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A Case Study & Finite Element Analysis on Initial Liquefaction Tank and Its Supporting Structure

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Abstract—This article describes a detailed computational investigation and some prior experimental work of a large, elevated initial liquefaction tank and its associated support structure. Because the tank holds a high-density liquid and is subjected to very high dynamic loads, it is important to properly assess the structural integrity and adequate design for the tank and its supporting structures. The assessment is accomplished using finite element modelling (FEM) using ANSYS, reviewing the tank shell, tank base, and support columns under combined hydrostatic and seismic loads. The model also includes the effects of fluid-structure interaction (FSI), which allows it to more accurately reflect the system's complex dynamics. The results demonstrate that the largest stresses and deformations occur at the main support columns and at the junction between the tank bottom cone and tank shell. The results of this research also demonstrate that the typical approach to designing static structures (such as support structures) does not adequately characterise dynamic stresses in large structures, and the need to use a non-linear analysis approach for the dynamic evaluation of supporting structures. Based upon the outcomes of this research study, several recommended structural optimisations are provided that include modification of the support thickness and strengthening the connections to prevent buckling of the vessel and reduce long-term fatigue.

Keywords— Initial Liquefaction Tank, Finite Element Analysis, Dynamic Loading, Ansys, Tank Supporting Structure, Stress Analysis, Steel Support Structure

I. INTRODUCTION

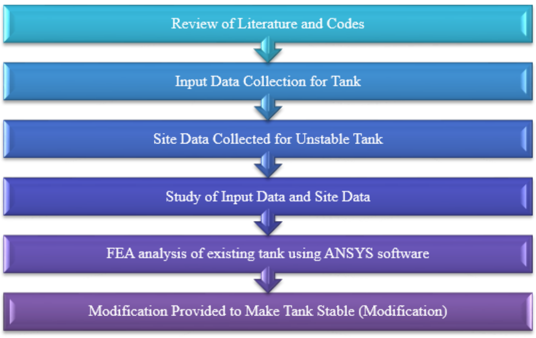
The success of producing grain-ethanol relies on a strong initial liquefaction tank (ILT), as it is where starch slurry is converted into fermentable sugar. The ILT needs to operate under high temperature and internal hydrostatic pressure while maintaining a continuously agitated state. As such, these combined static/dynamic loads create a very complex matrix of loads in an ILT. Due to the nature of industrial applications, this combined loading usually results in high localised stress concentration and dynamic resonance, leading to an accelerated rate of fatigue and excessive lateral movement of the ILT supporting steel structure.

Conventional static design methodologies do not accurately predict the actual dynamic interaction that can occur, therefore demonstrating the need for more advanced computer-aided diagnostics. A detailed FEA and case of a large-scale ILT and its supporting structure were presented in this paper. Using ANSYS, while providing a complete analysis of the ILT stresses and indicating the areas of risk due to dynamic resonance from agitator frequency, this was also subjected to a parametric optimisation of the steel supporting framework using STAAD. Pro to maximise lateral stiffness. By combining normative code design with non-linear numerical simulations, this research has improved the reliability, reduced the risk of structural failure and proposed a safe, dynamically tuned and material-efficient geometry redesign for demanding industrial uses.

II. OBJECTIVES

1. To collect and study the site data and process requirements of the Initial Liquefaction Tank used in ethanol/distillery plants.
2. To perform finite element analysis (FEA) of the ILT and its supporting structure using suitable software (e.g., ANSYS or STAAD.Pro) to evaluate stress, strain, and deformation
3. To analyse the behaviour of the ILT under various loading conditions.
4. To compare site observations and simulation results to ensure the structural integrity and safety of the modified design
5. To provide modification for the tank & it's supporting structure to make stable against dynamic loads.

