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Analytical Approach To Evaluate The Behavior Of Overhead Tank With P-Delta Analysis

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Abstract: When lateral loads are applied directly to a structure, the P- Delta effect typically results, with the deformed shape of the structure being the dominant factor in the structure's equilibrium state. When the elements are damaged, this type of influence is taken into account in second order analysis. In high rise buildings, vertical loads create additional loads at distorted regions as they travel along the structural members. The structure's study does not take this increased load into account. To analyze the structure and research the effects of P-Delta, an accurate mathematical model of the structure is taken into consideration. In current study, the overhead flat surfaced tank was analysis with and without p-delta analysis and the results were recorded and compared.

Index Terms **- STAAD.Pro, P-Delta, Overhead Tank, Seismic Analysis.**

I. INTRODUCTION

The concept of design of various structures varies on many conditions such as type of construction material, type of service provided by the structure, type of loading etc. the process of structural design is a analytical and methodological investigation in relation to the strength, stability and rigidity of any structure such as buildings, bridges etc. The main principle behind conducting the structural analysis and design is to create the structure that can resist the applied forces and moments and transfers the load through different structural members to the ground without any failure so that it can serve its purpose during its intended lifespan. It the structure is not properly design and analyzed, then the structure might fail under applied force in one way or the other such as failure due to compression, tension, shear etc. and therefore fail to serves its intended purpose. This not only is detrimental to the structure but also harmful the human lives using that structure. A well-engineered structure will stay strong throughout its lifespan while minimizing the costly and hazardous failures.

When lateral loads are applied directly to a structure, the P-effect typically results, with the deformed shape of the structure being the dominant factor in the structure's equilibrium state. When the elements are damaged, this type of influence is taken into account in second order analysis. In high rise buildings, vertical loads create additional loads at distorted regions as they travel along the structural members. The structure's study does not take this increased load into account. To analyses the structure and research the effects of P-Delta, an accurate mathematical model of the structure is taken into consideration. When P-Delta is taken into account, second-order analysis combines two effects to provide a resolution as under:

Theory of large displacement: - In this stage, both the forces and moments are being considered due to deformed shape of building along with the members.

Stress stiffening: - In this particular stage, the effect of vertical load on structure stiffness has been observed. Tensile loads often straighten an element's geometry, increasing stiffness, whereas compressive loads emphasize deformation, reducing stiffness of the structure.

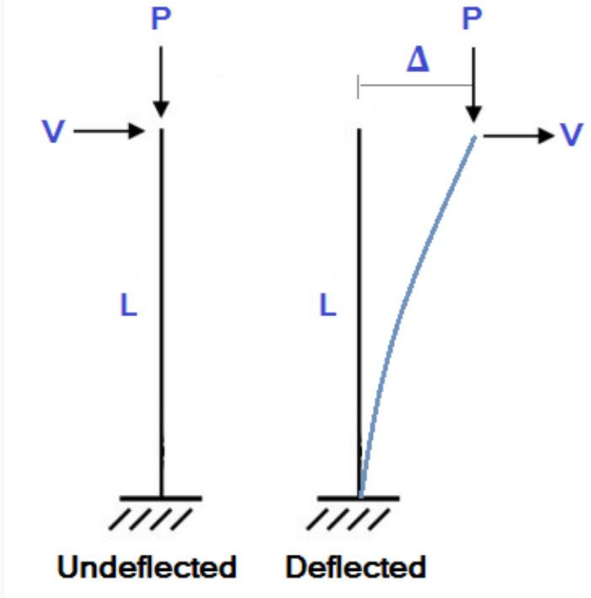


Figure 1. P-Delta Effect on Column.

Tall buildings that are subject to gravity loads and lateral displacement from wind or other factors typically exhibit P-Delta effects. A P-Delta Analysis should be carried out to account for the non-linearities if the lateral displacement and/or the vertical axial stresses across the structure are significant. When compared to a P-Delta (Non-Linear) Analysis, a linear static analysis frequently significantly underestimates displacement (among other conclusions).

II. MODELING OF THE TANK:

Models in STAAD.Pro: Flat bottom Overhead tank was modeled in Bentley's Staad.Pro (connect edition) software. Different input parameters such as dia. of tank, height of tank, stagging height, centre to centre distance between the bracing etc were determined before modeling the tank in the software. Different concrete properties were assigned to various structural members as per the requirement.

Table: 1. Input Parameters for Tank Model

S. No.	Parameter	Value
1	Capacity of tank	115 KL
2	Dia. of tank	7.0 m
3	Height of Tank	3.3 m
4	Free Board	0.3 m
5	Water height	3.0 m
6	Stagging Height	9.0 m and 12.0 m
7	Footing Depth	2.0 m
8	Centre to centre Distance Between the bracing	3.0 m

