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Dynamic Analysis of Underground Water Tank Considering Fluid - Structure Interaction

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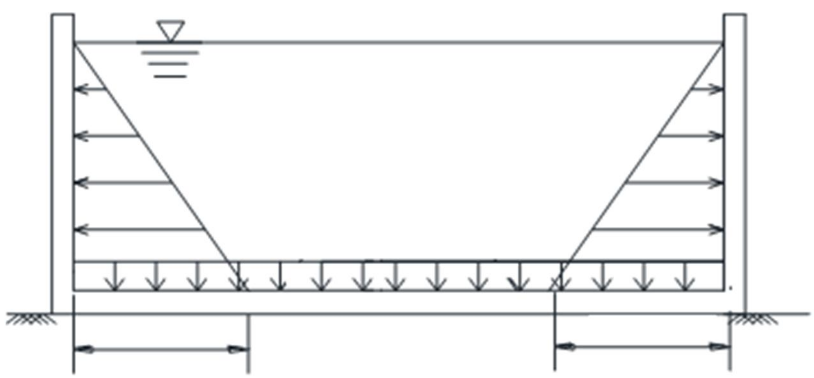
Abstract: In this research paper the main focus on dynamic analysis of open rectangular underground water tanks, focusing on the interaction between the fluid stored within and the structural integrity of the tank. In this paper Understanding the dynamic behavior of these tanks under with different loading scenarios like bending moments, loads, and displacement in water tank essential for ensuring their stability and safety. This project employs numerical technique to simulate and analyze the fluid-structure interaction (FSI) by using staad pro connect in which we use finite element method in underground water tanks. In this research we analyze the open rectangular underground water tank of capacity 576000 liter of water tank by using IS code 456 -2000 code for plain and reinforced concrete.
Keywords: Underground Water Tank, Fluid-Structure Interaction, Staad pro connect, Finite element method, Numerical Simulation, Dynamic Analysis, FSI.

I. INTRODUCTION

A. Fluid-structure-interaction (FSI)

The interrelate between fluid, structure, and soil significantly influences the dynamic behavior of fluid-containing structures. Fluid-structure interaction (FSI) arises at the interface between the fluid and the structure, where hydrodynamic pressure exerts forces on the structure, and structural movements, in turn, generate effective fluid loads. This interaction can be studied using various techniques, including added mass methods, finite element methods (FEM) with Lagrangian, Eulerian, or combined Lagrangian-Eulerian approaches, and analytical models like Housner's two-mass representation or Bauer's multi-mass representations.



Hydrostatic Pressure

Load combination on water tank:

1) Empty Tank:

When the tank is empty, external loads from saturated soil exert significant pressure on the tank walls (Figure 2a). This condition represents a critical loading scenario for design, as the tank must resist external forces without internal support from water.

2) Full Tank:

When the tank is full, hydrostatic pressure from the water inside the tank dominates, while the surrounding soil may shrink away from the walls (Figure 2b). In this scenario, the walls are subjected to internal pressure without counteracting external soil pressure.

- Normal Condition Of Water Tank: - Dead Load + Live Load + Earth Pressure;
- Full Condition Of Water Tank: - Dead Load + Live Load + Earth Pressure.
- Empty Condition Of Water Tank: - Dead Load + Live Load + Earth Pressure + Water Pressure.

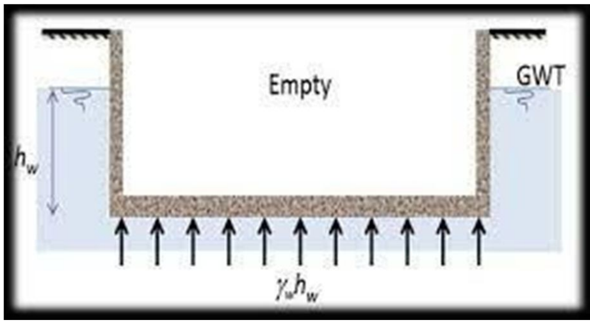


Fig :- 2(a)
Sketches Shows When Tank Is Empty

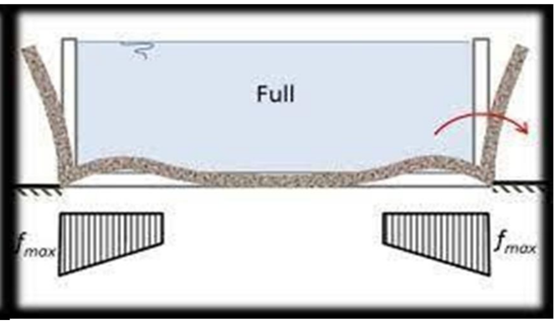


Fig :- 2(b)
Sketches Shows When Tank Is Full

II. LITERATURE REVIEW

1) Issar kapadia. Had done the "design, analysis and comparison of underground rectangular water tank by using staad provi8 software". This paper includes the study of UG Rectangular tank that how the shape deflected and what are the actions will be produced when tank empty or full by using STAAD Pro software is discussed.
2) Housner, G. W. (1963). The dynamic behavior of water tanks. Bulletin of the Seismological Society of America, 53(2), 381-387.
3) Akiyama, H., & Yoshimura, S. (2002). Seismic response analysis of underground water tanks considering soil-structure interaction. Engineering Structures, 24(9), 1203-1211.
4) Gogoi, I., & Maity, D. (2007). Seismic analysis of elevated water tanks with fluid-structure interaction. Journal of Sound and Vibration, 326(3-5), 370- 385.
5) Nallanathel. M et al. showed that corner stresses and maximum shear and bending stresses are less in case of circular tanks than remaining other designs and the shapes of water tanks plays vital role in the stress distribution and overall economy and by using Staad pro, the results obtained was very accurate than conventional results.
6) B.V. Ramana Murthy, M Chiranjeevi had done the "design of rectangular water tank by using staad pro software."

III. METHODOLOGY

A. Added mass method

1) Introduction:

The added mass method is a mathematical approach utilized to quantify the additional mass exerted on a structure due to its interaction with a surrounding fluid. This phenomenon, termed added mass, occurs when a structure either moves through a fluid or remains stationary while the fluid moves around it. The interaction generates an inertial effect caused by the displacement of the fluid, influencing the structure's dynamics.

2) Principle:

The added mass method operates on the principle of conservation of momentum, where the fluid's momentum, influenced by the structure's motion, creates an equivalent additional mass effect on the structure. This induced mass is integrated into the dynamic motion equations, enabling accurate representation of the structural behavior under fluid-induced loads.

3) Mathematical Formulation:

In the added mass method, the added mass is typically expressed as a function of the fluid density, the geometry of the structure, and the relative velocity between the fluid and the structure. The added mass matrix, often denoted as M□, represents the mass-like effects induced by the fluid and is added to the mass matrix of the structure in the dynamic equations.There is a formula used to calculate the added mass for a structure interacting with a fluid. The added mass matrix M□ is typically defined as:

$$\mathbf{M}_a = \rho \int_V \mathbf{N}(\mathbf{x})\mathbf{N}^T(\mathbf{x})dV$$

Where:

- $\mathbf{M}_a$ is the added mass matrix.
- ρ is the density of the fluid.
- $\mathbf{N}(\mathbf{x})$ is the shape function matrix associated with the finite element nodes of the structure.
- $\mathbf{x}$ represents the spatial coordinates.
- dV denotes the differential volume element over the fluid-structure interaction region.

This integral equation represents the contribution of the fluid to the added mass experienced by the structure. The shape functions N(□) describe the displacement of the structure at each finite element node, and the integration is performed over the volume of the fluid-structure interaction domain.

The added mass matrix M is then incorporated into the dynamic equations of motion for the structure to account for the additional mass induced by the fluid. This allows for a more accurate prediction of the dynamic response of the structure under fluid loading conditions.