III. METHODOLOGY



IV. DATA COLLECTION FROM THE FIELD AND ORGANIZATION

All the site data collected, and input data are also collected. The whole data is studied. The following is the data collected

Data collected from the site:
1. Type of Distillery Plant - Grain-Based Distillery Plant
2. Section - Liquefaction Section
3. Equipment - Initial Liquefaction Tank
4. Height of Tank - 8.65 m
5. Diameter of Tank - 5.848 m
6. Agitator type - Top-mounted agitator
7. Support - Steel Structure Frames
8. Tank Resting Level - 4.8 m

Input data received:
1. Shell thickness - 5mm
2. Bottom Cone thickness - 6mm
3. Top roof thickness - 5 mm
4. Material of Construction – SS 304 & Mild Steel
5. Fluid Density - 1100 kg/m3
6. Design Pressure - 0.1 bar
7. Design Temperature - 145 °C
8. Agitator Speed - 120 rpm
9. Design code used - ASME Section VIII, IS 800, IS-1893, IS-875

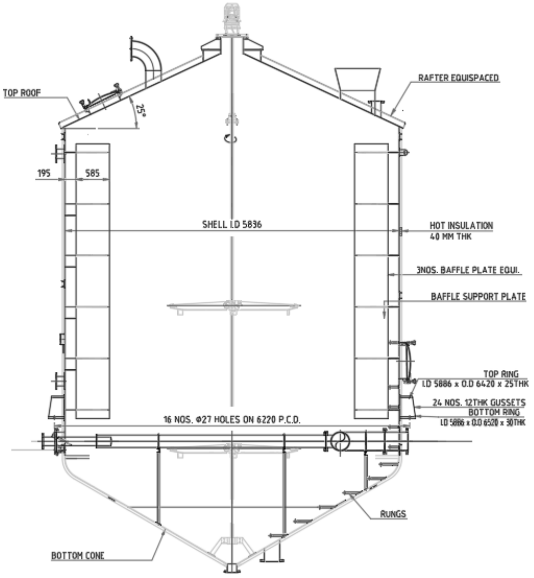


Figure 1 - GA Drawing of the initial liquefaction tank as per site

V. FIELD OBSERVATIONS

During the site visit, we have measured deflection of tank supporting structure at various levels.

They are as follows:
1. At tank resting level = 16 mm.
2. At the corner of bottom cone level = 12 mm.
3. At base plate level = 0 mm.

During the data collection stage, the following practical constraints were observed.
1. The combined stress effect due to tank, agitator, and piping could not be experimentally measured, additional safety margins must be considered.
2. Field observations during operation were not possible due to high operating temperatures and safety restrictions.
3. Frequent modifications or shutdowns for experimental purposes need to be avoided to prevent microbial contamination in process tanks.

VI. FEA ANALYSIS OF EXISTING INITIAL LIQUEFACTION TANK

A detailed finite element analysis (FEA) was performed using ANSYS software to simulate the static and dynamic behaviour of the ILT and its supporting structure. The natural frequency of a structure and its deformation (deflection) are inversely related.

The following observations have been found for FEA analysis:

1. The Natural frequencies observed for this structure start from 5.129 HZ. The frequency at the tank bottom cone, sparger and baffles are observed at 5 Hz, which requires additional stability as it is a critical region.
2. The deformation observed in the overall structure is high, requiring design modifications.
3. The maximum deformation of 15.5mm is observed at the bottom cone of the tank.
4. Stress concentrations are particularly high at the bottom cone to shell junction of the tank, with the highest stress reaching 780 MPa.
5. The equivalent von Mises stresses in the tank remain well below the yield limit of 205 MPa. The maximum observed stress, 77 MPa, occurs at the shell and is well within acceptable limits.
6. The equivalent von Mises stresses at the sparger support significantly exceed the yield limit.
7. Stress concentrations for sparger supports are particularly high at the connection points, with the maximum stress reaching 925 MPa at the bottom support

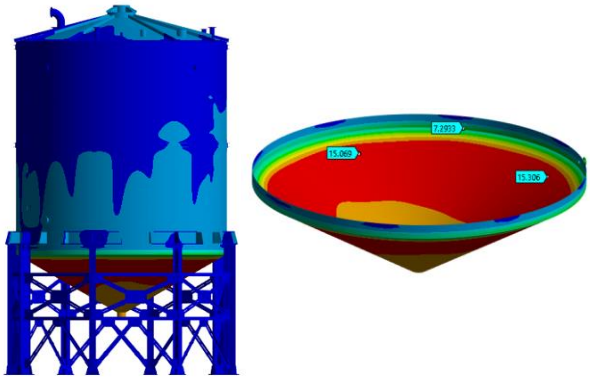


Figure 2 - Total Deformation observed in overall structure and Bottom cone of tank.