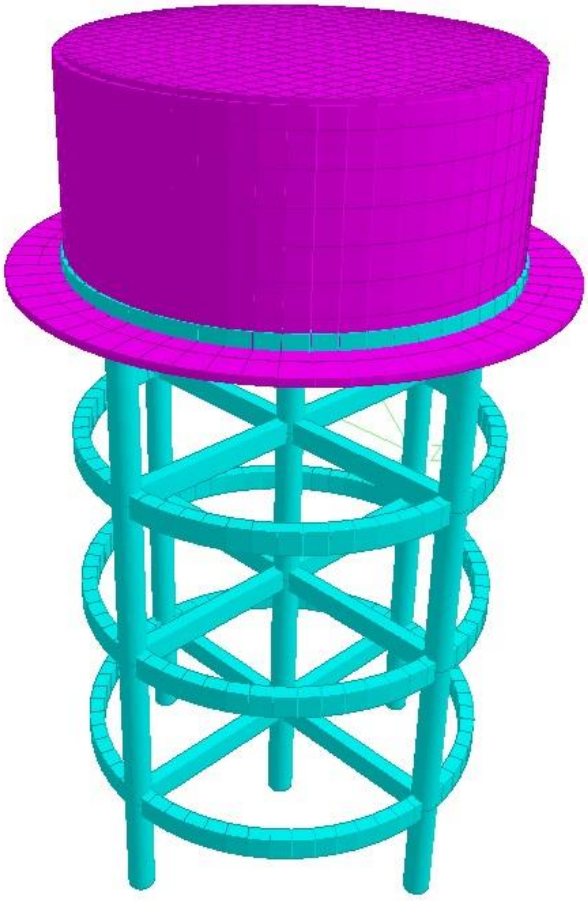
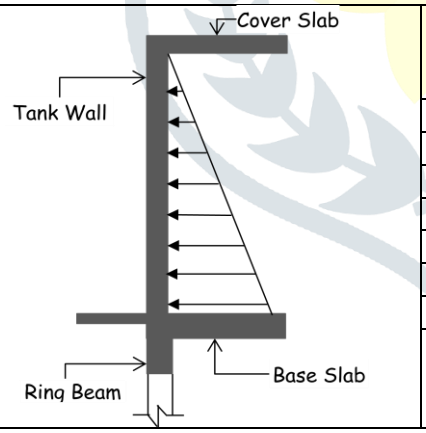


Figure 2. 3-D view of Flat Bottom Overhead Tank.

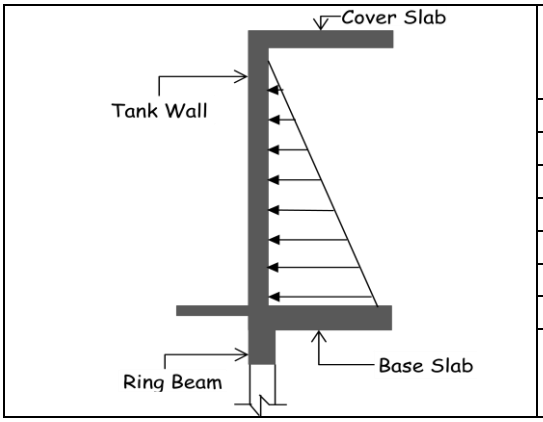
Water Pressure of Tank Walls: The conditions were considered for analyzing the tank structure i.e. working condition in which the free board is present and hydrotest condition in which there was no free board in the tank which represents the condition in which the water level is touching the top slab of the tank. The water pressure for both the cases were determined as under:

Water Pressure on tank walls under Hydro-Test Condition:



Depth from Top (m)	Water Pressure (kN/m2) at 0.5m increment in height
0.0	0.00
0.3	3.00
0.8	8.00
1.3	13.00
1.8	18.00
2.3	23.00
2.8	28.00
3.3	33.00

Water Pressure on tank walls under Working Condition:



Depth from Top (m)	Water Pressure (kN/m2) at 0.5m increment in height
FREE BOARD (0.3m)	
0.0	0.0
0.5	5.0
1.0	10.0
1.5	15.0
2.0	20.0
2.5	25.0
3.0	30.0

P-Delta Analysis: In structure P-Δ effect generally arises due to the direct action of lateral loads where the deformed structure shape is a dominating factor in the structure at state of equilibrium. In second order analysis, this kind of effects is taken care when the elements are in damaged condition. Tank model shall be assessed with and without P-Delta effect and the results shall be gathered after analyzing and designing the model.

