overturning moments and Shear of different seismic zones.

The Graphical User Interface

The graphical user interface is shown in Figure. Several important features of the interface are shown. Those features include the main window, main title bar, display title bar, menu bar, toolbars, display windows, status bar, mouse pointer position coordinates and the current units.

LOAD SPECIFICATIONS:

The structures are under different loads such as Dead load (DL), Live load (LL), Earthquake load (EQ) and Wind load (WL).

1. Water load: density x height of the wall = $10 \times 2.5 = 25\text{kN/m}^2$.
2. Wind load: Wind loads are considered as per, IS 875-part 3.
 - a. Wind speed: 33m/s
 - b. Terrain category: 2.
3. Seismic load: seismic loads are considered as per, IS 1893 (part-I) 2002.
 - a. Seismic zone: 2, 3, 4, 5
 - b. Zone factor Z: 0.1, 0.16, 0.24, 0.36.
 - c. Soil type: II (medium soil).
 - d. Importance factor: 1.5(Refer table 6).
 - e. Response reduction factor: 5 (Refer table 7) (OMRF-Ordinary RC Moment Resisting frame).
 - f. Structure type: RC frame Structure

WATER TANK SPECIFICATIONS:

Geometry and Material properties of the structure are given below.

1. Diameter of water tank calculation:
Calculation for 2lac litres
 $A = V/h$
 $= 200/2.5 = 80$
 $A = 3.14 * r^2$
 $80 = 3.14 * r^2$
 $r = 5.04$
 $D = 10.09\text{m}$
2. Number of stories: story4+tank grid.
3. Height: 15m.

4. Grade of steel: Fe 500.
5. Grade of concrete: For Columns - 25 Mpa.
For Beams – 25 Mpa.
6. Support conditions: Fixed.
7. Size of columns : 400 x 400mm
8. Size of beams: 450 x 230mm.
9. Thickness of wall: 250mm.
10. Thickness of slab: 250mm.

Before section properties, grid data is given i.e. column grid and tank grid.

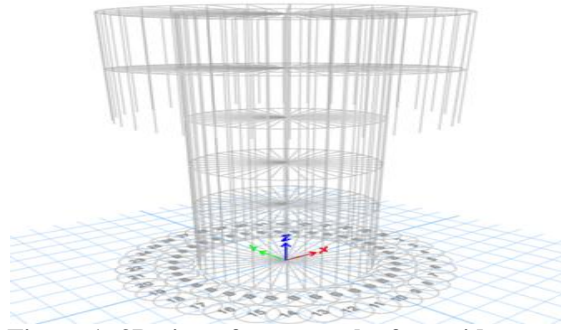


Figure 1: 3D view of water tank after grid system

STATIC SEISMIC LOADING:

The automatic data entry of equivalent static seismic loads according to various standards is applicable for common buildings where each story can be defined and can reasonably act as a rigid diaphragm. The parameters are to be applied to the seismic load calculation.

Seismic Load Direction Factor

Enter the directions and magnitudes of the seismic loads to be applied.

Scale Factor in Global X: Scale factor in GCS X-direction.

Scale Factor in Global Y: Scale factor in GCS Y-direction.

As per code seismic zone factor for zone 2: 0.1, zone 3: 0.16, zone 4: 0.24 and zone 5: 0.36.

Importance factor: 1.5.

Assigning properties:

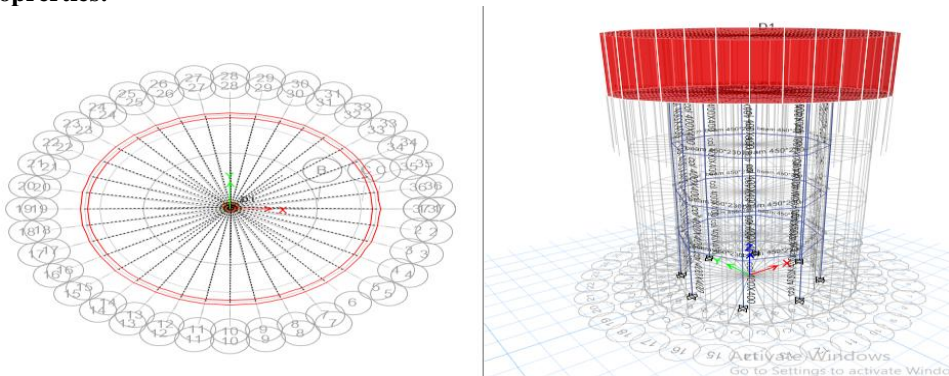


Figure 2: Plan view and 3d view after assigning model

MODELLING AND ANALYSIS IN ETABS:

Analysis:

- After all the loads are assigned, now click analyze=>run analysis. After the complete structure is analyzed, the deformed shape of the structure is shown in 3D view. This is due to the loads that are acting on all the sections i.e., beam, columns, walls and slabs. The concrete design command is given to complete beam and column design. The results of design can be viewed graphically or in the form of table.
- Design reactions exporting.

Zone 2:

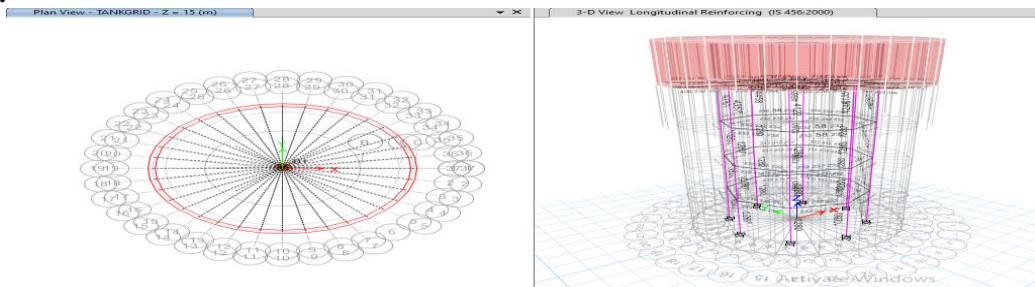


Figure 3: Plan view and 3d model of zone 2 after analysis

Zone 3:

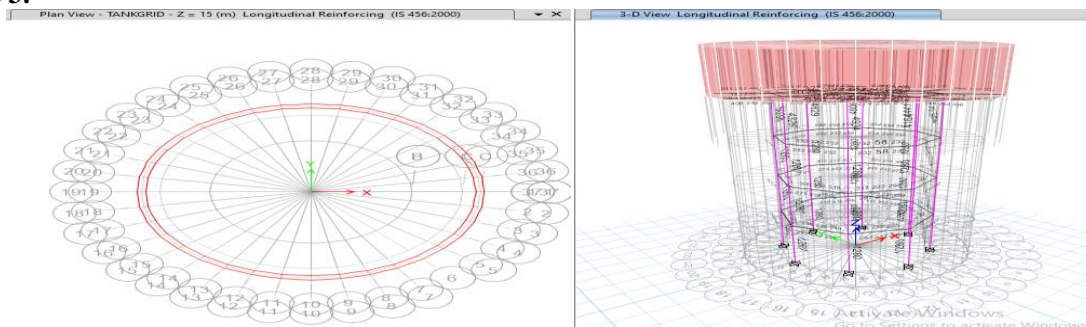


Figure 4: Plan view and 3d model of zone 3 after analysis

[Document title]

Zone 4:

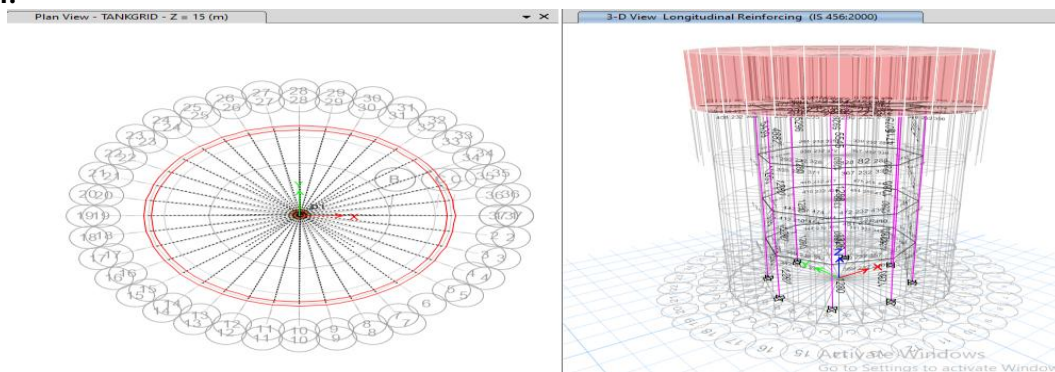


Figure 5: Plan view and 3d model of zone 4 after analysis

Zone 5:

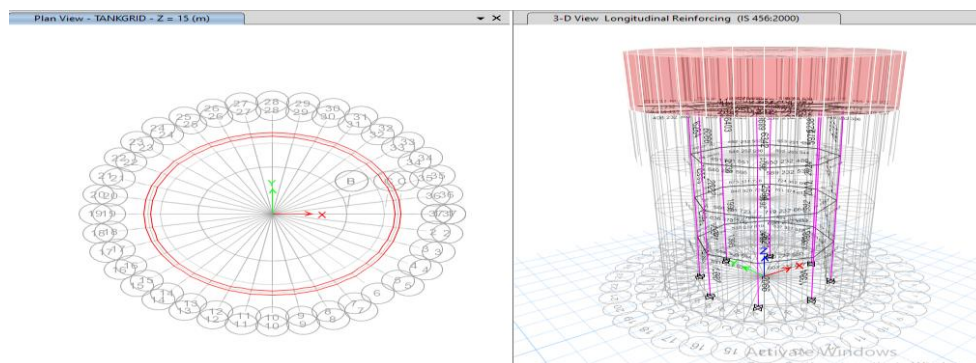


Figure 6: Plan view and 3d model of zone 5 after analysis

IV. RESULTS AND DISCUSSION:

After modeling and analysis by using ETABS, the graphical results of water tank are shown below in terms of story displacement, story drift, story shear and overturning moments. The results of each zone and comparison are discussed below using MS Excel.

GRAPHICAL REPRESENTATION:

Story displacement:

Total displacement of any storey with respect to ground and there is maximum permissible limit prescribed in IS codes.

Permissible story displacement is $H/300$.

Max story displacement for combo: 0.9water load+0.9dead load+1.5eqx (dcon 17)

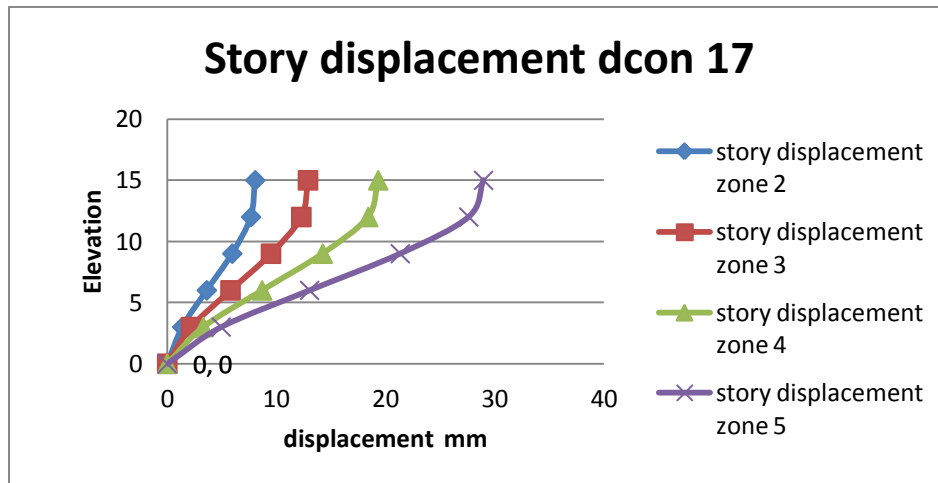


Figure 7: comparison of story displacement dcon17

[Document title]

- From the below table, it clearly shows that max displacement is 28.967mm, for zone 5 at 15m height.
- Max displacement for zone 2 is 8.064mm, zone 3 is 12.888mm, zone 4 is 19.319mm and zone 5 is 28.967mm.
- By considering different zones, zone 5 getting maximum story displacements which contains maximum zone factor 0.36 and zone 2 getting least story displacement which contains zone factor 0.1.
- As per IS: 1893 the max total deflection is total height/300 i.e.; $15000/300=50$ mm, the deflection is in control.