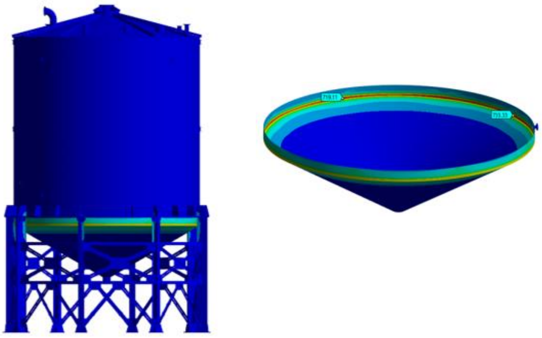


Figure 3 - Equivalent Von Mises Stresses Induced in Tank and Bottom Cone of Tank Junction

VII. MODIFIED & OPTIMIZED DESIGN OF INITIAL LIQUEFACTION TANK

Based on FEA analysis, design changes have done in modified optimized design of tank.

1. Natural frequency observed starts for 5.129 Hz at bottom cone, its's thickness has increased up to 8mm from 6mm to provide stability as it is a critical region.
2. Stress concentrations are particularly high at the bottom cone to shell junction of the tank, with highest stress reaching 780 MPa. The thickness at knuckle portion has increased to 10mm from 8mm.
3. Natural frequency observed starts for 5 Hz at sparger and baffles, creates a critical region, and stiffener supporters have been added to baffle plates to provide stability, as it is a critical region.
4. Steam sparger arrangement changed and saddle supports provided.
5. Top roof slope reduced to 15°, initially it was 25°.

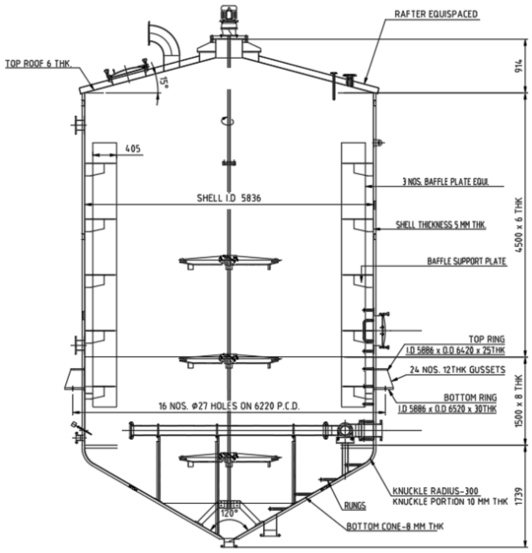


Figure 4 - GA Drawing of Initial Liquefaction Tank Modified Optimised Design.

The finite element analysis (FEA) of the existing tank revealed severe localised stress concentrations and a high risk of dynamic resonance during operations. The modified design incorporates geometric and structural optimisations to mitigate these failures.

VIII. TANK SUPPORTING STRUCTURE DESIGN

1. Existing Tank Supporting Structure

A detailed STAAD.Pro model of the existing supporting structure was developed based on field measurements, fabrication drawings, and site conditions. The model replicates the actual geometry, loading, column-beam layout, bracing configuration, and support conditions observed on site.

This STAAD model serves as the basis for subsequent structural design checks, load-transfer evaluation, and optimisation of the supporting framework under the combined loads obtained from FEA analysis.