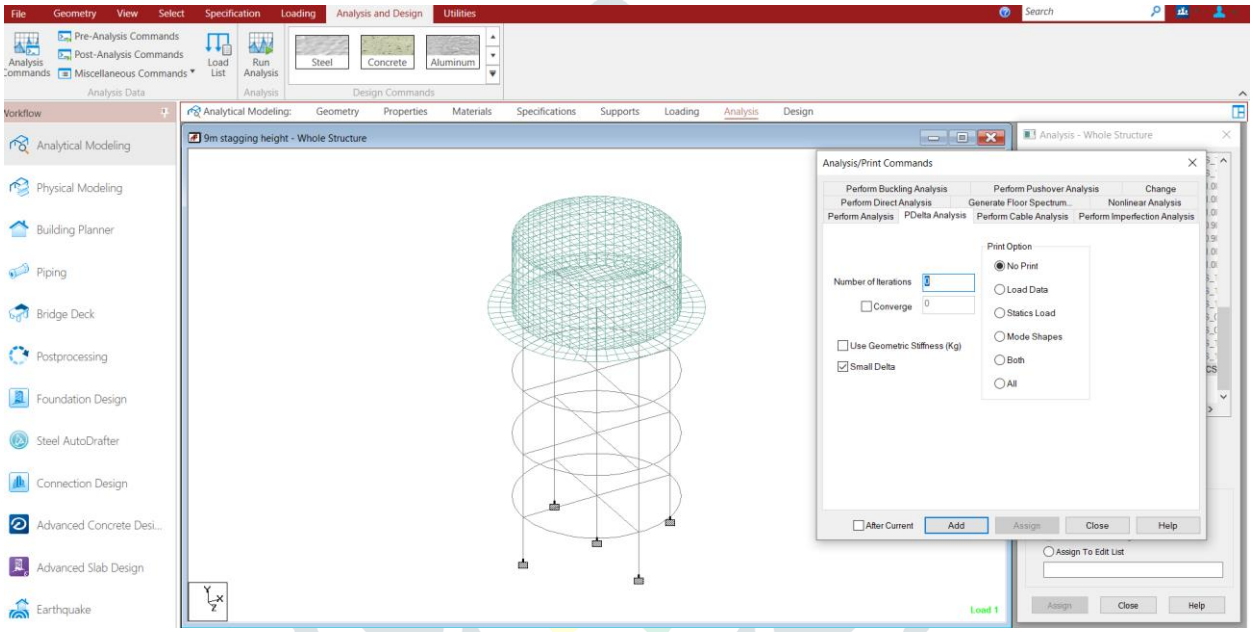


Figure 3. P-Delta Analysis in Staad.Pro.

RCDC Software: By importing the support reactions from the staad models (with and without p-delta analysis) to RCDC software, footing was designed. The results of the two different sets (models with and without p-delta analysis) of footing were collected. The design report of footing of 5 columns (C1 to C5) of tank in RCDC software was scrutinized.

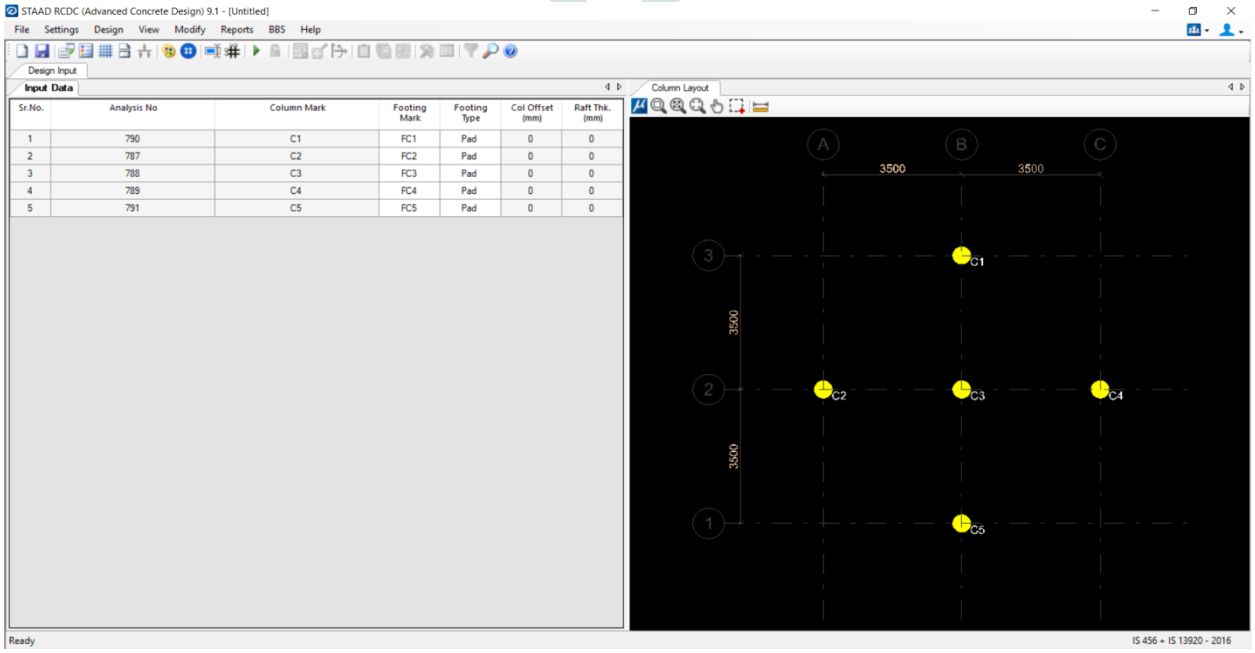


Figure 4. Designing footing in RCDC Software.

III. RESULTS AND DISCUSSION

RESULTS OF TANK WITH 9 M STAGGING HEIGHT

Displacement of Columns: When the load is applied to the column it tends to sway from its original position towards 'X', 'Y' and 'Z' direction. These maximum displacements of nodes of all columns were obtained from the staad.pro post processing and as shown below.

Table: 2. Displacement Chart of Columns of the Tank.