B. Implementation

Implementation of the added mass method typically employs Numerical Techniques such as finite element analysis (FEA)

The process involves:

1) Problem Formulation: Establishing fluid-structure interaction parameters and boundary conditions.
2) Iterative Solution: Solving the coupled system of equations iteratively to capture the structural response.
3) Dynamic Analysis: Incorporating added mass effects into the motion equations for accurate simulation of fluid-induced loads.

IV. MODELLING AND ANALYSIS

A. Finite Element Method:

1) Introduction:

The Finite Element Method (FEM) is a highly effective numerical technique used for analyzing and modeling complex systems in engineering. It is extensively applied across a variety of fields, such as structural engineering, mechanical engineering, and civil engineering, to solve problems related to stress analysis, heat transfer, fluid flow, and electromagnetic fields.

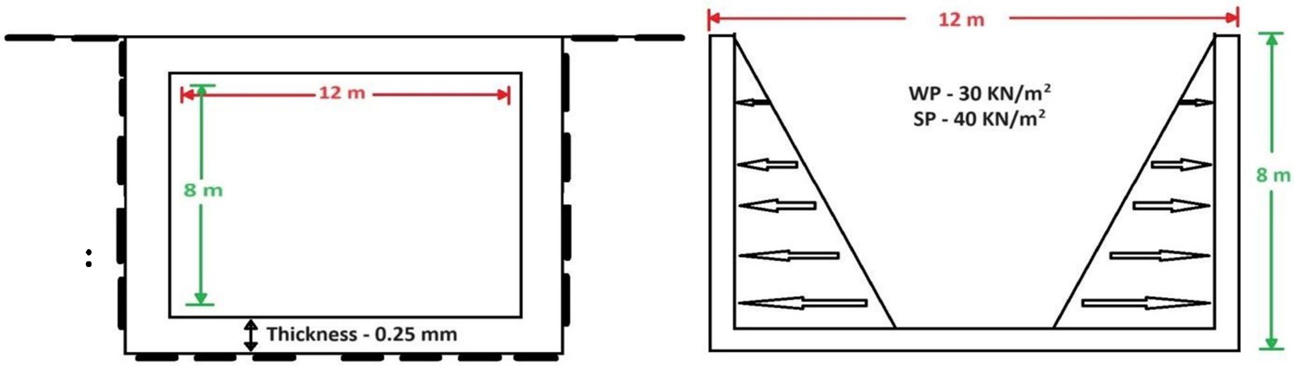
MODELING AND ANALYSIS:

At first analyze the open rectangular shape underground water tank of capacity 576000 litre. The dimension of underground tank is 12m*8m*6m and thickness is 0.25mm.Using code IS 456 In compressive strength of concrete is 30 KN/m square and yield stress 415KN/m square . Analysis is being done by the help of stadd pro v8i software. After provide All required Structural configuration we will assign stresses and load calculation in it.

Table :1 Structural configuration

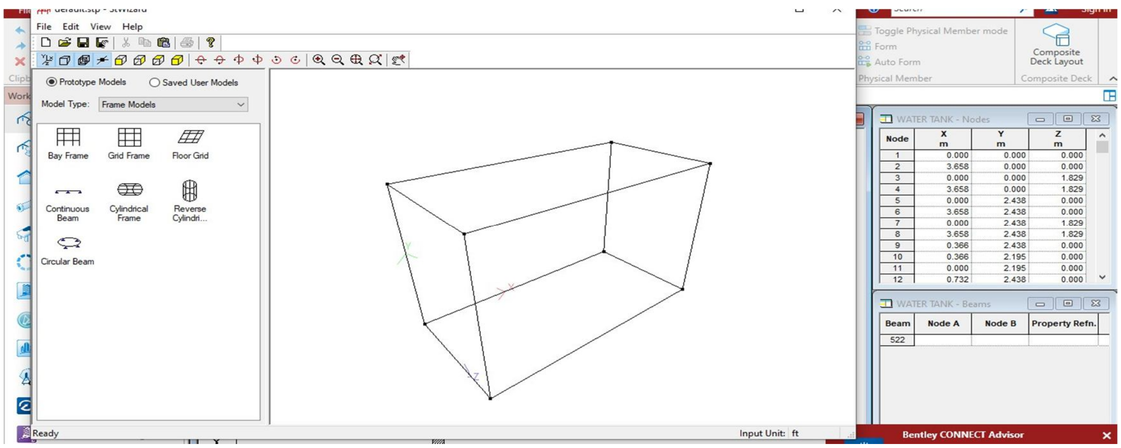
S.no.	Parameter	Size
1.	Capacity of water tank	576m3
2.	Shape of water tank	Rectangular
3.	Unit weight of soil	40 KN/m2
4.	Angle of internal friction (Ø)	37º
5.	Bearing capacity of soil	230 KN/m2
6.	Thickness of plate	0.25m

7.	Size of tank	12x8x6m
8.	Grade of concrete	M25
9.	Yield strength	Fe415
10.	Hydrostatic pressure	30 KN/m2

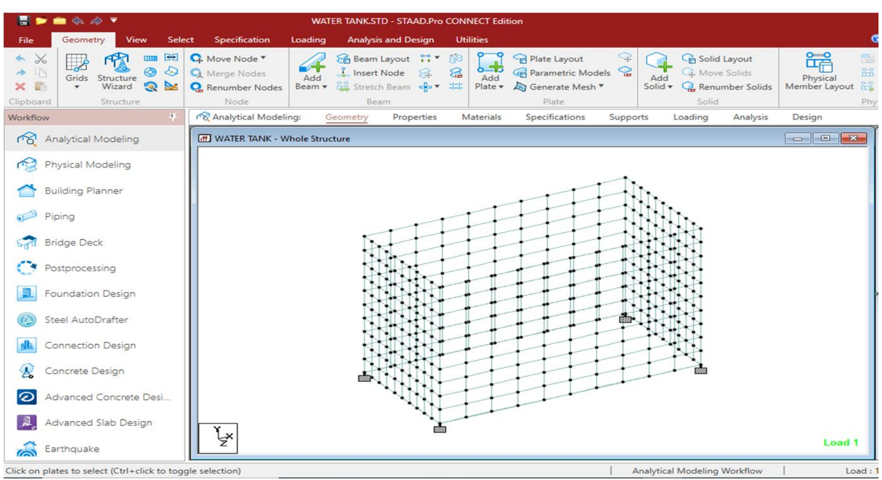


PLAN AND ELEVATION OF WATER TANK

- Modeling by Staad.Pro connect Finite Creating Model:



3D Model of Tank



Assign Nodes

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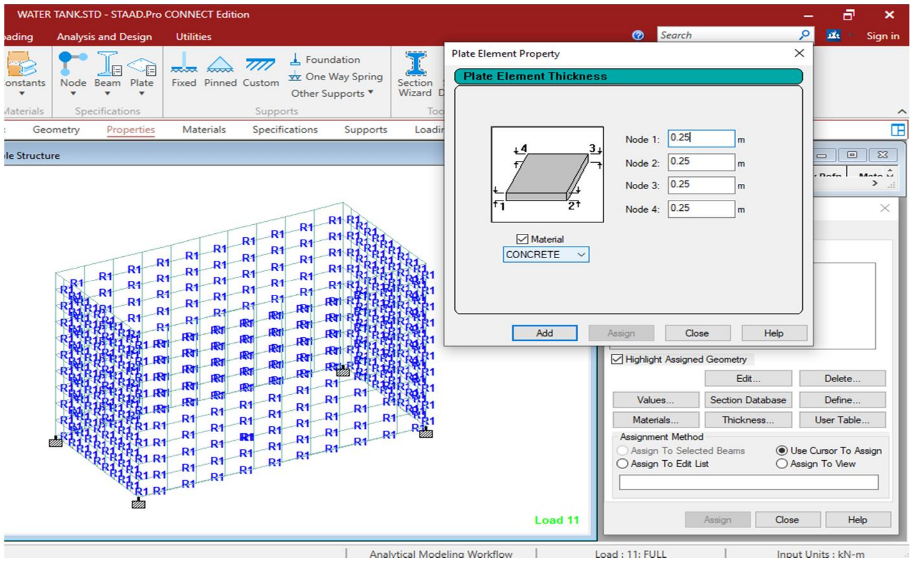
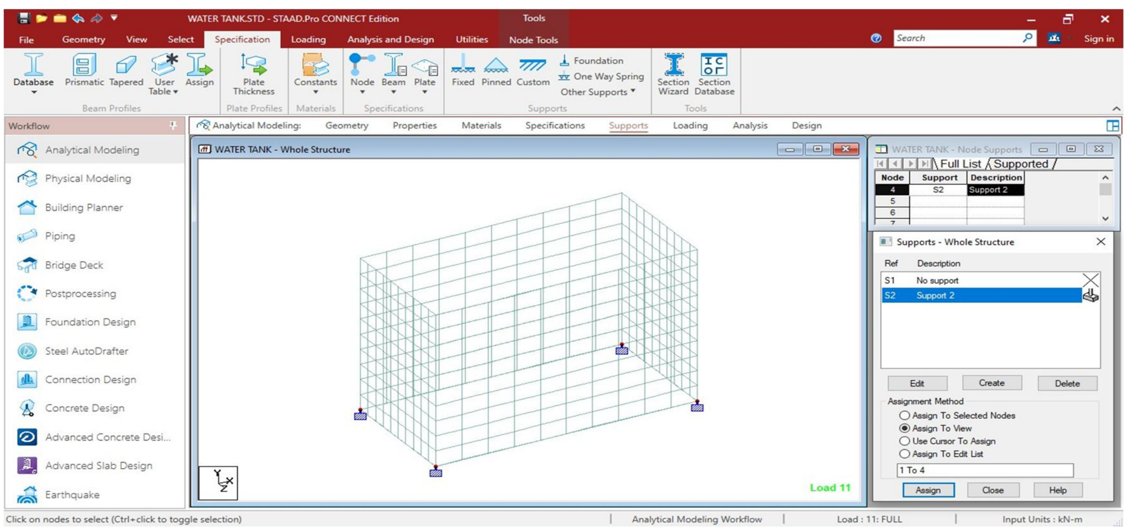


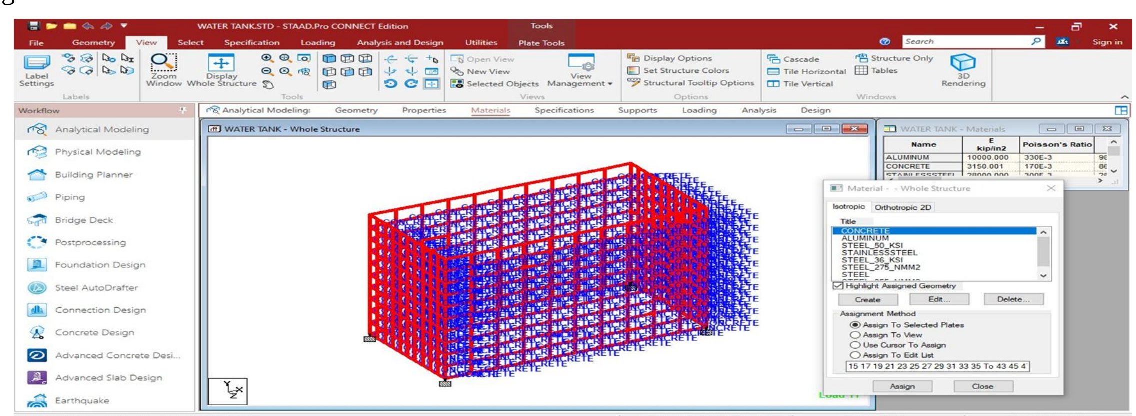
Define the Thickness of Plate

- Assigning of Support:



Support Assigning on Tank

- Assign material:



Define Material

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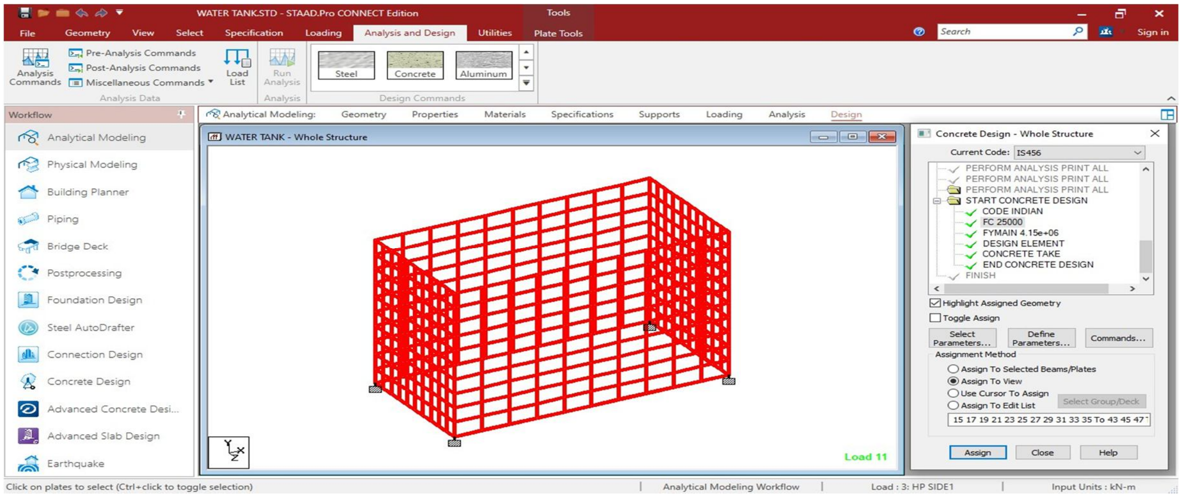
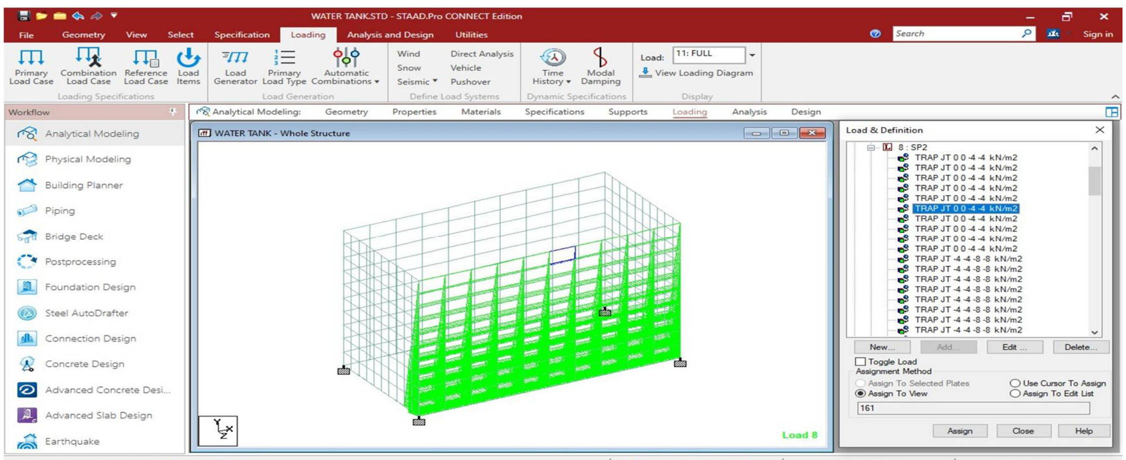
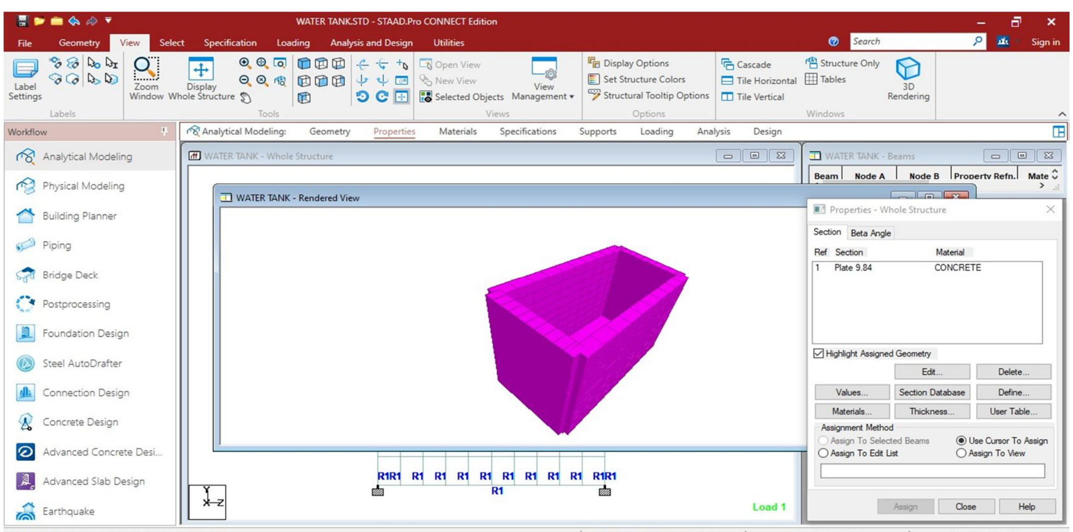