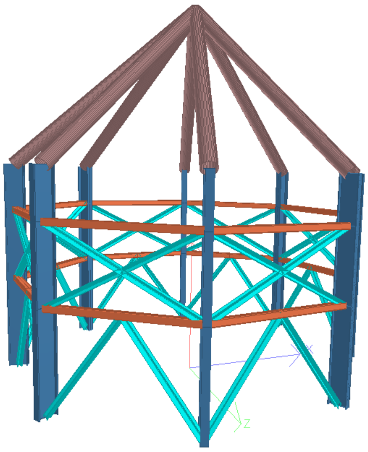
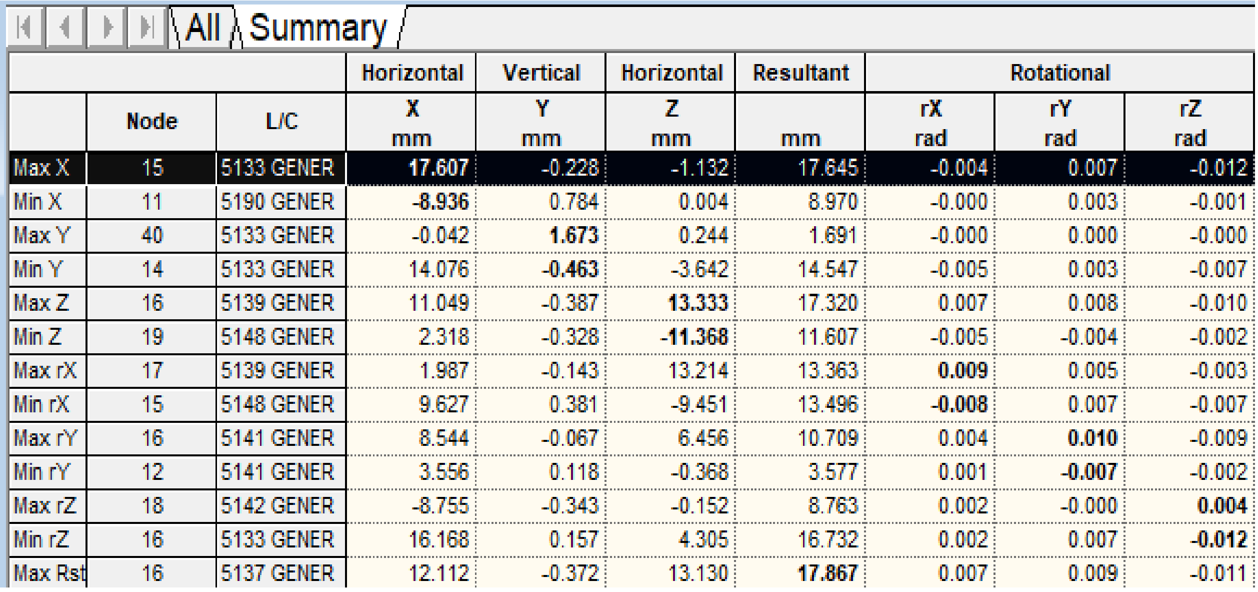


Figure 5 – 3D Rendered View of STAAD Model of Existing Supporting Structure



	Node	L/C	Horizontal	Vertical	Horizontal	Resultant	Rotational		
			X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	15	5133 GENER	**17.607**	-0.228	-1.132	17.645	-0.004	0.007	-0.012
Min X	11	5190 GENER	**-8.936**	0.784	0.004	8.970	-0.000	0.003	-0.001
Max Y	40	5133 GENER	-0.042	**1.673**	0.244	1.691	-0.000	0.000	-0.000
Min Y	14	5133 GENER	14.076	**-0.463**	-3.642	14.547	-0.005	0.003	-0.007
Max Z	16	5139 GENER	11.049	-0.387	**13.333**	17.320	0.007	0.008	-0.010
Min Z	19	5148 GENER	2.318	-0.328	**-11.368**	11.607	-0.005	-0.004	-0.002
Max rX	17	5139 GENER	1.987	-0.143	13.214	13.363	**0.009**	0.005	-0.003
Min rX	15	5148 GENER	9.627	0.381	-9.451	13.496	**-0.008**	0.007	-0.007
Max rY	16	5141 GENER	8.544	-0.067	6.456	10.709	0.004	**0.010**	-0.009
Min rY	12	5141 GENER	3.556	0.118	-0.368	3.577	0.001	**-0.007**	-0.002
Max rZ	18	5142 GENER	-8.755	-0.343	-0.152	8.763	0.002	-0.000	**0.004**
Min rZ	16	5133 GENER	16.168	0.157	4.305	16.732	0.002	0.007	**-0.012**
Max Rst	16	5137 GENER	12.112	-0.372	13.130	**17.867**	0.007	0.009	-0.011

Figure 6 – Node Displacement Values of STAAD.Pro of Existing Supporting Structure

Maximum allowable Deflection as per IS 800 is (height/500) = 9.6mm

Maximum deflection observed for the existing supporting structure as per analysis is 17.867 mm > 9.6mm

Deflection observed at the tank resting level at site is 16 mm, which nearly matches the analysis.