Column No.	Node No.	With P-Delta Analysis				Without P-Delta Analysis			
		X Dir (mm)	Y Dir (mm)	Z Dir (mm)	Resultant (mm)	X Dir (mm)	Y Dir (mm)	Z Dir (mm)	Resultant (mm)
1	1	27.050	-0.723	0.000	27.059	26.865	-0.726	0.000	26.875
	489	22.045	-0.481	0.000	22.050	21.884	-0.483	0.000	21.889
	494	13.186	-0.262	0.000	13.189	13.082	-0.264	0.000	13.085
	499	3.241	-0.090	0.000	3.242	3.213	-0.091	0.000	3.215
	504	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	18	27.071	-1.255	-0.010	27.100	26.887	-1.255	-0.010	26.916
	492	22.470	-0.960	0.003	22.491	22.307	-0.960	0.003	22.327
	497	13.488	-0.631	0.000	13.502	13.382	-0.631	0.000	13.397
	502	3.358	-0.266	0.001	3.369	3.330	-0.266	0.001	3.341
	507	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	3	27.068	-1.785	0.000	27.127	26.883	-1.783	0.000	26.943
	491	22.040	-1.439	0.000	22.087	21.878	-1.436	0.000	21.925
	496	13.186	-0.999	0.000	13.224	13.081	-0.996	0.000	13.119
	501	3.240	-0.441	0.000	3.269	3.212	-0.440	0.000	3.242
	506	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	47	27.071	-1.255	0.010	27.100	26.887	-1.255	0.010	26.916
	493	22.470	-0.960	-0.003	22.491	22.307	-0.960	-0.003	22.327
	498	13.488	-0.631	0.000	13.502	13.382	-0.631	0.000	13.397
	503	3.358	-0.266	-0.001	3.369	3.330	-0.266	-0.001	3.341
	508	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	2	27.061	-0.831	0.000	27.074	26.876	-0.830	0.000	26.889
	490	22.038	-0.662	0.000	22.048	21.877	-0.662	0.000	21.887
	495	13.187	-0.449	0.000	13.195	13.082	-0.449	0.000	13.090
	500	3.243	-0.194	0.000	3.249	3.216	-0.194	0.000	3.221
	505	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The above table represents the displacement of each node of the column in X, Y and Z direction along with the resultant displacement with respect to the base. It has been observed that the maximum resultant displacement of C1, C2, C3, C4 and C5

(with P-delta) is 27.059 mm, 27.100 mm, 27.127 mm, 27.100 mm and 27.074 mm respectively. Whereas, the maximum resultant displacement of C1, C2, C3, C4 and C5 (without P-delta) is 26.875 mm, 26.916 mm, 26.943 mm, 26.916 mm and 26.889 mm respectively.

Bending Moment of Columns: The results of bending moment of column of tank with and without P-Delta analysis were shown below.

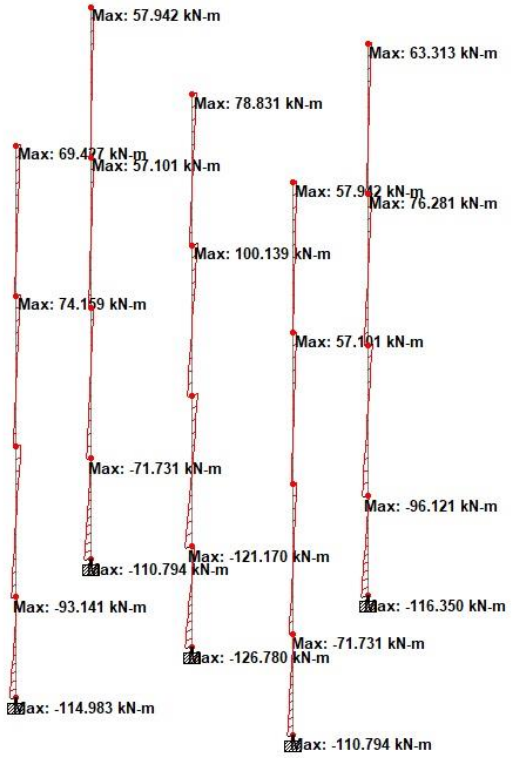


Figure 5. Maximum Bending Moment of Columns of tank with P-Delta Analysis.