Max story displacement for combo: 0.9water load+0.9dead load-1.5eqx (dcon 18)

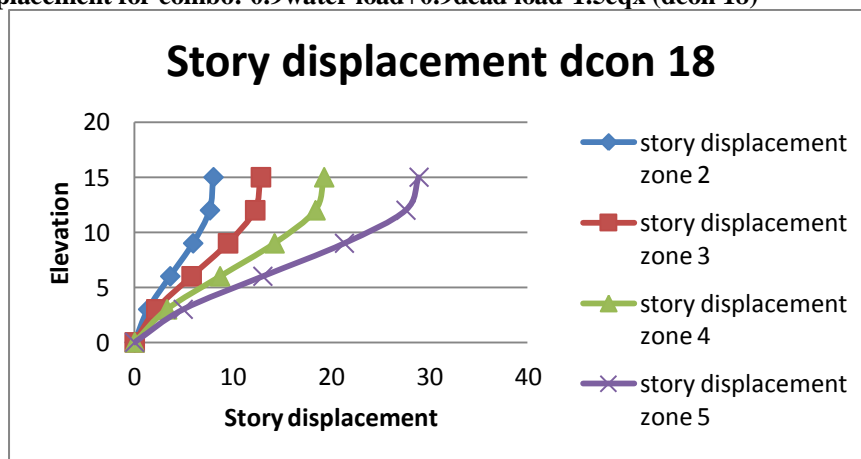


Figure 8: comparison of story displacement dcon18

- From the below table, it clearly shows that max displacement is 28.917mm, for zone 5 at 15m height.
- Max displacement for zone 2 is 8.015mm, zone 3 is 12.838mm, zone 4 is 19.27mm and zone 5 is 28.917mm.
- By considering different zones, zone 5 getting maximum story displacements which contains maximum zone factor 0.36 and zone 2 getting least story displacement which contains zone factor 0.1.
- As per IS: 1893 the max total deflection is total height/300 i.e.; $15000/300=50$ mm, the deflection is in control.

Max story displacement for combo: 0.9water load+0.9dead load+1.5eqy (dcon 19)

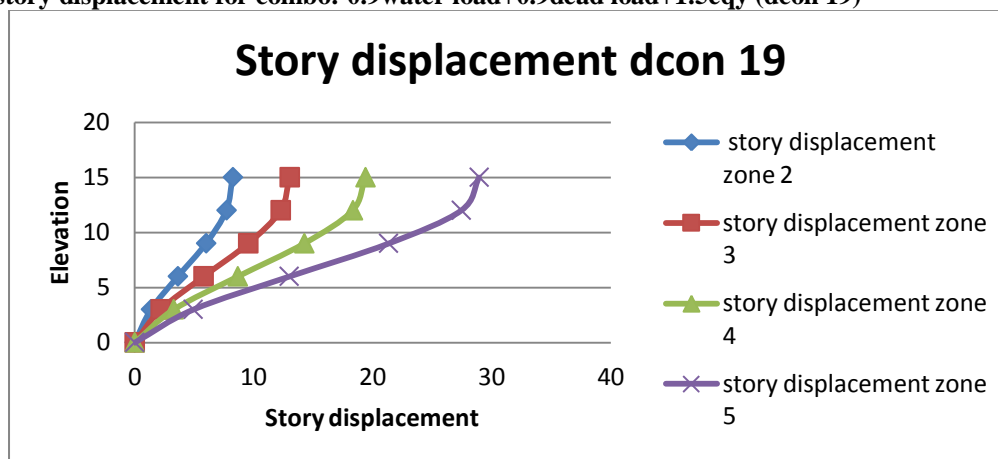


Figure 9: comparison of story displacement dcon19

[Document title]

- From the below table, it clearly shows that max displacement is 28.946mm, for zone 5 at 15m height.
- Max displacement for zone 2 is 8.252mm, zone 3 is 13.028mm, zone 4 is 19.395mm and zone 5 is 28.946mm.
- By considering different zones , zone 5 getting maximum story displacement which contains maximum zone factor 0.36 and zone 2 getting least story displacement which contains zone factor 0.1
- As per IS: 1893 the max total deflection is total height/300 i.e.; $15000/300=50\text{mm}$, the deflection is in control.

Max story displacement for combo: 0.9water load+0.9dead load-1.5eqy (dcon 20)

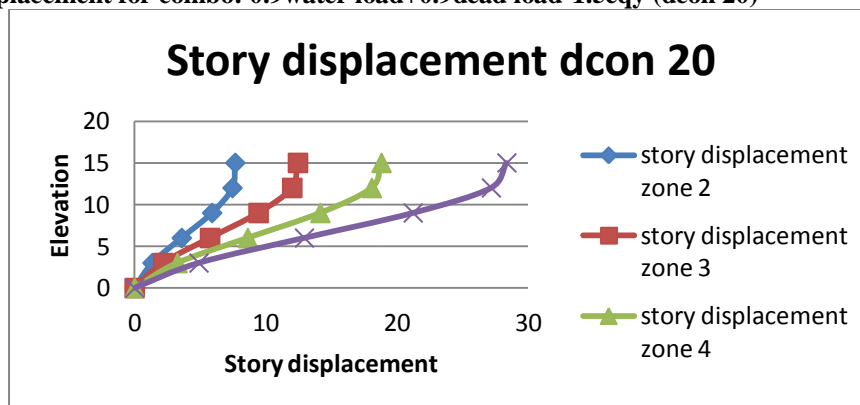


Figure 10: comparison of story displacement dcon20

- From the below table, it clearly shows that max displacement is 28.359mm, for zone 5 at 15m height.
- Max displacement for zone 2 is 7.666mm, zone 3 is 12.441mm, zone 4 is 18.808mm and zone 5 is 28.359mm.
- By considering different zones , zone 5 getting maximum story displacement which contains maximum zone factor 0.36 and zone 2 getting least story displacement which contains zone factor 0.1
- As per IS: 1893 the max total deflection is total height/300 i.e.; $15000/300=50\text{mm}$, the deflection is in control.

