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P-DELTA ANALYSIS OF RCC WATER TANK IN DIFFERENT SEISMIC ZONES

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Abstract - Elevated Water tank structures also known as Over Head Tanks (OHT) or Elevated Service Reservoir (ESR) are required to store the clear water or drinkable water that is coming from the Water treatment plant unit. These tanks will be used to supply drinkable water to households. ESR can be in different types in shape like Rectangular or Circular or Intze. Since these are elevated structures, these should not be treated like regular structures and analysis of these structures shouldn't be done in linear static analysis only. Non-linear analysis should be done in such a way that, behaviour of the structure is safe against the resultant behaviour. P-Delta analysis is considered to do the non-linear analysis for an Intze tank. P-Delta analysis also known as second order analysis. The analysis results are compared for the Intze(ESR) located in different seismic zones i.e. Zone-II, Zone-III, Zone-IV & Zone-V. The whole analysis is done by using STAAD.Pro 2023 connect edition.

***KEYWORDS** - P-Delta Analysis, STAAD. Pro, ESR, Intze, OHSR, OHT, Nonlinear Analysis.*

1.INTRODUCTION

Elevated water tanks are critical structures which will be used for water storage purposes. These structures will be subjected to horizontal loads (Lateral loads) due to wind and earthquake (seismic forces) in addition to dead, live and liquid loads. Because of these horizontal/lateral loads stresses will be developed and displacements will be high due to the elevation of tank, it will result in high center of gravity. During the earthquake event, these overhead tanks experienced dynamic forces due to sloshing of water which will make the load distribution complex and will amplify the structure response. Wind loads will also impact these structures since these tanks are elevated as wind pressures will increase with varying heights above ground level. The design of these elevated water tanks should be analyzed against these horizontal loads through non-linear analysis or dynamic analysis. To reduce stresses or deflections we must provide proper anchorage, beam bracings and column to column distances as per the Indian standard codes pertaining to seismic regulations.

P-Delta Effect

Non-linearity may be classified into various categories. To put it in a simple statement, "Stress-Strain relationship is not linear as in the case of linear analysis". The following are the various categories of non-linearity:

1. Geometric non-linearity
2. Material non-linearity
3. Boundary condition non-linearity

P-Delta effect falls under the Geometric Non-linearity category. This non-linearity is due to the excessive deformation or deflection of the material or structure, even though they are in the elastic limit. For easy understanding, when a structure is loaded, it will deflect or deform to relieve stress. This deflection is said to be the first-order effect. Without any additional loading, if any stresses or adverse effects are induced in a structure due to the first-order deflection, it is called a second-order effect. P-Delta analysis is nothing but analyzing a structure by applying loads on the deflected form of a structure. A deflected structure may encounter significant moments because the ends of the members have changed their position. The P-Delta effect, also referred to as the second-order effect, is a critical concept in structural engineering that influences the stability and performance of structures under external loads. This phenomenon arises due to the interaction between axial loads (denoted as P) and lateral displacements (denoted as Δ) in a structure, leading to additional moments that can amplify stresses and deformations. While often overlooked in preliminary design stages, the P-Delta effect plays a vital role in ensuring the safety and reliability of modern structures, particularly tall buildings and slender systems.

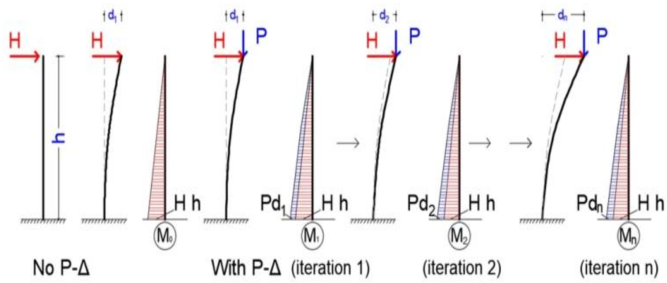

Figure 1: P-Delta on single column

As a structure deflects laterally, the vertical loads do not remain aligned with their original axis. Instead, they create an eccentricity, resulting in an additional moment that magnifies the lateral forces acting on the structure. This increase in internal forces can lead to excessive deflections, instability, or, in extreme cases, structural failure.