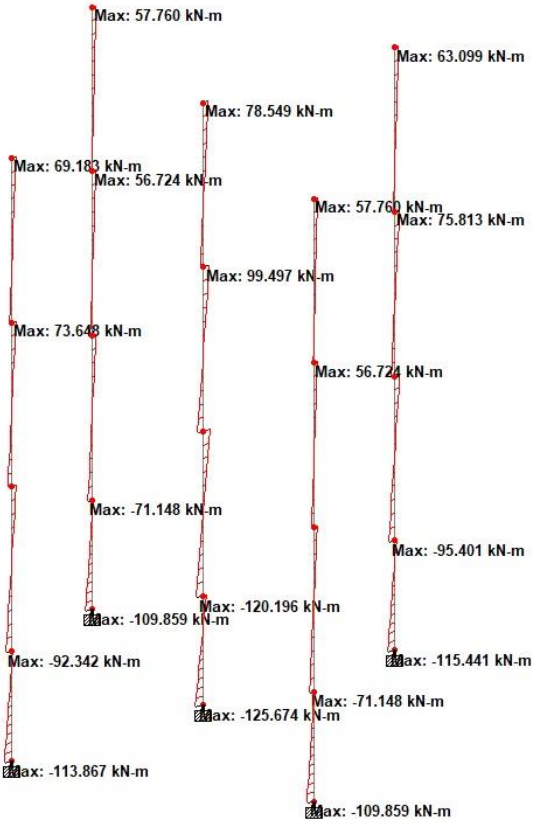


Figure 6. Maximum Bending Moment of Columns of tank without P-Delta Analysis

From the above fig., it has been observed that the maximum bending moment comes out for the central column (C5) for the tank with and without P-Delta analysis. i.e., 126.780 KN-m and 125.674 KN-m. The Increase in the bending moment of C5 was 1.106 KN-m and the percentage increase was calculated as +0.88%. However, the maximum percentage increase in B.M was seen in C1 i.e., +0.98%. Whereas, the percentage increase in C2, C3 and C4 comes out to be +0.85%, +0.79% and +0.85% respectively.

Shear Force of Columns: The results of Shear Force of column of tank with and without P-Delta analysis were shown below:

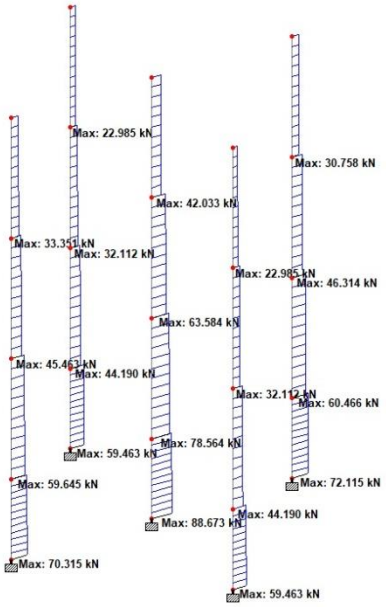


Figure 7. Maximum Shear Force of Columns of tank with P-Delta Analysis.

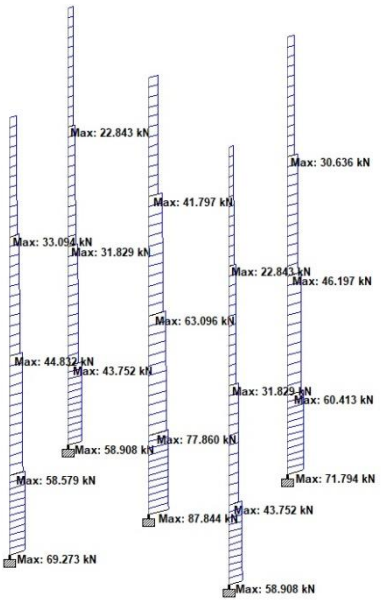


Figure 8. Maximum Shear Force of Columns of tank without P-Delta Analysis.

From the fig., it has been observed that the maximum shear force comes out for the central column (C5) for the tank with and without P-Delta analysis. i.e., 88.673 KN and 87.844 KN. The Increase in the shear force of C5 was 0.83 KN-m and the percentage increase was calculated as +0.95%. However, the maximum percentage increase in S.F. was seen in C1 i.e., +1.5%. Whereas, the percentage increase in C2, C3 and C4 comes out to be +0.94%, +0.45% and 0.94% respectively.

Total Quantity of Tank: The results of material quantity of the tank with and without P-Delta analysis were shown below:

Table: 3. Total Material Quantity of tank.

Tank	Concrete Qty, m3	Steel Qty, KN
With P-Delta	28.4	17.6
Without P-Delta	28.4	16.6

From the above table, it has been concluded that the steel quantity changes while keeping the concrete quantity constant when the P-Delta Analysis is done.

TOTAL VOLUME OF CONCRETE = 28.4 CU.METER

BAR DIA (in mm)	WEIGHT (in New)
8	5805
10	5476
12	5836
16	309
20	169
*** TOTAL=	17595

Figure 9. Material Quantity of tank with P-Delta Analysis.

TOTAL VOLUME OF CONCRETE = 28.4 CU.METER

BAR DIA (in mm)	WEIGHT (in New)
8	5805
10	5464
12	4813
16	309
20	169
*** TOTAL=	16561

Figure 10. Material Quantity of tank without P-Delta Analysis.

From the fig., it has been observed that the Total Steel quantity comes out for the tank with and without P-Delta analysis. i.e., 17.60 KN and 16.60 KN. The Increase in the steel quantity was 1.04 KN-m and the percentage increase was calculated as +6.28%.

RESULTS OF TANK WITH 12 M STAGGING HEIGHT

Displacement of Columns: When the load is applied to the column it tends to sway from its original position towards 'X', 'Y' and 'Z' direction. These maximum displacements of nodes of all columns were obtained from the staad.pro post processing and as shown below:

TABLE: 4. DISPLACEMENT CHART OF COLUMNS OF THE TANK.