Assign Concrete

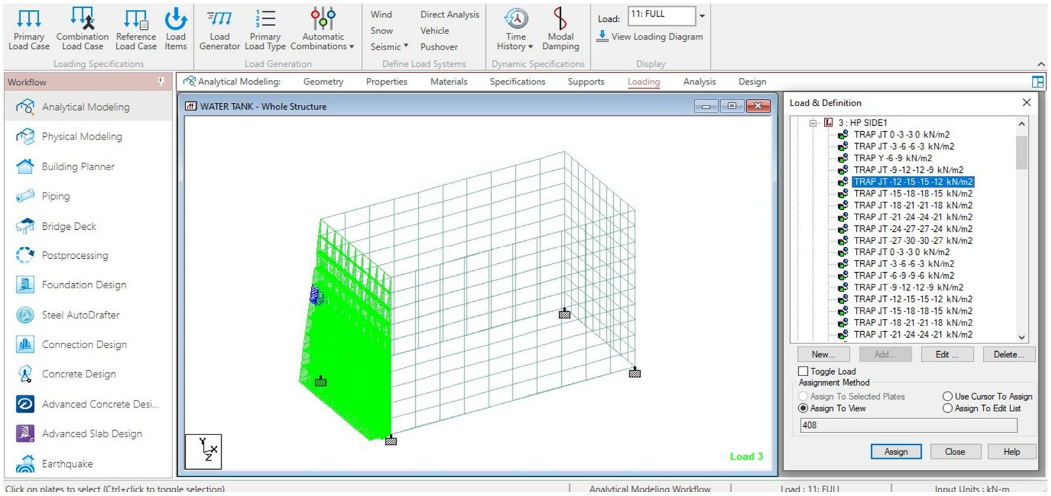
- Load Creating and Assigning Soil Pressure on Tank:



Soil Presure on Tank

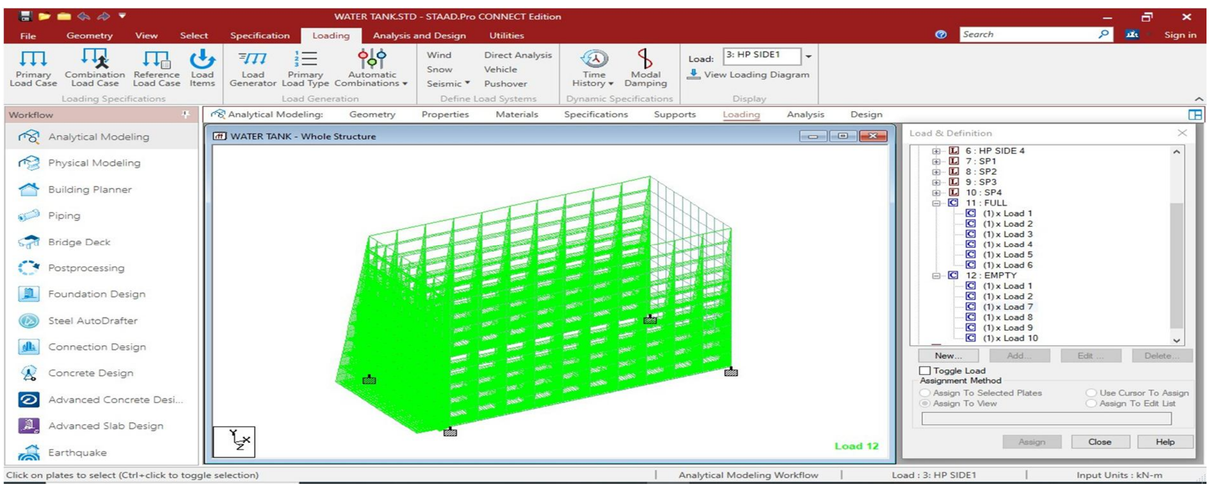


3D Rendering View of Tank

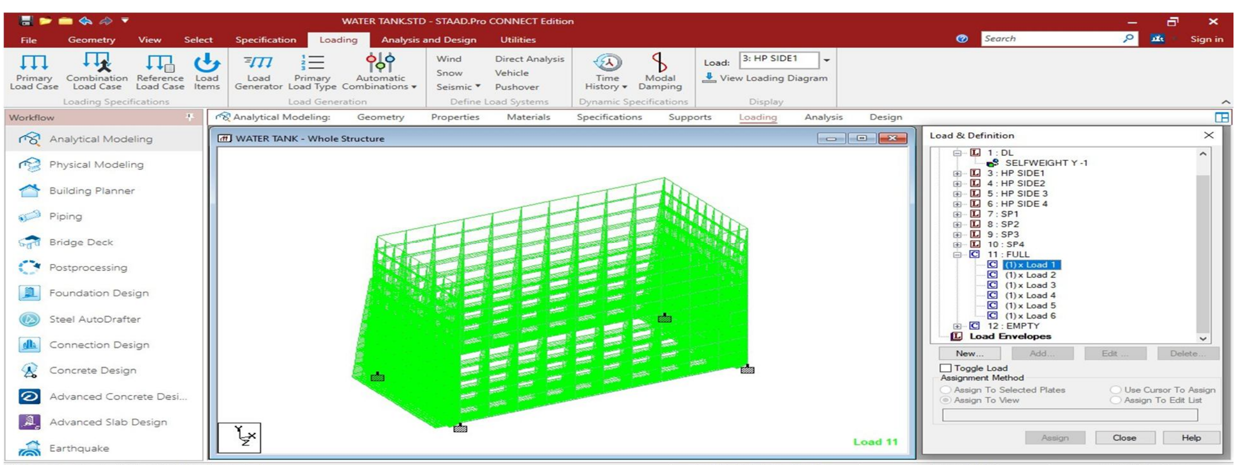


Hydrostatic pressure on tank

- LOAD COMBINATION OF WATER TANK:



Empty Condition



Full Tank Condition

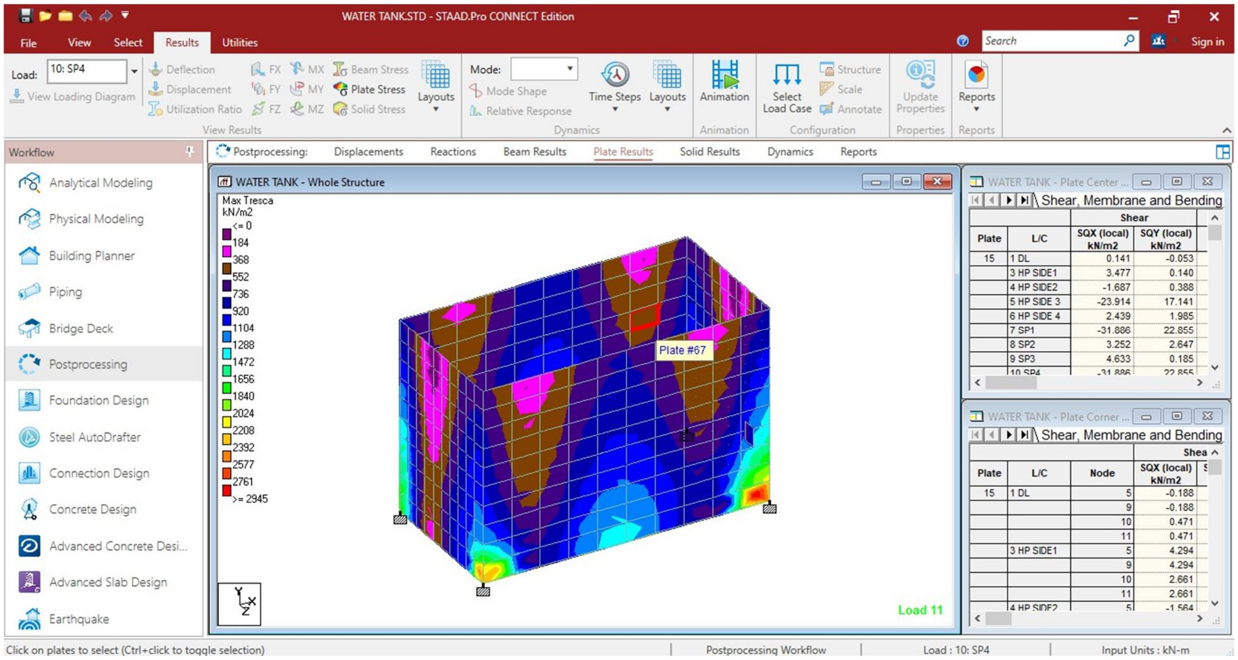
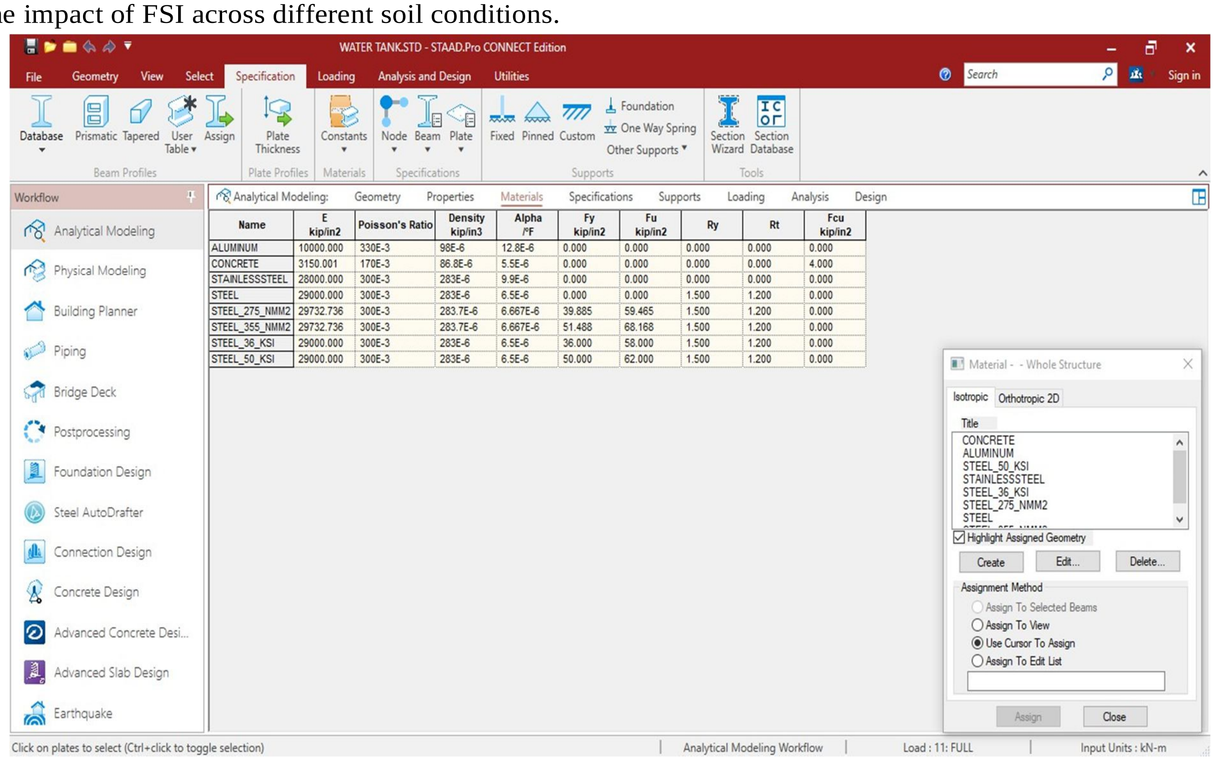