Hence, Geometric imperfections in the structure need to consider. The displacement estimate of the response may, or may not, explicitly consider P-delta (also referred to as "second order analysis", "higher order analysis", or "consideration of geometric nonlinearity") effects. P-delta tends to increase the structural period and decrease structural dynamic stability. It is desirable that the net post-elastic stiffness of a structure considering P-delta effects should be significantly greater than zero to mitigate the possibility of seismic ratcheting. P-delta may have different effects on structures with the same period, damping and hysteretic behavior, so consideration of P-delta does not have a unique effect, and this is not always appreciated. There is a need to address this issue of the non-unique effect of P-delta so that it may be considered appropriately in design. The effect of P-delta on a general hysteresis loop is shown in Figure.

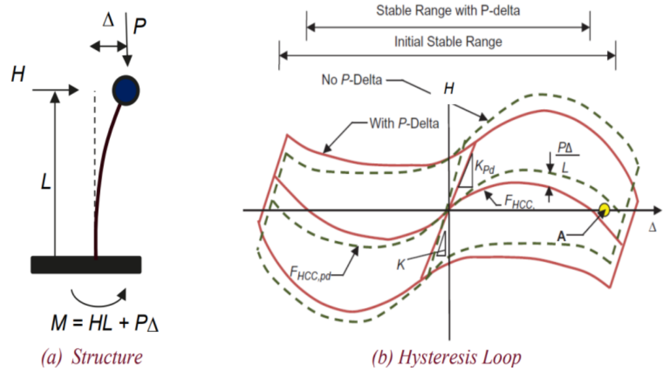

Figure 1: P-Delta Effect on Hysteresis Loop

P-Delta effect can be categorized into two types:
1. Big P-Delta Effect (P-Δ): This occurs when there is a significant difference in displacement at the top and bottom of a column due to horizontal loads. The vertical loads acting on this displacement led to the generation of additional moments, which can affect overall structural stability.
2. Small P-Delta Effect (P-δ): This effect is associated with local deformations relative to the member's chord between end nodes. It typically becomes significant in slender members where small deflections can alter the internal force distribution

The P-Delta effect can be explained in two key components:
1. Gravity-Induced P-Delta Effect: Occurs due to the interaction between the axial load (gravity) and the lateral displacement caused by external forces.
2. Dynamic P-Delta Effect: Becomes prominent during dynamic events such as seismic activity, where the oscillation of the structure exacerbates the lateral movements and amplifies the moments.

The P-Delta effect is most pronounced in the following scenarios:
1. Tall and Slender Structures: Skyscrapers, towers, and other tall buildings
2. Cantilever Structures: Structures like elevated tanks, chimneys, and bridges that rely on cantilever systems are sensitive to P-Delta effects due to their limited lateral stiffness.
3. Structures with Heavy Axial Loads: Buildings or systems with substantial vertical loads relative to their lateral stiffness experience pronounced P-Delta effects.
4. Seismic Regions: In areas prone to earthquakes, the combination of lateral ground motions and dynamic P-Delta effects can significantly affect structural performance.

Effects of P-Delta on Structural Behavior

The P-Delta effect introduces several challenges in the behavior of a structure:
- Amplified Deflections: As lateral displacements increase, the additional moments generated by the P-Delta effect further amplify deflections, creating a feedback loop that can destabilize the structure.
- Increased Internal Forces: The additional moments caused by the effect increase the forces within structural members, demanding stronger or more resilient designs.
- Reduced Stability: In extreme cases, the P-Delta effect can cause instability, leading to structural collapse if not properly accounted for.
- Material and Cost Implications: Addressing the P-Delta effect often requires stronger materials, larger cross-sections, or additional bracing, impacting both the design and cost of the project.