Column No.	Node No.	With P-Delta Analysis				Without P-Delta Analysis			
		X Dir (mm)	Y Dir (mm)	Z Dir (mm)	Resultant (mm)	X Dir (mm)	Y Dir (mm)	Z Dir (mm)	Resultant (mm)
1	1	43.769	-0.734	0	43.775	43.435	-0.739	0	43.441
	489	38.358	-0.493	0	38.361	38.05	-0.499	0	38.053
	494	28.789	-0.278	0	28.79	28.544	-0.283	0	28.545
	499	16.6	-0.116	0	16.601	16.452	-0.12	0	16.453
	1638	3.984	-0.025	0	3.984	3.947	-0.027	0	3.947
	1643	0	0	0	0	0	0	0	0
2	18	43.791	-1.67	-0.01	43.823	43.457	-1.67	-0.01	43.489
	492	38.814	-1.377	0.003	38.838	38.504	-1.377	0.003	38.528
	497	29.215	-1.049	0	29.234	28.968	-1.049	0	28.987
	502	16.845	-0.687	0.001	16.859	16.696	-0.687	0.001	16.71
	1641	4.08	-0.288	0	4.091	4.043	-0.288	0	4.054
	1646	0	0	0	0	0	0	0	0
3	3	43.787	-2.604	0	43.865	43.453	-2.599	0	43.531
	491	38.3	-	0	38.419	38.0	-	0	38.111

		52	2.259			44	2.253		
	496	28.79	-1.819	0	28.847	28.544	-1.814	0	28.601
	501	16.6	-1.256	0	16.648	16.451	-1.252	0	16.499
	1640	3.982	-0.551	0	4.02	3.946	-0.549	0	3.984
	1645	0	0	0	0	0	0	0	0
4	47	43.791	-1.67	0.01	43.823	43.457	-1.67	0.01	43.489
	493	38.814	-1.377	-0.003	38.838	38.504	-1.377	-0.003	38.528
	498	29.215	-1.049	0	29.234	28.968	-1.049	0	28.987
	503	16.845	-0.687	-0.001	16.859	16.696	-0.687	-0.001	16.71
	1642	4.08	-0.288	0	4.091	4.043	-0.288	0	4.054
	1647	0	0	0	0	0	0	0	0
5	2	43.78	-1.191	0	43.797	43.446	-1.191	0	43.463
	490	38.351	-1.017	0	38.364	38.043	-1.017	0	38.056
	495	28.786	-0.797	0	28.797	28.541	-0.797	0	28.552
	500	16.602	-0.533	0	16.611	16.454	-0.533	0	16.462
	1639	3.987	-0.228	0	3.993	3.949	-0.228	0	3.956
	1644	0	0	0	0	0	0	0	0

The above table represents the displacement of each node of the column in X, Y and Z direction along with the resultant displacement with respect to the base. It has been observed that the maximum resultant displacement of C1, C2, C3, C4 and C5 (with P-delta) is 43.775 mm, 43.823 mm, 43.865 mm, 43.823 mm and 43.797 mm respectively. Whereas, the maximum resultant displacement of C1, C2, C3, C4 and C5 (without P-delta) is 43.441 mm, 43.489 mm, 43.531 mm, 43.489 mm and 43.423 mm respectively.

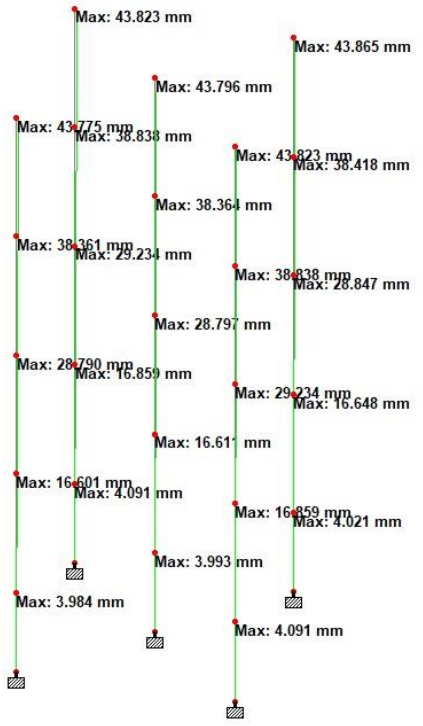


Figure 11. Maximum Displacement of Columns of Tank with P-Delta Analysis.

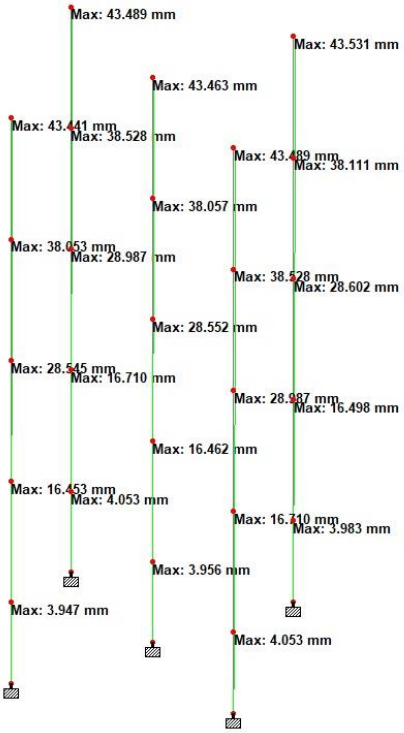


Figure 12. Resultant Displacement of Columns of Tank without P-Delta Analysis.