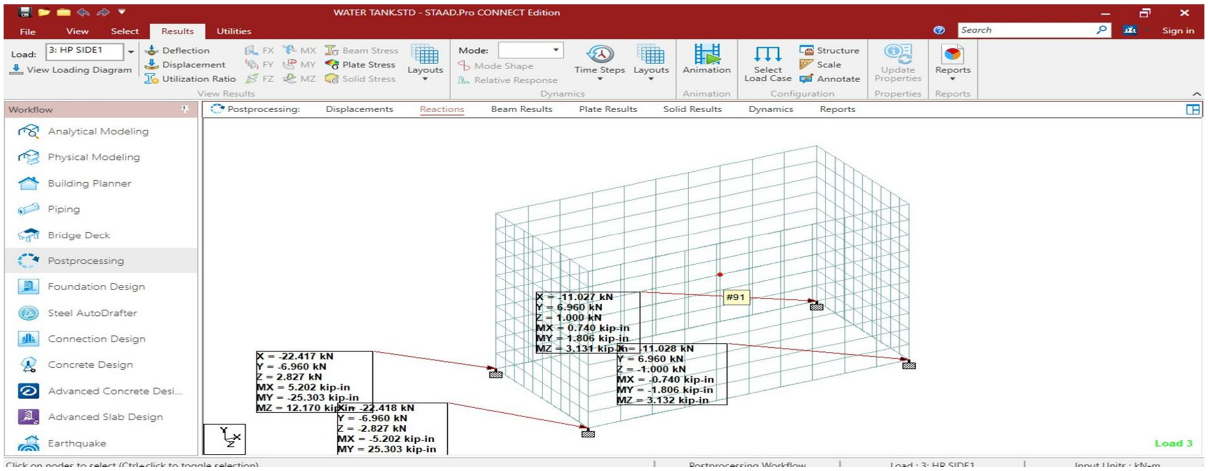
Plate stress in tank

V. RESULT & DISCUSSION

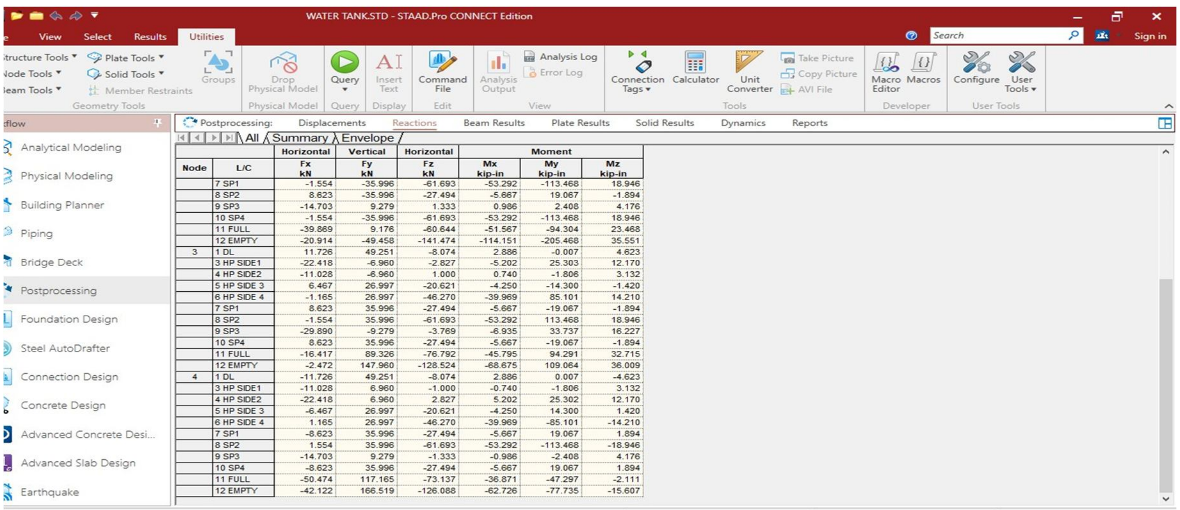
A three-dimensional finite element analysis was performed using STAAD Pro Connect to study the dynamic behavior of underground water tanks under varying load conditions, including empty and full scenarios. The analysis focused on dynamic methodologies, specifically the added mass method, to evaluate the effects of fluid-structure interaction (FSI). Various soil conditions— medium, hard, and soft—were modeled to understand their influence on the tank's response. Multiple models were developed to comprehensively analyze the dynamic performance of underground water tanks and assess the impact of FSI across different soil conditions.



Assign material and IS 456 code

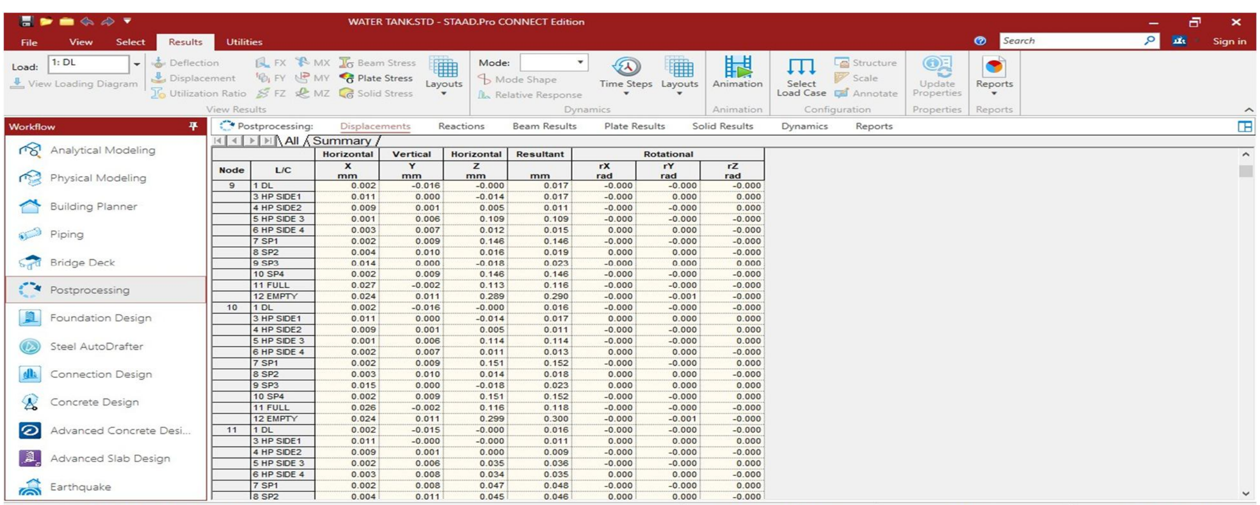


Calculation and assign load on support



		Horizontal	Vertical	Horizontal	Moment		
Node	L/C	Fx kN	Fy kN	Fz kN	Mx kip-in	My kip-in	Mz kip-in
	7 SP1	-1.554	-35.996	-61.693	-53.292	-113.468	18.946
	8 SP2	8.623	-35.996	-27.494	-5.667	19.067	-1.894
	9 SP3	-14.703	9.279	1.333	0.986	2.408	4.176
	10 SP4	-1.554	-35.996	-61.693	-53.292	-113.468	18.946
	11 FULL	-39.869	9.176	-60.644	-51.567	-94.304	23.468
	12 EMPTY	-20.914	-49.458	-141.474	-114.151	-205.468	35.551
3	1 DL	11.726	49.251	-8.074	2.886	-0.007	4.623
	3 HP SIDE1	-22.418	-6.960	-2.827	-5.202	25.303	12.170
	4 HP SIDE2	-11.028	-6.960	1.000	0.740	-1.806	3.132
	5 HP SIDE 3	6.467	26.997	-20.621	-4.250	-14.300	-1.420
	6 HP SIDE 4	-1.165	26.997	-46.270	-39.969	85.101	14.210
	7 SP1	8.623	35.996	-27.494	-5.667	-19.067	-1.894
	8 SP2	-1.554	35.996	-61.693	-53.292	113.468	18.946
	9 SP3	-29.890	-9.279	-3.769	-6.935	33.737	16.227
	10 SP4	8.623	35.996	-27.494	-5.667	-19.067	-1.894
	11 FULL	-16.417	89.326	-76.792	-45.795	94.291	32.715
	12 EMPTY	-2.472	147.960	-128.524	-68.675	109.064	36.009
4	1 DL	-11.726	49.251	-8.074	2.886	0.007	-4.623
	3 HP SIDE1	-11.028	6.960	-1.000	-0.740	-1.806	3.132
	4 HP SIDE2	-22.418	6.960	2.827	5.202	25.302	12.170
	5 HP SIDE 3	-6.467	26.997	-20.621	-4.250	14.300	1.420
	6 HP SIDE 4	1.165	26.997	-46.270	-39.969	-85.101	-14.210
	7 SP1	-8.623	35.996	-27.494	-5.667	19.067	1.894
	8 SP2	1.554	35.996	-61.693	-53.292	-113.468	-18.946
	9 SP3	-14.703	9.279	-1.333	-0.986	-2.408	4.176
	10 SP4	-8.623	35.996	-27.494	-5.667	19.067	1.894
	11 FULL	-50.474	117.165	-73.137	-36.871	-47.297	-2.111
	12 EMPTY	-42.122	166.519	-126.088	-62.726	-77.735	-15.607