Mitigating the P-Delta Effect

To ensure structural safety and reliability, engineers must carefully account for the P-Delta effect during design and analysis. Some common strategies include:
1. Advanced Structural Analysis: Using second-order analysis methods or nonlinear computational models to accurately predict the impact of P-Delta effects on the structure.
2. Increase Lateral Stiffness: Incorporating bracing systems, shear walls, or moment-resisting frames to reduce lateral displacements and minimize the effect.
3. Optimize Member Design: Enhancing the capacity of structural members to resist the amplified forces and moments induced by P-Delta effects.
4. Dynamic Analysis for Seismic Loads: Evaluating the behavior of the structure under dynamic lateral loads, such as earthquakes, to account for the dynamic P-Delta effect.

2. OBJECTIVE OF THE STUDY

In the current investigation the following goals are set:
1.The essential point of this work is the near investigation of P-Delta analysis on Elevated Service reservoir in different seismic various zones.
2.Determination of displacements, reactions and other results in ESRs in different seismic zones utilizing P-Delta Analysis
3.To discover the impact of P-Delta analysis on ESR in serviceability checks.
4.To figure out the impact of seismicity on ESRs

In urban regions, ESRs are deployed to provide water to the households. The Importance of these structures is significant and should be designed with governing combinations in different analysis available in structural analysis. This analysis will give us the basic information related to the structural behavior of ESRs in different earthquake zones.

3. MODELLING OF THE STRUCTURE

Design Considerations

An overhead tank is considered for the current investigation. Plan and Elevation perspective on the casing model considered for the investigation are demonstrated as follows.
The current investigation manages 4 - various types of models:
1. Overhead Tank – Zone 2
2. Overhead Tank – Zone 3
3. Overhead Tank – Zone 4
4. Overhead Tank – Zone 5

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Elevation

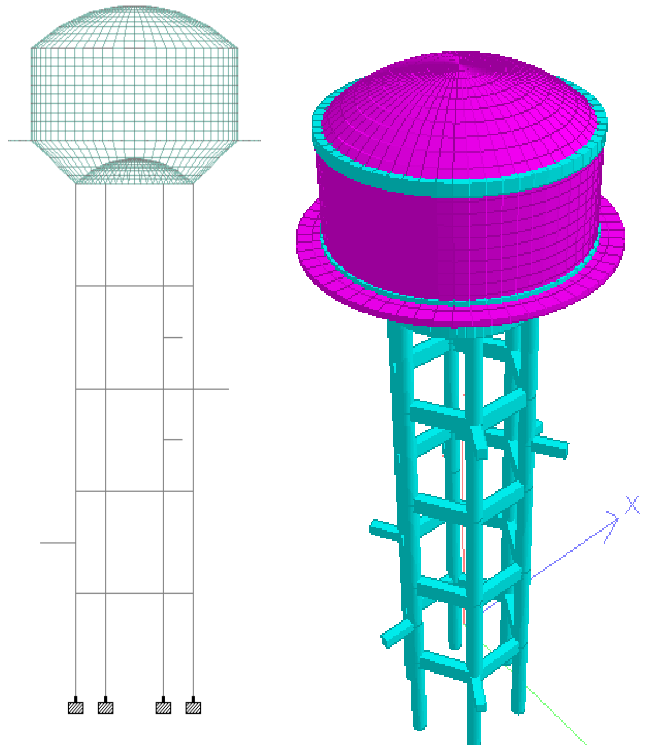

Figure 3: Elevation and 3D view of Overhead tank

Preliminary Data:

Type of frame : Ordinary RC moment resisting frame fixed at the base for Zone II and Special RC moment resisting frame for Zones III, IV, V
Seismic zone : II, III, IV, V
Stack height : 3 m
Depth of Walls, Slab : 200 mm
Spacing between frames : 2 m along both directions
Live load on roof level : 1.5 kN/m^2
Live load on Floor level : 3.0 kN/m^2
Materials : M 25 concrete, Fe 415
Density of concrete : 25 kN/m^3
Type of soil : Rocky
Response spectra : IS 1893(Part1):2016
Damping of structure : 5 %
Live load on floor level and roof level are taken from IS-875 (Part-2) considered RC framed buildings.