The above fig. shows the resultant displacement of the columns with and without P-Delta analysis. The maximum displacement was seen for the column C3 of both the tanks i.e., tank with and without P-Delta analysis i.e., 43.865 mm and 43.531 mm respectively. The increase in the displacement of this column comes out to be 0.334 mm and percentage increase was +0.77%.

Bending Moment of Columns: The results of bending moment of column of tank with and without P-Delta analysis were shown below:

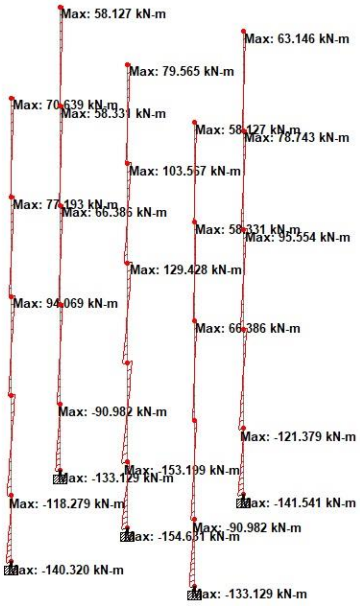


Figure 13. Maximum Bending Moment of Columns of tank with P-Delta Analysis.

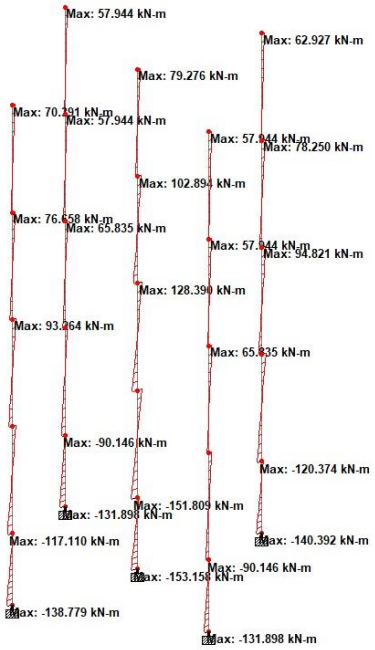


Figure 14. Maximum Bending Moment of Columns of tank without P-Delta Analysis.

From the above fig., it has been observed that the maximum bending moment comes out for the central column (C5) for the tank with and without P-Delta analysis. i.e., 154.631 KN-m and 153.158 KN-m. The Increase in the bending moment of C5 was 1.473 KN-m and the percentage increase was calculated as +0.96%. However, the maximum percentage increase in B.M was seen in C1 i.e., +1.11%. Whereas, the percentage increase in C2, C3 and C4 comes out to be +0.93%, +0.82% and +0.93% respectively.

Shear Force of Columns: The results of Shear Force of column of tank with and without P-Delta analysis were shown below:

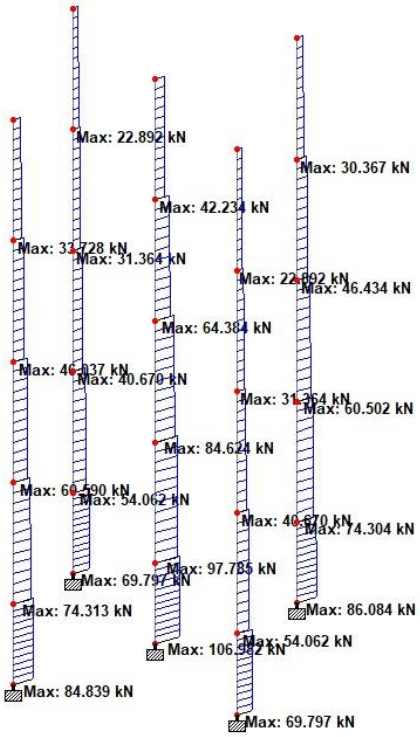


Figure 15. Maximum Shear Force of Columns of tank with P-Delta Analysis.

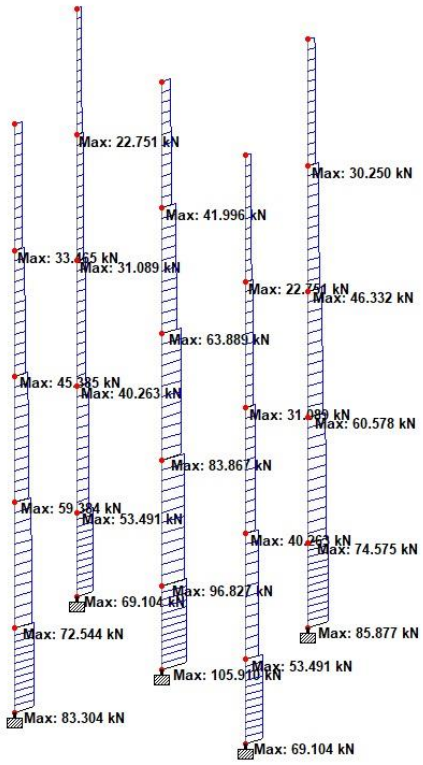


Figure 16. Maximum Shear Force of Columns of tank without P-Delta Analysis.

From the above fig., it has been observed that the maximum shear force comes out for the central column (C5) for the tank with and without P-Delta analysis. i.e., 106.982 KN and 105.910 KN. The Increase in the shear force of C5 was 1.07 KN-m and the percentage increase was calculated as +1.01%. However, the maximum percentage increase in S.F. was seen in C1 i.e., +1.84%. Whereas, the percentage increase in C2, C3 and C4 comes out to be +1.00%, +0.25% and 1.00% respectively.