Support reactions



		Horizontal	Vertical	Horizontal	Resultant	Rotational		
Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
9	1 DL	0.002	-0.016	-0.000	0.017	-0.000	-0.000	-0.000
	3 HP SIDE1	0.011	0.000	-0.014	0.017	-0.000	0.000	0.000
	4 HP SIDE2	0.009	0.001	0.005	0.011	-0.000	-0.000	0.000
	5 HP SIDE 3	0.001	0.006	0.109	0.109	-0.000	-0.000	-0.000
	6 HP SIDE 4	0.003	0.007	0.012	0.015	0.000	0.000	-0.000
	7 SP1	0.002	0.009	0.146	0.146	-0.000	-0.000	-0.000
	8 SP2	0.004	0.010	0.016	0.019	0.000	0.000	-0.000
	9 SP3	0.014	0.000	-0.018	0.023	-0.000	0.000	0.000
	10 SP4	0.002	0.009	0.146	0.146	-0.000	-0.000	-0.000
	11 FULL	0.027	-0.002	0.113	0.116	-0.000	-0.000	-0.000
	12 EMPTY	0.024	0.011	0.289	0.290	-0.000	-0.001	-0.000
10	1 DL	0.002	-0.016	-0.000	0.016	-0.000	-0.000	-0.000
	3 HP SIDE1	0.011	0.000	-0.014	0.017	0.000	0.000	0.000
	4 HP SIDE2	0.009	0.001	0.005	0.011	-0.000	-0.000	0.000
	5 HP SIDE 3	0.001	0.006	0.114	0.114	-0.000	-0.000	0.000
	6 HP SIDE 4	0.002	0.007	0.011	0.013	0.000	0.000	-0.000
	7 SP1	0.002	0.009	0.151	0.152	-0.000	-0.000	0.000
	8 SP2	0.003	0.010	0.014	0.018	0.000	0.000	-0.000
	9 SP3	0.015	0.000	-0.018	0.023	0.000	0.000	0.000
	10 SP4	0.002	0.009	0.151	0.152	-0.000	-0.000	0.000
	11 FULL	0.026	-0.002	0.116	0.118	-0.000	-0.000	-0.000
	12 EMPTY	0.024	0.011	0.299	0.300	-0.000	-0.001	-0.000
11	1 DL	0.002	-0.015	-0.000	0.016	-0.000	-0.000	-0.000
	3 HP SIDE1	0.011	-0.000	-0.000	0.011	0.000	0.000	0.000
	4 HP SIDE2	0.009	0.001	0.000	0.009	-0.000	-0.000	-0.000
	5 HP SIDE 3	0.002	0.006	0.035	0.036	-0.000	-0.000	0.000
	6 HP SIDE 4	0.003	0.008	0.034	0.035	0.000	0.000	-0.000
	7 SP1	0.002	0.008	0.047	0.048	-0.000	-0.000	0.000
	8 SP2	0.004	0.011	0.045	0.046	0.000	0.000	-0.000

Displacement results on water tank

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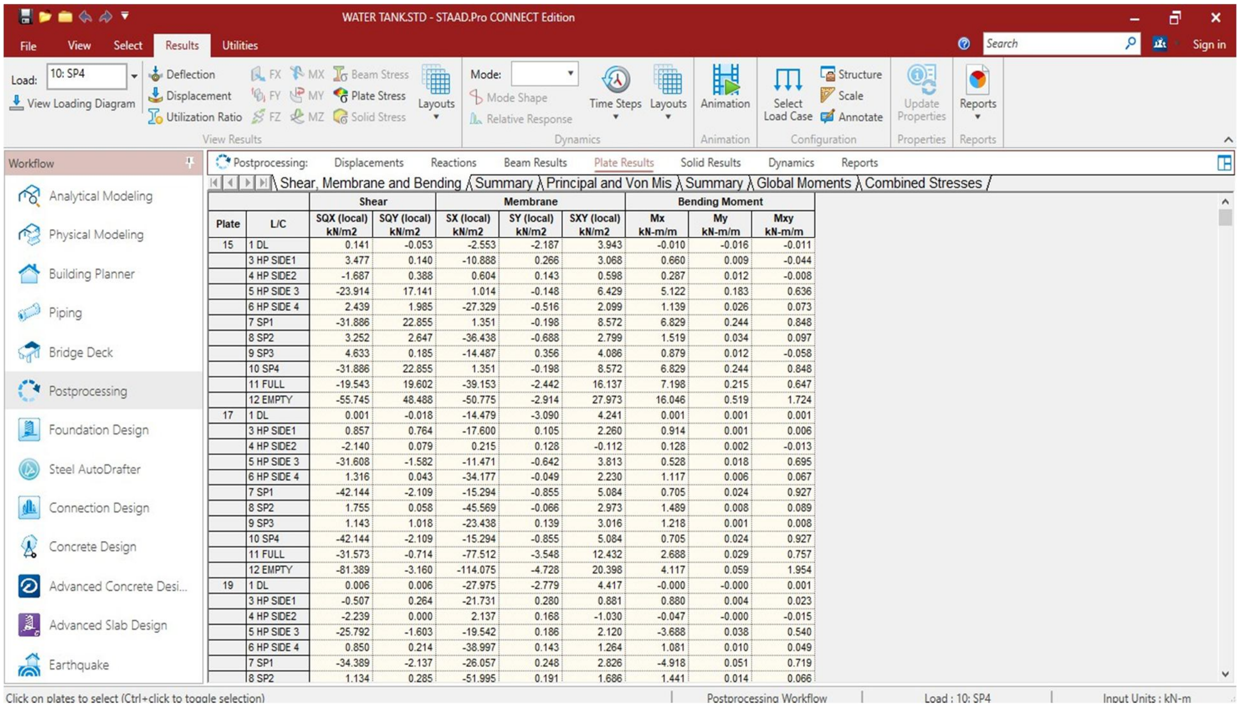

		Shear		Membrane			Bending Moment		
Plate	L/C	SQX (local) kN/m2	SQY (local) kN/m2	SX (local) kN/m2	SY (local) kN/m2	SXY (local) kN/m2	Mx kN-m/m	My kN-m/m	Mxy kN-m/m
15	1 DL	0.141	-0.053	-2.553	-2.187	3.943	-0.010	-0.016	-0.011
	3 HP SIDE1	3.477	0.140	-10.888	0.266	3.068	0.660	0.009	-0.044
	4 HP SIDE2	-1.687	0.388	0.604	0.143	0.598	0.287	0.012	-0.008
	5 HP SIDE 3	-23.914	17.141	1.014	-0.148	6.429	5.122	0.183	0.636
	6 HP SIDE 4	2.439	1.985	-27.329	-0.516	2.099	1.139	0.026	0.073
	7 SP1	-31.886	22.855	1.351	-0.198	8.572	6.829	0.244	0.848
	8 SP2	3.252	2.647	-36.438	-0.688	2.799	1.519	0.034	0.097
	9 SP3	4.633	0.185	-14.487	0.356	4.086	0.879	0.012	-0.058
	10 SP4	-31.886	22.855	1.351	-0.198	8.572	6.829	0.244	0.848
	11 FULL	-19.543	19.602	-39.153	-2.442	16.137	7.198	0.215	0.647
	12 EMPTY	-55.745	48.488	-50.775	-2.914	27.973	16.046	0.519	1.724
17	1 DL	0.001	-0.018	-14.479	-3.090	4.241	0.001	0.001	0.001
	3 HP SIDE1	0.857	0.764	-17.600	0.105	2.260	0.914	0.001	0.006
	4 HP SIDE2	-2.140	0.079	0.215	0.128	-0.112	0.128	0.002	-0.013
	5 HP SIDE 3	-31.608	-1.582	-11.471	-0.642	3.813	0.528	0.018	0.695
	6 HP SIDE 4	1.316	0.043	-34.177	-0.049	2.230	1.117	0.006	0.067
	7 SP1	-42.144	-2.109	-15.294	-0.855	5.084	0.705	0.024	0.927
	8 SP2	1.755	0.058	-45.569	-0.066	2.973	1.489	0.008	0.089
	9 SP3	1.143	1.018	-23.438	0.139	3.016	1.218	0.001	0.008
	10 SP4	-42.144	-2.109	-15.294	-0.855	5.084	0.705	0.024	0.927
	11 FULL	-31.573	-0.714	-77.512	-3.548	12.432	2.688	0.029	0.757
	12 EMPTY	-81.389	-3.160	-114.075	-4.728	20.398	4.117	0.059	1.954
19	1 DL	0.006	0.006	-27.975	-2.779	4.417	-0.000	-0.000	0.001
	3 HP SIDE1	-0.507	0.264	-21.731	0.280	0.881	0.880	0.004	0.023
	4 HP SIDE2	-2.239	0.000	2.137	0.168	-1.030	-0.047	-0.000	-0.015
	5 HP SIDE 3	-25.792	-1.603	-19.542	0.186	2.120	-3.688	0.038	0.540
	6 HP SIDE 4	0.850	0.214	-38.997	0.143	1.264	1.081	0.010	0.049
	7 SP1	-34.389	-2.137	-26.057	0.248	2.826	-4.918	0.051	0.719
	8 SP2	1.134	0.285	-51.995	0.191	1.686	1.441	0.014	0.066