Member and Material Properties

Dimensions of the beams and columns are determined based on trial-and-error process in analysis of Staad. Proby considering nominal sizes for beams and columns and safe sizes are as show in the table below.

	Beam(m)	Column(m)
Staging	0.3x0.45	Dia 0.45

Material properties of the structure resemble M25grade for frame and M30grade for overhead tank and Fe500 steel.

Capacity		V	=	110	Cum
Staging		S	=	12	M
SBC of soil		q	=	25.00	T/sqm
Depth of SBC		d_f	=	3.00	m
Dead storage water column		d_s	=	150	mm
Free board		f_b	=	350	mm
Ground Level	4 no's	(G.L)	=	0.00	m
Low Water Level		(L.W.L)	=	12.00	m
Effective water height in cylindrical portion			=	2.70	m
Effective water height in conical portion			=	1.275	m
Max Water Level		(M.W.L)	=	15.83	m
Live load on top dome		L_d	=	1500	N/sqm
Live load on balcony and staircase		L_{bs}	=	3000	N/sqm
Live load on ladder, steps, balcony landing beams		L_{ls}	=	3000	N
Dead load of hand railing		L_{hr}	=	100	N/m
Grade of concrete (Tank Portion)		f_{ck}	=	M	30
Grade of concrete (Staging Portion)		f_{ck}	=	M	25
Nominal maximum size of Coarse aggregate			=	20	mm
Grade of steel		f_y	=	Fe	500
Internal dia of cylindrical wall		D	=	7.00	m
Centre to centre dia of columns		D_c	=	4.00	m
Top dome	Rise	h□	=	1.25	m
	Thickness at spring	t□	=	150	mm
	Thickness at crown		=	125	mm
Top ring beam	Width	b□	=	300	mm
	Depth	d□	=	300	mm
Vertical wall	Thickness at top	t□	=	200	mm
	Thickness at bottom	t□	=	200	mm
Ring beam at junction of wall	Width	b□	=	350	mm
& conical dome	Depth	d□	=	350	mm
Balcony	Projection from ring beam face		=	850	mm
	Depth	d□	=	150	mm
Cone wall	Thickness	t□	=	250	mm
Bottom dome	Rise	h□	=	0.75	m
	Thickness at spring	t□	=	200	mm
	Thickness at crown		=	200	mm
Bottom ring beam	Width	b□	=	450	mm
	Depth	d□	=	750	mm
				0.750	m
Plaster Thickness			=	20	mm
			=	0.02	m

i.A_h for impulsive mode:

Seismic Zone	II	III	IV	V
Z=	0.1	0.16	0.24	0.36
R=	3	5	5	5
I=	1.5	1.5	1.5	1.5
Damping=	0.05	0.05	0.05	0.05
Soil type =	Rock	Rock	Rock	Rock
Multiplying factor =	1	1	1	1
For T_i =	1.26	1.26	1.26	1.26
(S_a/g) =	IF(1.26<0.55,2.5,(1.36/1.26))	IF(1.26<0.55,2.5,(1.36/1.26))	IF(1.26<0.55,2.5,(1.36/1.26))	IF(1.26<0.55,2.5,(1.36/1.26))
	1.08	1.08	1.08	1.08
$(A_h)I$ =	0.1/2x1.5/3x1.08	0.16/2x1.5/5x1.08	0.24/2x1.5/5x1.08	0.36/2x1.5/5x1.08
=	0.027	0.026	0.039	0.0583

ii.Ah for convective mode:

(Ah)c= (Z/2) x (I/R) x (Sa/g)