Story drift:

Story drift is the difference of displacements between two consecutive stories divided by the height of that story. Drift is a very complex topic in structural engineering. It is the lateral displacement of one level relative to the level above or below. Story drift ratio is the story drift divided by the story height.

Max story drifts for combo: 0.9water load+0.9dead load+1.5eqx (dcon 17)

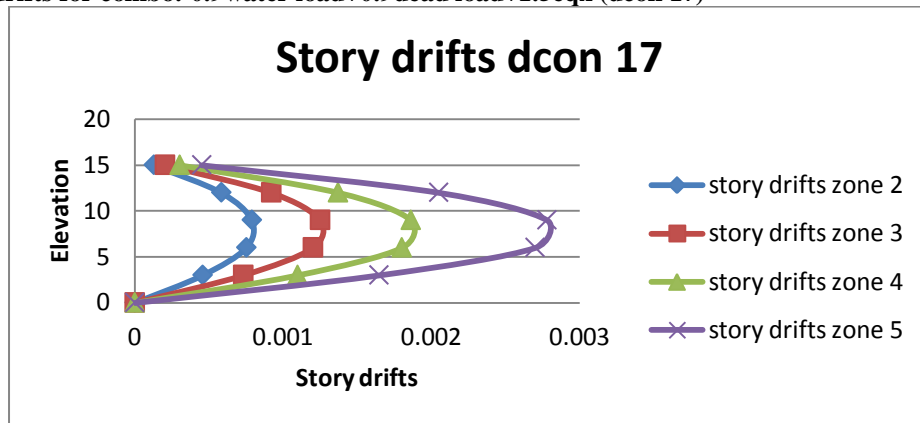


Figure 11: comparison of story drift dcon17

- From the below table, it clearly shows that max drift is 0.00278, for zone 5 at 9m height.
- Max drift for zone 2 is 0.00079, zone 3 is 0.00125, zone 4 is 0.001862 and zone 5 is 0.00278.
- By considering different zones, zone 5 getting maximum story drifts which contains maximum zone factor 0.36 and zone 2 getting least story drift which contains zone factor 0.1.
- As per IS: 1893 the max drift is 0.01, the drift is in control.

Max story drifts for combo: 0.9water load+0.9dead load-1.5eqx (dcon 18)

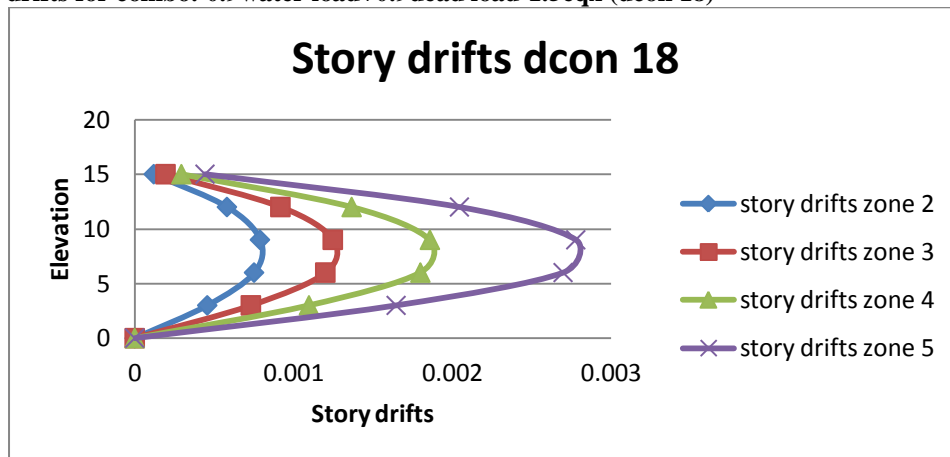


Figure 12: comparison of story drift dcon18

- From the below table, it clearly shows that max drift is 0.002779, for zone 5 at 9m height.
- Max drift for zone 2 is 0.000789, zone 3 is 0.001248, zone 4 is 0.001862 and zone 5 is 0.00278.
- By considering different zones, zone 5 getting maximum story drifts which contains maximum zone factor 0.36 and zone 2 getting least story drift which contains zone factor 0.1.
- As per IS: 1893 the max drift is 0.01, the drift is in control.