Total Quantity of Tank: The results of material quantity of the tank with and without P-Delta analysis were shown below:

Table: 5. Total Material Quantity of tank.

Tank	Concrete Qty, m3	Steel Qty, KN
With P-Delta	35.0	23.73
Without P-Delta	35.0	22.56

From the above table, it has been concluded that the steel quantity changes while keeping the concrete quantity constant when the P-Delta Analysis is done.

TOTAL VOLUME OF CONCRETE = 35.0 CU.METER

BAR DIA (in mm)	WEIGHT (in New)
8	7202
10	6046
12	8031
16	624
20	1821
*** TOTAL=	23724

Figure 17. Material Quantity of tank with P-Delta Analysis.

TOTAL VOLUME OF CONCRETE = 35.0 CU.METER

BAR DIA (in mm)	WEIGHT (in New)
8	7257
10	6061
12	7708
16	439
20	826
25	265
*** TOTAL=	22555

Figure 18. Material Quantity of tank without P-Delta Analysis.

From the above fig., it has been observed that the Total Steel quantity comes out for the tank with and without P-Delta analysis. i.e., 23.73 KN and 22.56 KN. The Increase in the steel quantity was 1.17 KN-m and the percentage increase was calculated as +5.19%.

IV. CONCLUSION

Conclusions for Tank having 9m Stagging Height

- The maximum displacement was seen for the column C3 of both the tanks i.e. tank with and without P-Delta analysis i.e. 27.127 mm and 26.943 mm respectively. The increase in the displacement of this column comes out to be 0.184 mm and percentage increase was 0.68%.
- It has been observed that the maximum bending moment comes out for the central column (C5) for the tank with and without P-Delta analysis. i.e., 126.780 KN-m and 125.674 KN-m. The Increase in the bending moment of C5 was 1.106 KN-m and the percentage increase was calculated as +0.88%. However, the maximum percentage increase in B.M was seen in C1 i.e., +0.98%. Whereas, the percentage increase in C2, C3 and C4 comes out to be +0.85%, +0.79% and +0.85% respectively.
- It has been observed that the maximum shear force comes out for the central column (C5) for the tank with and without P-Delta analysis. i.e., 88.673 KN and 87.844 KN. The Increase in the shear force of C5 was 0.83 KN-m and the percentage increase was calculated as +0.95%. However, the maximum percentage increase in S.F. was seen in C1 i.e., +1.5%. Whereas, the percentage increase in C2, C3 and C4 comes out to be +0.94%, +0.45% and 0.94% respectively.
- It has been observed that the Total Steel quantity comes out for the tank with and without P-Delta analysis. i.e., 17.60 KN and 16.60 KN. The Increase in the steel quantity while keeping the concrete quantity constant was 1.04 KN-m and the percentage increase was calculated as +6.28%.

Conclusions for Tank having 12 m Stagging Height

- The maximum displacement was seen for the column C3 of both the tanks i.e. tank with and without P-Delta analysis i.e. 43.865 mm and 43.531 mm respectively. The increase in the displacement of this column comes out to be 0.334 mm and percentage increase was +0.77%.
- It has been observed that the maximum bending moment comes out for the central column (C5) for the tank with and without P-Delta analysis. i.e., 154.631 KN-m and 153.158 KN-m. The Increase in the bending moment of C5 was 1.473 KN-m and the percentage increase was calculated as +0.96%. However, the maximum percentage increase in B.M was seen in C1 i.e., +1.11%. Whereas, the percentage increase in C2, C3 and C4 comes out to be +0.93%, +0.82% and +0.93% respectively.
- It has been observed that the maximum shear force comes out for the central column (C5) for the tank with and without P-Delta analysis. i.e., 106.982 KN and 105.910 KN. The Increase in the shear force of C5 was 1.07 KN-m and the percentage increase was calculated as +1.01%. However, the maximum percentage increase in S.F. was seen in C1 i.e., +1.84%. Whereas, the percentage increase in C2, C3 and C4 comes out to be +1.00%, +0.25% and 1.00% respectively.
- It has been observed that the Total Steel quantity comes out for the tank with and without P-Delta analysis. i.e., 23.73 KN and 22.56 KN. The Increase in the steel quantity while keeping the concrete quantity constant was 1.17 KN-m and the percentage increase was calculated as +5.19%.

Therefore, it can be finally concluded that the difference between the forces and moments of the tanks with and without P-Delta are very small.

V. FUTURE SCOPE

The current analytical study has few limitations which can be covered in further studies. The future scope of the study is as under:

a) The height of the tank is taken only up to 12 m. Therefore, the height of the supporting columns can be taken more than 12 m for further studies to understand the behaviour of the P-Delta analysis more accurately.

b) The seismic zone III was considered for the current study; therefore, other seismic zone can be considered which may produce different results in the further study.

c) Comparative study can be taken in the future comparing the foundation results of RCDC software and STAAD Foundation software.

d) If the capacity of the tank is increased in the future under the same study, then the results may be differed.

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