Seismic Zone	II	III	IV	V
Damping=	0.005	0.005	0.005	0.005
Multiplying factor=	1.75	1.75	1.75	1.75
For Tc =	2.79	2.79	2.79	3
(Sa/g)=	IF(2.79>4,0.34, (1.36/2.79))	IF(2.79>4,0.34, (1.36/2.79))	IF(2.79>4,0.34, (1.36/2.79))	IF(2.79>4,0.34, (1.36/2.79))
=	0.49	0.49	0.49	0
(Ah)c =	0.1/2x1.5/3x (0.49x1.75)	0.16/2x1.5/5x (0.49x1.75)	0.24/2x1.5/5x (0.49x1.75)	0.36/2x1.5/5x (0.49x1.75)
=	0.0214	0.0206	0.0309	0.0463
Av=	0.018	0.0173	0.0259	0.0389

Total overturning moment $M^* = \sqrt{Mi^2 + Mc^2}$

Zone 2	=√797.95^2 + 208.22^2	=824.67kN-m
Zone 3	=√766.03^2 + 199.89^2	=791.68 kN-m
Zone 4	=√1149.04^2 + 299.83^2	=1187.51 kN-m
Zone 5	=√1723.56^2 + 449.75^2	=1781.27 kN-m

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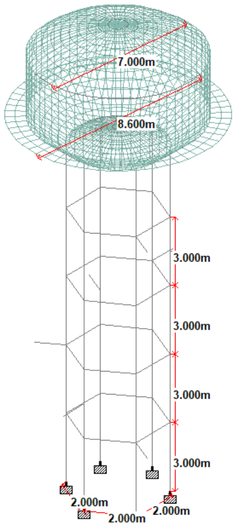
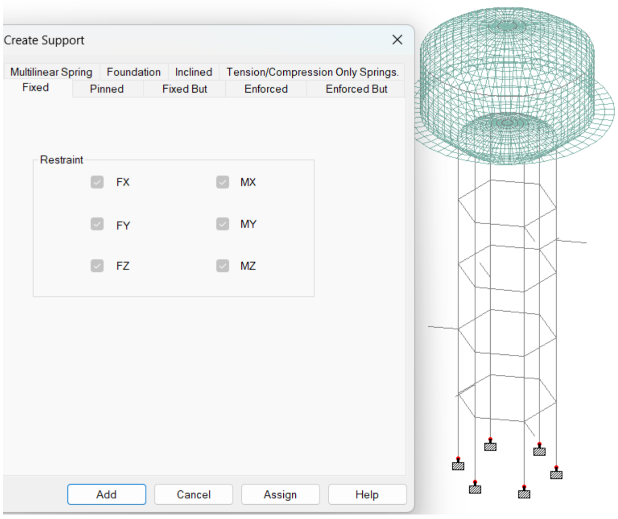
Modeling of Structure in Staad.Pro

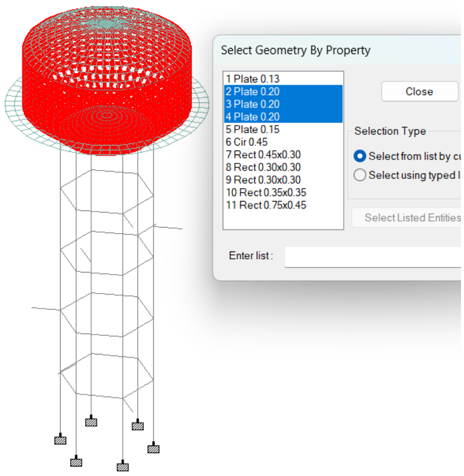
Step1: Create a 3-d frame in structure wizard as shown in the plan



Step2: Supports
The base supports of the structure were assigned as fixed.