Max story drifts for combo: 0.9water load+0.9dead load+1.5eqy (dcon 19)

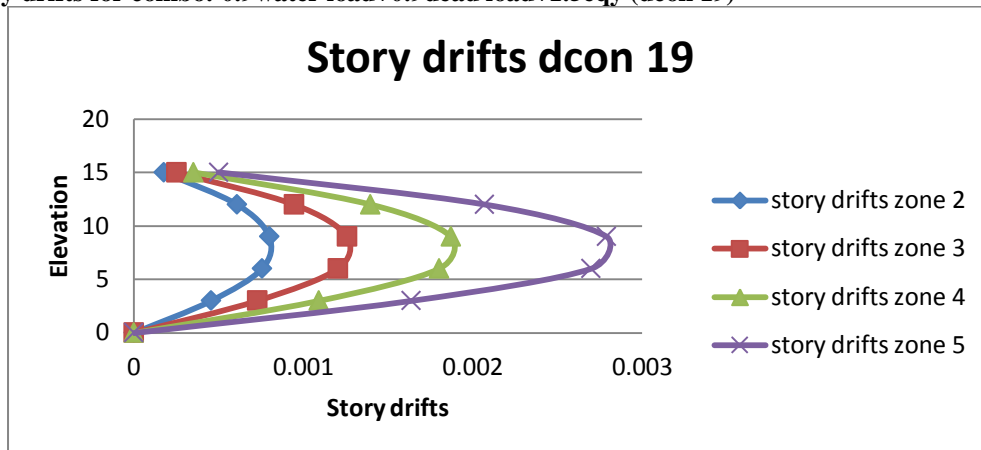


Figure 13: comparison of story drift dcon19

- From the below table, it clearly shows that max drift is 0.00279, for zone 5 at 9m height.
- Max drift for zone 2 is 0.0008, zone 3 is 0.001259, zone 4 is 0.001872 and zone 5 is 0.00279.
- By considering different zones, zone 5 getting maximum story drifts which contains maximum zone factor 0.36 and zone 2 getting least story drift which contains zone factor 0.1.
- As per IS: 1893 the max drift is 0.01, the drift is in control.

Max story drifts for combo: 0.9water load+0.9dead load-1.5eqy (dcon 20)

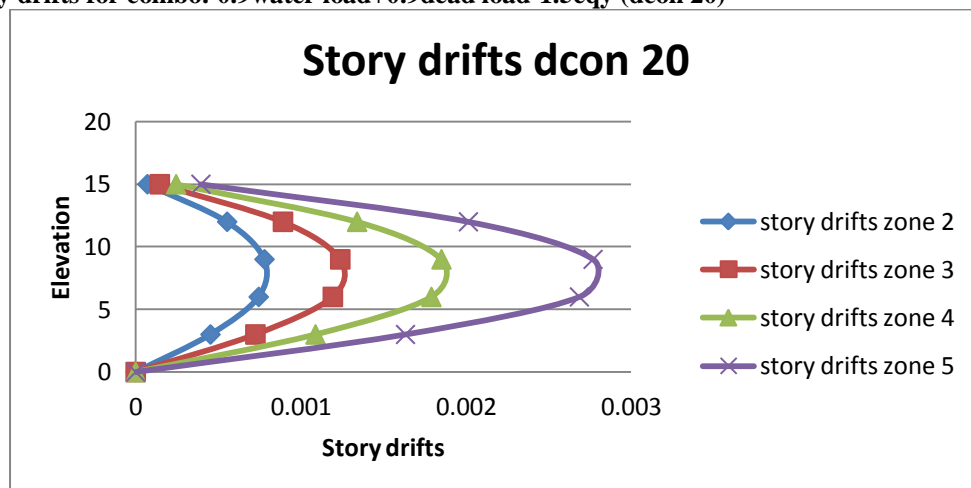


Figure 14: comparison of story drift dcon20

- From the below table, it clearly shows that max drift is 0.00277, for zone 5 at 9m height.
- Max drift for zone 2 is 0.00078, zone 3 is 0.001239, zone 4 is 0.001852 and zone 5 is 0.00277.
- By considering different zones, zone 5 getting maximum story drifts which contains maximum zone factor 0.36 and zone 2 getting least story drift which contains zone factor 0.1.
- As per IS: 1893 the max drift is 0.01, the drift is in control

Story shear:

In story shear, you can visualize the possible governing lateral load on a certain floor at a given direction. And this will aid to understanding or investigating why wind governs over seismic on certain direction or vice versa.

Story shears for combo: 0.9water load+0.9dead load+1.5eqx (dcon 17)

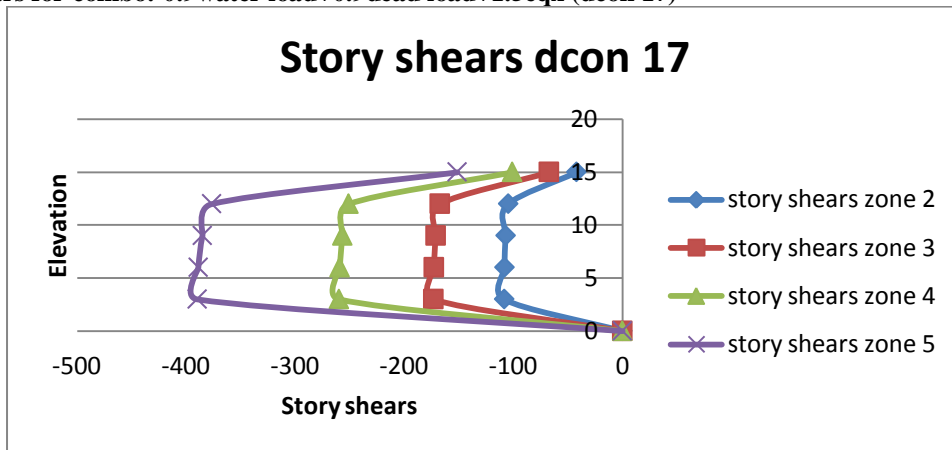


Figure 15: comparison of story shear dcon17

- From the below table, it clearly shows that max story shear is -42.0719kN, for zone 2 at 15m height.
- Story shear for zone 2 is -42.0719kN, zone 3 is -67.315kN, zone 4 is -100.9725kN and zone 5 is -151.4587kN.
- By considering different zones , zone 2 getting maximum story shears which contains zone factor 0.1 and zone 5 getting least story shear which contains zone factor 0.36.
-

Story shears for combo: 0.9water load+0.9dead load-1.5eqx (dcon 18)