Bending moment and shear stress result of water tank

a) Area of steel

DESCRIPTION	STAAD RESULT
TOTAL STEEL	29000 mm2
STEEL ON EACH FACE	14500mm2

b) Steel required in side wall

DESCRIPTION	STAAD RESULT
Total steel	5500mm2

VI. CONCLUSIONS

In conclusion, the dynamic analysis of underground water tanks considering fluid-structure interaction (FSI) has emerged as a crucial endeavor in ensuring the stability, safety, and sustainability of water storage systems.

Furthermore, this project has shed light on the environmental considerations, cost implications, regulatory compliance, and lifecycle assessment aspects associated with underground water tanks, providing a holistic understanding of the challenges and opportunities in water infrastructure engineering.

1) Environmental Considerations: Discuss the environmental impact of underground water tanks and the importance of ensuring their structural integrity to prevent potential hazards such as groundwater contamination.
2) Cost-Benefit Analysis: Include a cost-benefit analysis of implementing dynamic analysis techniques for underground water tanks, considering factors such as construction costs, maintenance expenses, and potential savings from improved structural performance.
3) Regulatory Compliance: Highlight the relevance of regulatory standards and codes governing the design and operation of underground water tanks, emphasizing the importance of compliance to ensure public safety and regulatory approval.
4) Lifecycle Assessment: Consider the lifecycle assessment of underground water tanks, including factors such as material selection, construction methods, and end-of-life disposal, to evaluate their overall sustainability and environmental footprint.

VII. SCOPE OF FUTURE WORK

1) Refinement of Numerical Models: Refining numerical models and techniques is vital for accurate dynamic analysis. Future efforts should enhance mesh resolution, integrate advanced material models, and optimize algorithms to better capture fluid-structure interaction in underground water tanks.
2) Experimental Validation: Experimental validation is crucial to confirm computational findings and their real-world applicability. Future research could include testing scaled or full-scale prototypes under dynamic loading to verify underground water tank performance.
3) Optimization of Design Strategies: Innovative design and optimization are key to improving the resilience and efficiency of underground water tanks. This includes developing novel damping mechanisms, optimizing structures, and exploring alternative materials for better performance and durability.
4) Environmental Considerations: Incorporating environmental factors into underground water tank design is vital for sustainability and reducing ecological impacts. Future research should explore eco-friendly materials, energy optimization, and measures to prevent groundwater contamination
5) Risk Assessment and Management: Comprehensive risk assessments are vital to identify hazards and vulnerabilities of underground water tanks. Future work should develop risk management strategies, including early warning systems, emergency plans, and retrofitting to enhance safety and resilience.
6) Integration of Smart Technologies: Integrating smart technologies can greatly improve the monitoring and management of underground water tanks. Future research should develop predictive maintenance algorithms, real-time monitoring, and automated controls for optimized performance and reliability.

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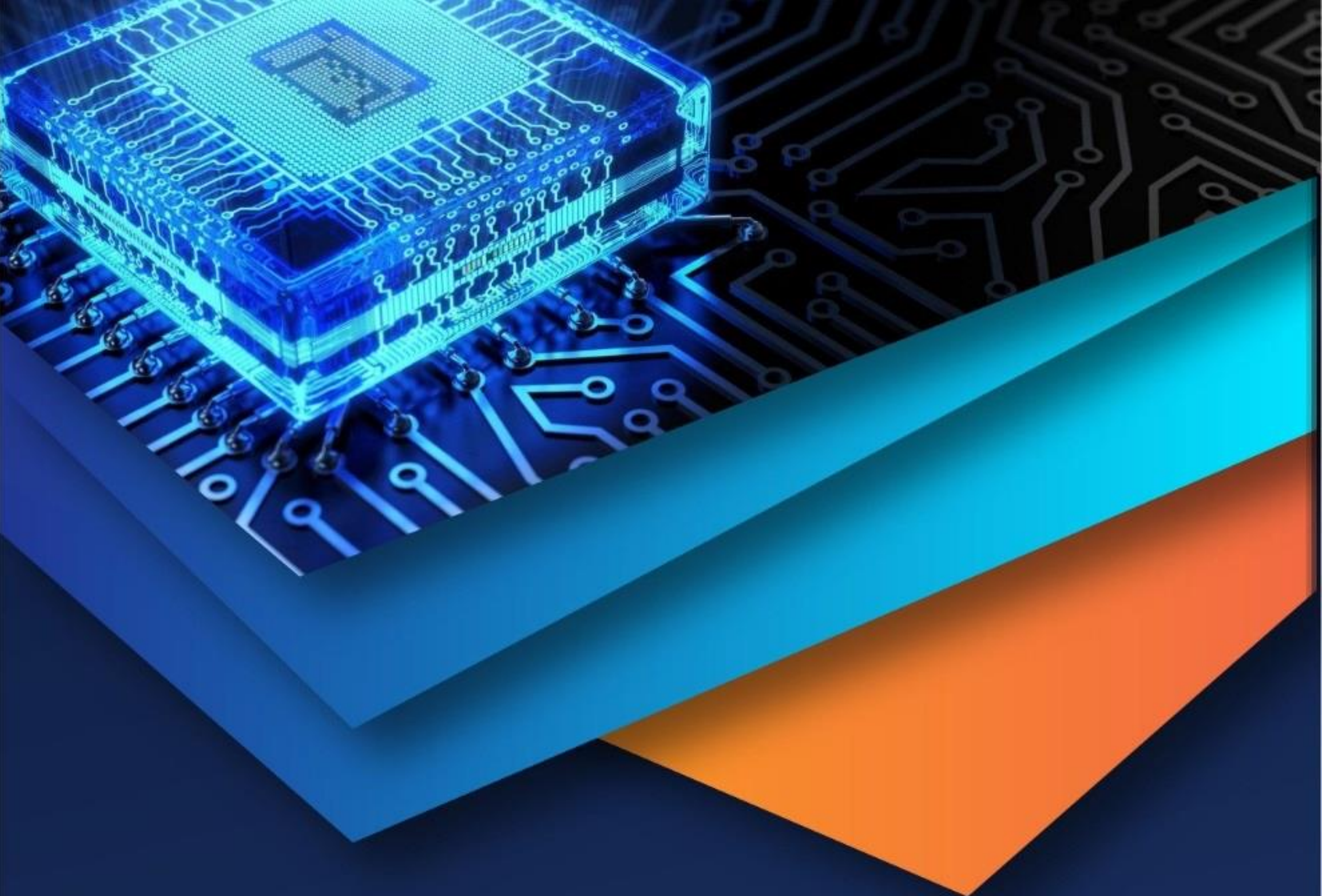

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