2. Modified Supporting Structure

Based on the performance evaluation of the existing structure, necessary modifications were incorporated in the STAAD model to improve stability and load-carrying efficiency. The key modifications include:

1. Cover plate provided to columns on both flanges to reduce deflection and withstand lateral forces occurring in the tank due to dynamic loading.
2. Adding bracing members and stiffeners to improve lateral stability and torsional resistance.
3. Adjusting support conditions to ensure uniform load transfer from the tank base to the foundation.
4. Optimising member sizes of additional bracings provided to maintain a balance between safety, economy, and structural performance

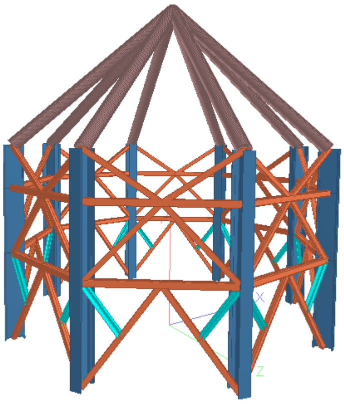
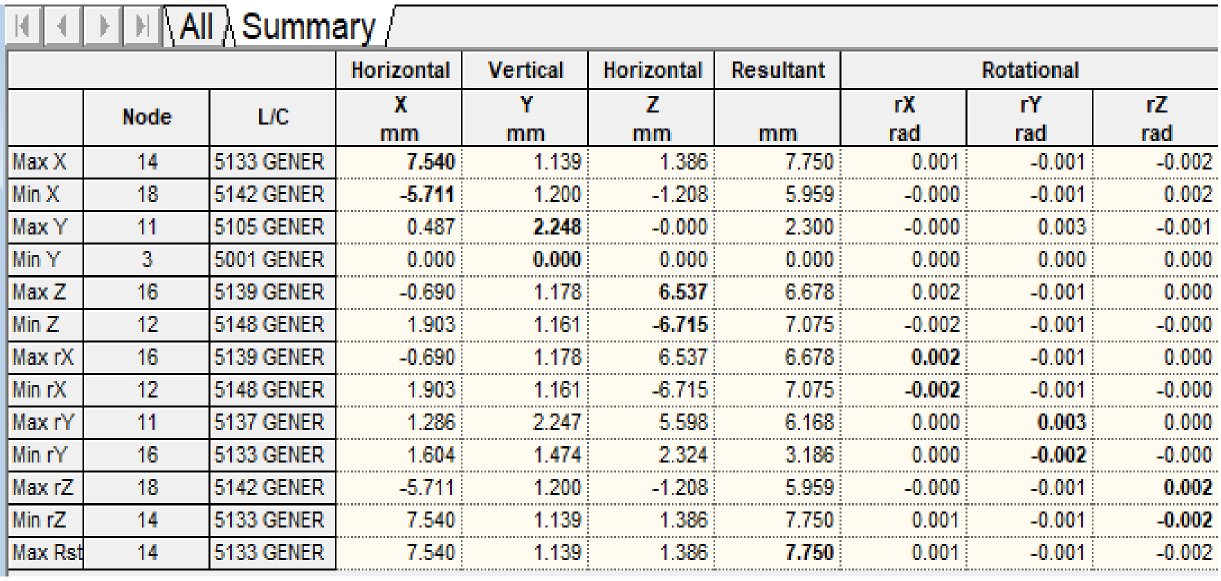