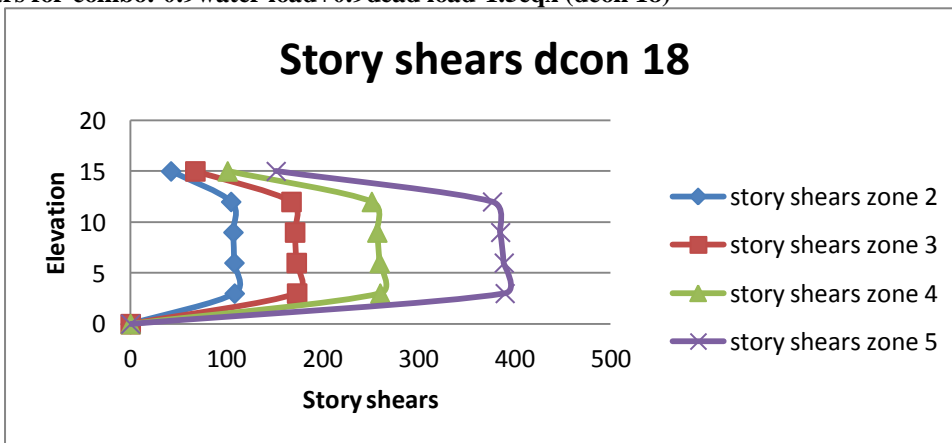


Figure 16: comparison of story shear dcon18

- From the below table, it clearly shows that max story shear is 42.0719kN, for zone 2 at 15m height.
- Story shear for zone 2 is 42.0719kN, zone 3 is 67.315kN, zone 4 is 100.9725kN and zone 5 is 151.4587kN.
- By considering different zones , zone 2 getting maximum story shears which contains zone factor 0.1 and zone 5 getting least story shear which contains zone factor 0.36 .

Story shears for combo: 0.9water load+0.9dead load+1.5eqy (dcon 19)

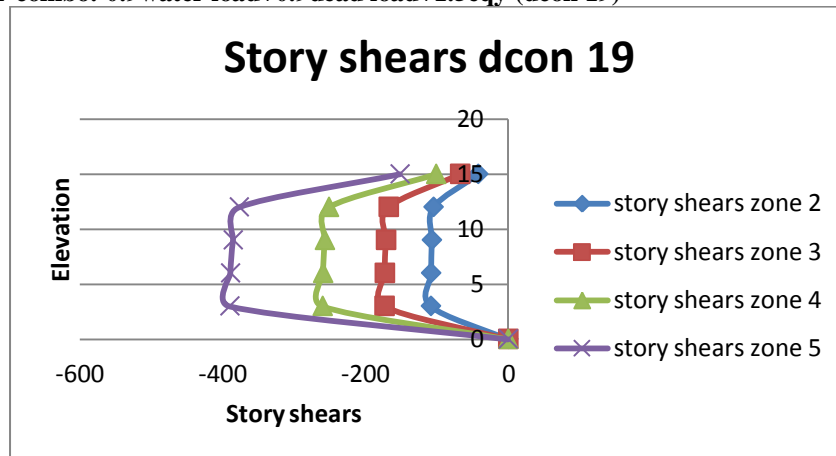


Figure 17: comparison of story shear dcon19

- From the below table, it clearly shows that max story shear is -42.0878kN, for zone 2 at 15m height.
- Story shear for zone 2 is -42.0878kN, zone 3 is -27.3406kN, zone 4 is -27.3406kN and zone 5 is -15.516kN.
- By considering different zones , zone 2 getting maximum story shears which contains zone factor 0.1 and zone 5 getting least story shear which contains zone factor 0.36 .

Story shears for combo: 0.9water load+0.9dead load-1.5eqy (dcon 20)

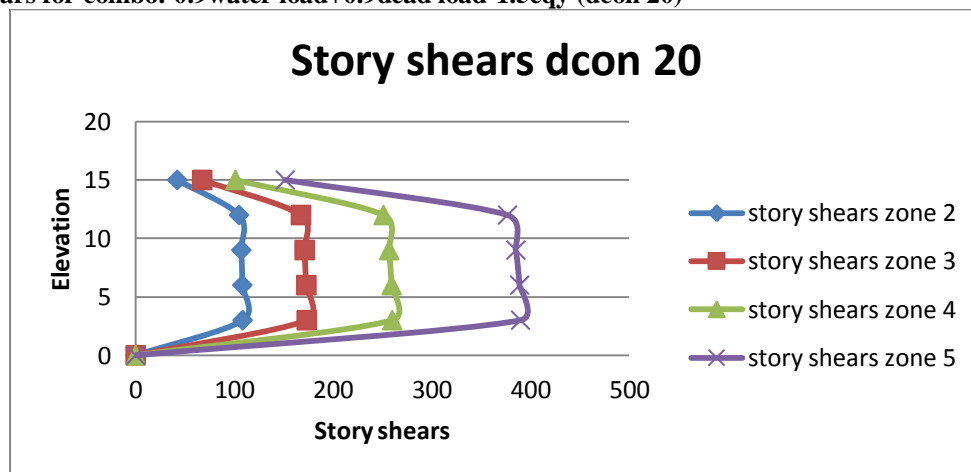


Figure 18: comparison of story shear dcon20

- From the below table, it clearly shows that max story shear is 389.919kN, for zone 5 at 3m height.
- Story shear for zone 2 is 108.3108kN, zone 3 is 173.2973kN, zone 4 is 259.946kN and zone 5 is 389.919kN.
- By considering different zones , zone 5 getting maximum story shears which contains zone factor 0.36 and zone 2 getting least story shear which contains zone factor 0.1 .

Overtuning moments:

The "overtuning moment" at any horizontal plane is the moment on the structure as a whole resulting from the dynamic earthquake forces above the plane, giving due regard to signs of the modal forces.