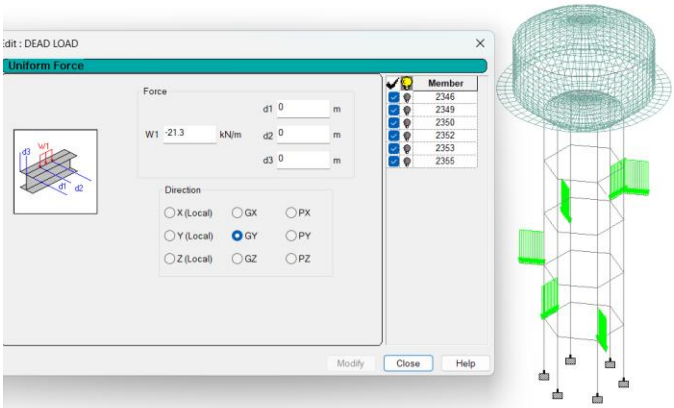


Step3: Member Property
Generation of member property can be done in STAAD.Pro by using the window as shown below. Define property (Beam and column cross section) For example: 300x230mm



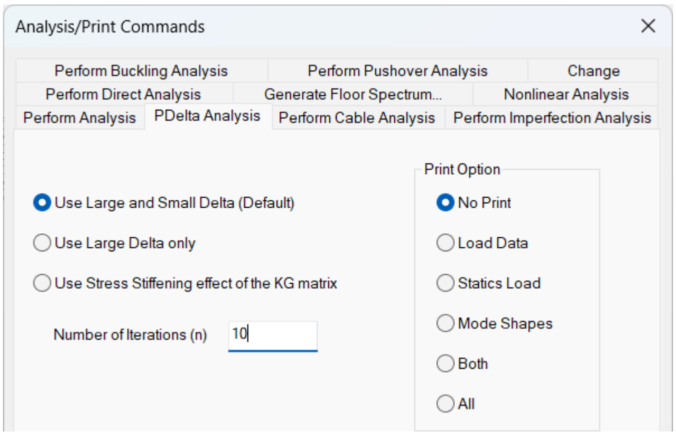
Step4: Loading
The loadings were calculated manually, and the rest was generated by stadd.pro. The loading cases were categorized as:

- Seismic Load Definitions
- EQx and EQy
- Dead Load: Self weight, Member load, Floor Load, Floor Finishes.



- Live Load: Floor load
- Water Load
- Load Combinations were created based on code provisions

Step5: Analysis
- P-Delta Analysis command should be given in Staad Pro to analyze the ESR as shown below figure.



4. RESULTS AND DISCUSSIONS

General

This chapter will give the results of the examination of the current project. To know the comparison of the ESRs located in different earthquake zones, results were shown in graphical way and tabular form.

Comparison of Base Shear

Base shear of ESRs due to the earthquake force is given in the tabular form below. Base shear is the response against the seismic load applied on tanks. This Particular shear usually acting at the support location of structure. Base shear load is compared for ESRs in different earthquake zones in tale 5 and

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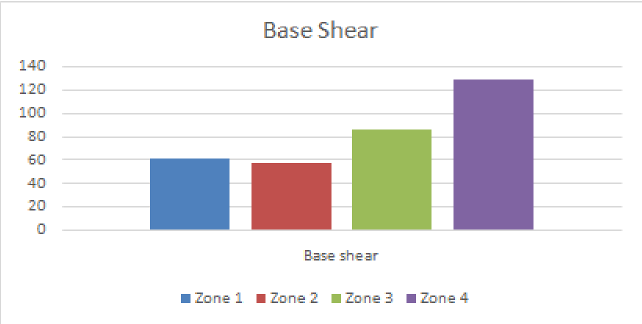
showed in graphical representation in figure 26. Base shear is increasing by increasing the earthquake zone location.

	Zone 2	Zone 3	Zone 4	Zone 5
Static analysis kN	60	57	85.44	128.2

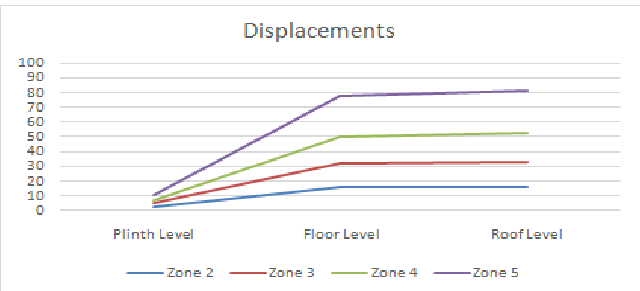


Comparison of Base Shear

Comparison of Displacements

Displacement is the lateral movement of the structure caused by lateral force. Displacement of ESRs is taken from the analysis results and these are shown in tabular form and graphical representation to know the difference due to increase earthquake zone. Deflection shape is most important, and the values should be thoroughly checked against the allowable limits as well. Here we compared the displacement for ESR located in different earthquake zones. From the graphical representation and Tabular form, we can finalize that displacement is increasing by increasing the earthquake zone.