Figure 7 – 3D Rendered View of STAAD Model of Modified Supporting Structure



			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	14	5133 GENER	**7.540**	1.139	1.386	7.750	0.001	-0.001	-0.002
Min X	18	5142 GENER	**-5.711**	1.200	-1.208	5.959	-0.000	-0.001	0.002
Max Y	11	5105 GENER	0.487	**2.248**	-0.000	2.300	-0.000	0.003	-0.001
Min Y	3	5001 GENER	0.000	**0.000**	0.000	0.000	0.000	0.000	0.000
Max Z	16	5139 GENER	-0.690	1.178	**6.537**	6.678	0.002	-0.001	0.000
Min Z	12	5148 GENER	1.903	1.161	**-6.715**	7.075	-0.002	-0.001	-0.000
Max rX	16	5139 GENER	-0.690	1.178	6.537	6.678	**0.002**	-0.001	0.000
Min rX	12	5148 GENER	1.903	1.161	-6.715	7.075	**-0.002**	-0.001	-0.000
Max rY	11	5137 GENER	1.286	2.247	5.598	6.168	0.000	**0.003**	0.000
Min rY	16	5133 GENER	1.604	1.474	2.324	3.186	0.000	**-0.002**	-0.000
Max rZ	18	5142 GENER	-5.711	1.200	-1.208	5.959	-0.000	-0.001	**0.002**
Min rZ	14	5133 GENER	7.540	1.139	1.386	7.750	0.001	-0.001	**-0.002**
Max Rst	14	5133 GENER	7.540	1.139	1.386	**7.750**	0.001	-0.001	-0.002

Figure 8 – Node Displacement Values of STAAD.Pro of Modified Supporting Structure

These modifications were validated through a revised STAAD analysis to confirm improved structural behaviour under combined vertical, horizontal, and torsional loads.

Maximum deflection observed for the modified supporting structure, as per analysis, is 7.540 mm < 9.6mm

Table 1 - Deflection and Material Take-Off (MTO) for STAAD.Pro Structural Models

Model	Model Description & Configuration	Max Deflection (mm)	Allowable Deflection (mm)	Total MTO (kN)
1	Existing Supporting Structure: Original column-beam layout with standard bracings.	17.867	9.6	48.138
2	Modified Supporting Structure: Heavy cover plates added to column flanges and dense bracing added.	7.540	9.6	86.872

IX. DISCUSSION

Severe structural deficiencies in the existing initial liquefaction tank structure were identified through a finite-element analysis while it was subjected to continuous dynamic loading. The maximum deflection of the structure originally was 17.867 mm, which exceeds the allowable maximum of 9.6 mm. The field measurements taken matched this finding, showing a deflection of 16 mm.

Critical stress levels were extremely high, with high stress concentrations at the bottom cone junction (780 MPa) and at the sparger supports (925 Mpa). Modifications were made to reduce the risk of failure due to the natural frequency occurring near 5 Hz (on the structure). The bottom cone thickness was increased to 8 mm, and heavy-duty bracing was added, resulting in a dramatic increase in structural stability. The deflection of the structure following these modifications was 7.540 mm (well within the allowable distance). The total material take-off increased as a result of these modifications from 48.138 kN to 86.872 kN.

X. CONCLUSION

The research proves the urgent need for the implementation of sophisticated non-linear computational evaluations, such as finite element modelling in ANSYS and structural analysis in STAAD Pro, when designing large-scale industrial structures subjected to both static and dynamic loads. The Existing Initial Liquefaction Tank was evaluated and found to have several weaknesses, including excessive lateral movement and localised high stress concentrations at the bottom cone, shell, and support to the sparger. With a modified design approach, there were several successful structural optimisations which included,

1. Increasing the thickness of the bottom cone and knuckle sections, lowering the roof slope angle from 25 degrees to 15 degrees, provided significantly more strength in the tank against internal hydrostatic force and elevated temperatures and dynamic environment.
2. The addition of baffle plate stiffeners and redesigning the saddle supports to the steam sparger assured no dynamic resonance affecting tank performance.
3. The columns supporting the framework were reinforced with column cover plates, and well-placed diagonal bracing resulted in a significant reduction of the overall amount of structural deflection to 7.540 mm, meeting IS 800 requirements.

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