Overturning moments for combo: 0.9water load+0.9dead load+1.5eqx (dcon 17)

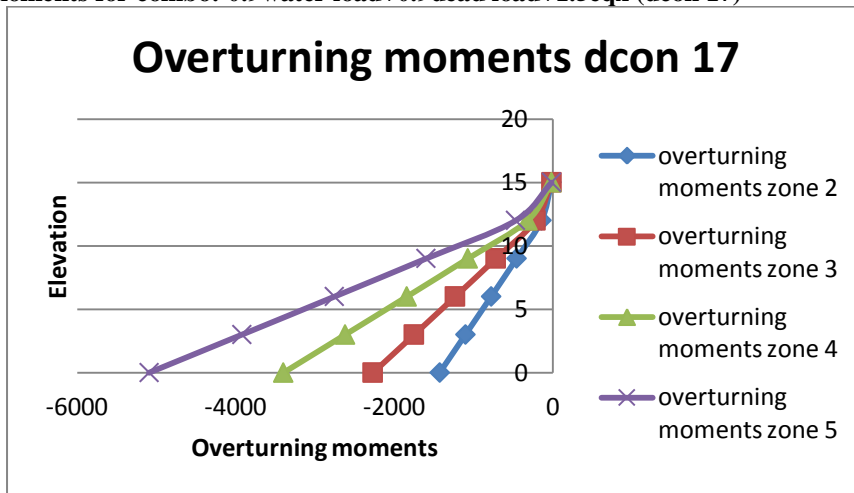


Figure 19: comparison of overturning moments dcon17

- From the below table, it clearly shows that max overturning moment is -14.4765kN-m , for zone 2, 3, 4 and 5 at 15m height.
- Overturning moment for zone 2 is -14.4765kN-m, zone 3 is -14.4765kN-m, zone 4 is -14.4765kN-m and zone 5 is -14.4765kN-m.
- By considering different zones, zone 2, 3, 4 and 5 getting maximum overturning moments.
-
- **Overturning moments for combo: 0.9water load+0.9dead load-1.5eqx (dcon 18)**

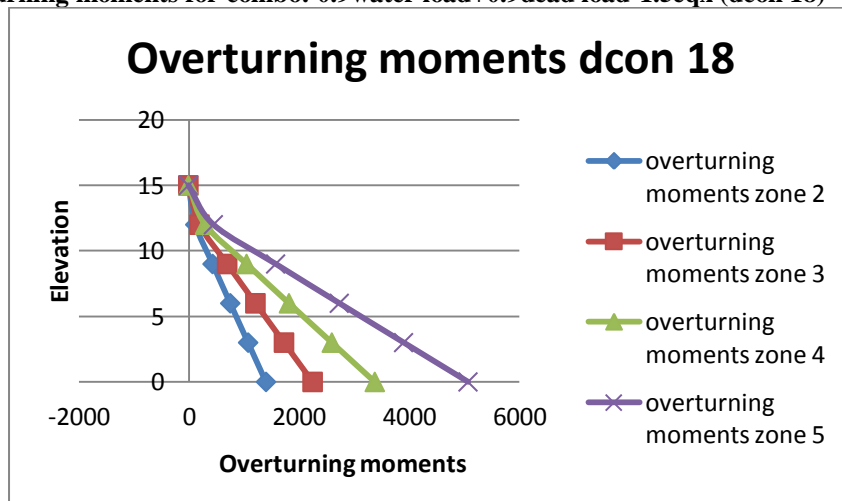


Figure 20: comparison of overturning moments dcon18

- From the below table, it clearly shows that max overturning moment is 5060.5495kN-m, for zone 5 at base.
- Overturning moment for zone 2 is 1395.253kN-m, zone 3 is 2241.0906kN-m, zone 4 is 3368.8742kN-m and zone 5 is 5060.5495kN-m.
- By considering different zones, zone 5 getting maximum overturning moment which contains zone factor 0.36 and zone 2 getting least overturning moment which contains zone factor 0.1.

Overturning moments for combo: 0.9water load+0.9dead load+1.5eqy (dcon 19)

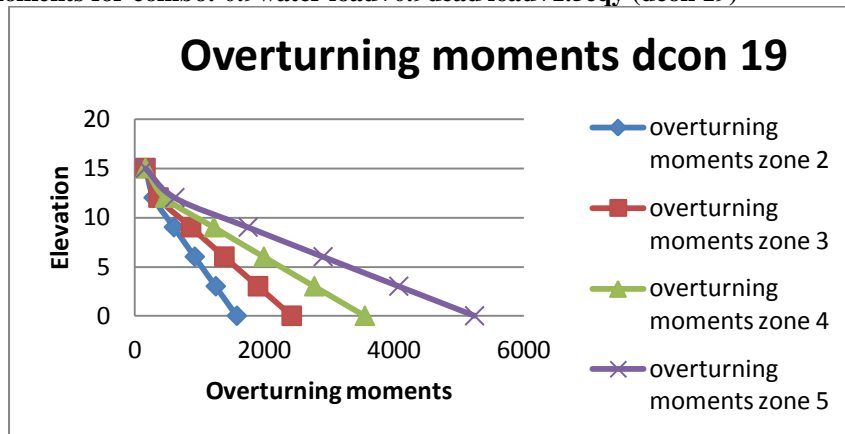


Figure 21: comparison of overturning moments dcon19

- From the below table, it clearly shows that max overturning moment is 5242.42kN-m, for zone 5 at base.
- Overturning moment for zone 2 is 1575.732kN-m, zone 3 is 2421.089kN-m, zone 4 is 3550.102kN-m and zone 5 is 5242.42kN-m.
- By considering different zones, zone 5 getting maximum overturning moment which contains zone factor 0.36 and zone 2 getting least overturning moment which contains zone factor 0.1.