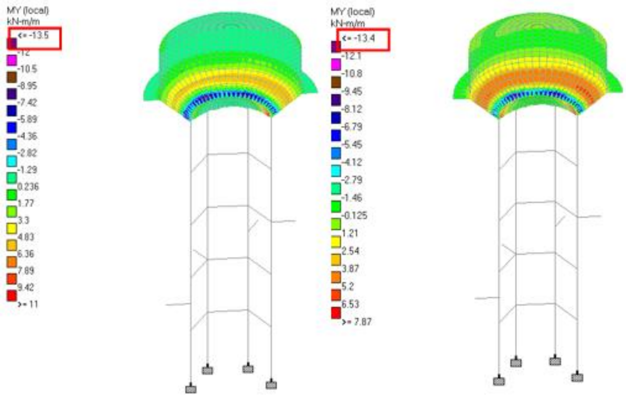
Storey Level	Maximum Displacements (mm)			
	Zone 2	Zone 3	Zone 4	Zone 5
Plinth Level Nodes	2.4	2.5	2.6	3.4
Floor Level	15.9	15.9	18.7	27.8
Roof Level	16.3	16.5	19.6	29.2



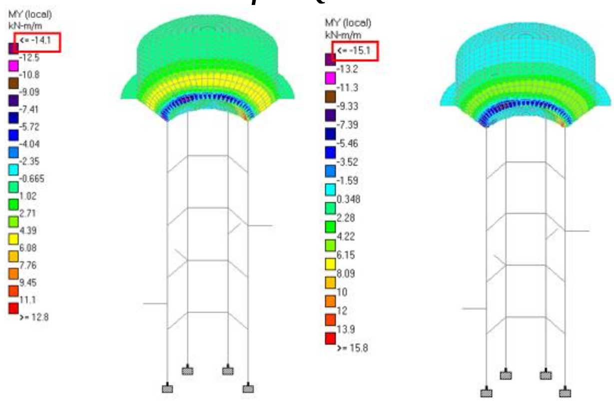
Comparison of Displacements

Comparison of Contour Stresses for plates

Plate moments in Y-direction represented as contours for different earthquake zones are shown below. From the results, Moments are increasing with increasing earthquake zone.



MY stress contour for EQ Zone – II& Zone - III



MY stress contour for EQ Zone – IV & Zone - V

5. CONCLUSIONS

- P-Delta analysis was done to examine the ESRs located in different earthquake zones. To examine the results due to earthquake only, considered Wind pressure constant in all earthquake zones. Anyway, Earthquake and Wind won't come in same instance, so ignored that effect mostly. Results were shown in tabular form and graphical representation to know the comparison in a much clearer view.
- Base shear of each ESRs were examined and showed in tabular and graphical representation. Results concluded that Base shear is increasing when they're located in the higher earthquake zones.
- Displacements of each ESRs were examined and showed in tabular and graphical representation. Results concluded that Displacements are increasing when they're located in the higher earthquake zones. Displacement will be controlled by providing less distance between brace beam to brace beam. Increasing the no of columns will also reduce the deflection and spacing between columns will also reduce the deflection of ESR.
- Support Reactions, Plate Stresses & Beam end forces for ESRs in different Earthquake zones are increasing with increasing earthquake zone.
- P-Delta analysis taken instead of static analysis, to know the second order moments affect which increase the reactions/results with some percentage variation compared to static analysis.

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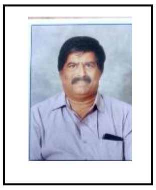

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