Overturning moments for combo: 0.9water load+0.9dead load-1.5eqy (dcon 20)

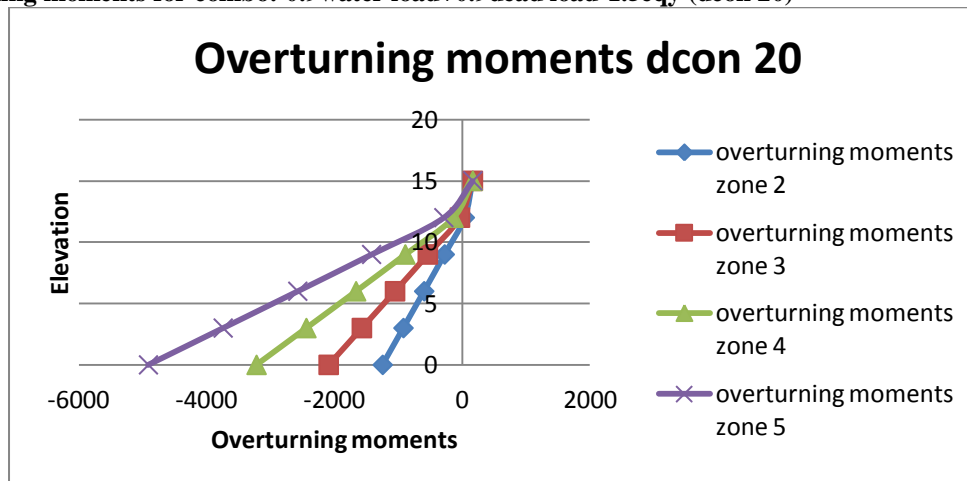


Figure 22: comparison of overturning moments dcon20

- From the below table, it clearly shows that max overturning moment is 165.4671kN-m , for zone 2, 3, 4 and 5 at 15m height.
- Overturning moment for zone 2 is 165.4671kN-m, zone 3 is 165.4671kN-m, zone 4 is 165.4671kN-m and zone 5 is 165.4671kN-m.
- By considering different zones, zone 2, 3 4 and 5 getting same overturning moments.

DESIGN OF STRUCTURAL MEMBERS:

Slab Design:

Slab thickness: 250mm
 Concrete fck: 20Mpa
 Steel fy: 500Mpa

Loading:

Slab load
 Dead load DL = 6.250KN/m
 Live load LL = 30KN/m
 Finishes load = 1KN/m

Total load = 37.250KN/m

Factored load = 56KN/m

Slab data:

Slab type: Regular

Load: 56KN/m

Longer span (ly):4m

Shorter span (lx):2m

ly/lx ratio:2.00

Loading on edges		one way	two way
W longer	51 KN/m	$.=w*lx/2$	$=(w*lx/2) + (1-(1/3)*(lx/ly)^2)$
W shorter	37 KN/m	$.=w*lx/3$	
Moments		one way	two way
Mx	24 KN-m	$.=w*lx^2/ 8$	$=\alpha_x * w*lx^2$
My	13 KN-m		$.=\alpha_y * w*lx^2$

Thickness CheckOK $=M_{ulim} > M_{ux} \text{ or } M_{uy}$

Deflection 0 mm $= 5*W*l^4/(384EI)$

Area of Steel	Astx	Asty
	300 sqmm	300 sqmm

Spacing required in mm

8#		10#		12#		16#	
x	y	x	y	x	y	x	x
168 c/c	168 c/c	262 c/c	262 c/c	377 c/c	377 c/c	670 c/c	670 c/c

= ast of bar*1000/ast req

Final Ast provided	x	y
	10@150	10@150

DESIGN OF ISOLATED FOOTING:

Footing size design:

Load Pu = 975KN

Design load P = 715KN

Moment in X direction Mux: 25KN-m

Moment in Y direction Muy: 1KN-m

Column size Cx = 400mm

Cy = 400mm

SBC q = 180KN/sqm

Footing size required A: 3.97sqmm

Footing size provided: L= 2.20m

B= 2.20m

Area provided: 4.84mts

Zx= 1.77

Net upward pressure: 157KN/m²

FOOTING SIZE OK

Slab design:

Lx= 0.900

Ly= 0.900

Bending moment in x dir Mx= 96KN-m

Bending moment in y dir My= 96KN-m

Concrete= 25Mpa

Steel= 500Mpa

Minimum depth required: 170

Depth provided $D = 600\text{mm}$
 Clear cover $c = 50\text{mm}$
 Effective cover $d' = 56\text{mm}$
 Effective depth $d' = 544\text{mm}$

Area of Steel	Spacing c/c in mm		
	12#	16#	20#
653 sqmm	173 c/c	308 c/c	481 c/c
653 sqmm	173 c/c	308 c/c	481 c/c

Minimum A_{st} required in x direction.
 Minimum A_{st} required in y direction.

A_{st} across x direction	12mm dia @ 150mm c/s	754sqmm
A_{st} across y direction	12mm dia @ 150mm c/s	754sqmm

One way shear along x direction:

$V_{u1} = 185\text{KN}$
 $Z_c = 0.155\text{Mpa}$
 $Z_v = 0.263\text{Mpa}$
 $V_{c1} = 315\text{KN}$

One way shear check ok

One way shear along y direction:

$V_{u1} = 185\text{KN}$
 $Z_c = 0.155\text{Mpa}$
 $Z_v = 0.263\text{Mpa}$
 $V_{c1} = 315\text{KN}$

One way shear check ok

Two way shear:

$V_{u2} = 933\text{KN}$
 $Z_c = 0.454\text{Mpa}$
 $k_s * Z_v = 1.250\text{Mpa}$
 $V_{c1} = 2568\text{KN}$

Two way shear check OK

Conclusion

- As per IS: 1893 the max total deflection is total height/300 i.e.; $15000/300 = 50\text{mm}$, the deflection is in control.
- Zone 2 having lesser displacement and story shear compare to zone 3, 4 and 5.
- As per IS: 1893 the max drift is 0.01, the drift is in control.
- By considering different zones , zone 5 getting maximum story shears which contains zone factor 0.36 and zone 2 getting least story shear which contains zone factor 0.1 .
- By considering different zones, zone 5 getting maximum overturning moment which contains zone factor 0.36 and zone 2 getting least overturning moment which contains zone factor 0.1.
- Reinforcement in columns and beams are more in zone 5 compared to other zones.

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