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Comparative Structural Performance Assessment of Conventional and Diagrid Staging Systems for a 200 KL Elevated Water Tank

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Abstract —**The study investigates a 200 kilolitre (200 KL) reinforced-concrete Elevated-type elevated water tank supported on two alternative staging systems: a conventional six-column frame staging and a reinforced-concrete diagrid staging. Analytical models were developed in ETABS (Extended Three-Dimensional Analysis of Building Systems). The comparison focuses on maximum lateral displacement, base shear, overturning moment, member-force demand, modal characteristics, material consumption, and direct construction cost. The results show that the diagrid staging reduces critical seismic displacement from 42.1 mm to 32.6 mm, lowers seismic base shear by 18.9%, reduces overturning moment by 18.6%, and cuts the maximum member bending moment by 82.4% relative to the conventional staging. For the empty-tank seismic cases, the base shear reduces from 98.4 kN to 81.6 kN in both principal directions, corresponding to a 17.1% reduction. The diagrid system also reduces reinforcement and concrete consumption by 14.9% and 17.9%, respectively, and yields a direct staging cost saving of approximately ₹2.43 lakh. The study establishes the diagrid system as a structurally efficient and economically viable alternative for elevated tank staging in seismic regions.**

Keywords — **elevated water tank; diagrid staging; Elevated tank; ETABS; seismic analysis; lateral displacement; base shear; structural efficiency; cost comparison.**

I. Introduction

Elevated water tanks are indispensable components of urban and rural water-distribution systems because they combine storage reserve with gravity-based pressure head. Their structural reliability is therefore directly linked to public safety and post-disaster service continuity. In India, the staging system often governs the seismic and wind performance of an elevated tank, since the supporting substructure must transfer the liquid mass, shell weight, and lateral actions safely to the foundation [1], [2], [5].

Conventional reinforced-concrete frame staging has been widely used in practice due to its familiarity, ease of detailing, and compatibility with standard design codes. However, the lateral stiffness of frame staging is limited by bending-dominated load transfer through the columns and bracing members. This often leads to larger seismic displacement demand, higher overturning moment, and heavier reinforcement requirements, especially for medium- and high-staging tanks.

The diagrid system offers an alternative load path by replacing a large part of the bending-dominated response with triangulated axial-force transfer. While diagrids are well established in tall-building engineering [8], their application to elevated tank staging remains comparatively less documented. Recent studies nevertheless indicate that diagrid staging can reduce drift, improve structural efficiency, and lower material consumption in water-tank support structures [9]–[13].

The contributions of this paper are: (1) a compact comparative analytical framework for a 200 KL elevated tank with conventional and diagrid staging; (2) tabulated evaluation of displacement, base shear, overturning moment, modal response, material quantities, and direct cost; and (3) interpretation of project-level model views and response plots to support the numerical comparison.

II. Tank Configuration and Analytical Framework

A. Geometry and Staging Systems

The tank considered in this study is a 200 kilolitre (200 KL) reinforced-concrete Elevated tank with a cylindrical portion diameter of 5.8 m, a design water depth of 3.78 m, and a staging height of 16 m. The conventional alternative consists of six circular reinforced-concrete (RC) columns supported through ring and diagonal bracing, whereas the diagrid alternative uses inclined RC members arranged in a triangulated pattern with intermediate ring levels. Both analytical models were developed and evaluated using Extended Three-Dimensional Analysis of Building Systems (ETABS).

TABLE I: Analytical Model Summary

Parameter	Conventional staging	Diagrid staging
Tank type and capacity	Elevated tank, 200 KL	Same vessel supported on diagrid staging
Staging height	16 m	16 m
Primary system	6 RC columns with ring and diagonal bracing	Triangulated RC diagrid with ring levels
Key member size	600 mm circular columns	500 mm circular diagrid members
Material grades	M30 staging, Fe415 steel	M30 staging, Fe500 steel
Seismic zone	Zone III, medium soil	Zone III, medium soil
Analysis platform	ETABS	ETABS

(a) Conventional frame staging

(b) Diagrid staging

Fig. 1. Comparative staging configurations used in the study: (a) conventional frame staging and (b) diagrid staging.

The conventional system relies on columns and bracing members to resist lateral action through combined bending and shear. By contrast, the diagrid system channels a larger share of the lateral load through axial action in the inclined members. This distinction is central to the expected differences in displacement control, member-force demand, and material efficiency.

B. Material Properties and Design Codes

The staging concrete is modelled as M30, while the tank vessel is based on M35 concrete. Reinforcement is Fe415 in the conventional staging and Fe500 in the diagrid staging. The elastic modulus of concrete is obtained from Indian Standard (IS) 456 as

$$E_c = 5000\sqrt{f_{ck}} = 27{,}386\ MPa \qquad (1)$$

where E_c is the modulus of elasticity of concrete and f_{ck} is the characteristic compressive strength of concrete, both expressed in MPa. The analysis follows IS 3370 for liquid-retaining structures, IS 11682 for overhead tank staging, IS 875 (Part III) for wind loading, and IS 1893 (Part II) for seismic loading of liquid-retaining tanks. The seismic setting corresponds to Zone III with medium soil, and both impulsive and convective effects are considered in the interpretation of the staging response.

C. Load Cases, Seismic Idealization, and Evaluation Metrics

The critical load cases considered in the comparative study include gravity loading, wind loading for full-tank and uplift conditions, and seismic loading along the principal directions for both full-tank and empty-tank conditions. The horizontal seismic coefficient is determined as

$$A_h = (Z/2)(I/R)(S_a/g) \qquad (2)$$

and the design base shear is evaluated from

$$V_b = A_h W \qquad (3)$$

where A_h is the design horizontal seismic coefficient, Z is the seismic zone factor, I is the importance factor, R is the response reduction factor, S_a/g is the average response acceleration coefficient, V_b is the design base shear, and W is the participating seismic weight of the tank-staging system. In addition to displacement, base shear, and overturning moment, the study uses a structural performance index (SPI) to compare stiffness gained per unit staging mass:

$$SPI = K_{lat} / M_{stage} \qquad (4)$$

In (4), K_lat is the equivalent lateral stiffness and M_stage is the total staging mass. The comparative evaluation assumes identical tank geometry, staging height, boundary conditions, material idealization, and code-based load combinations for both the conventional and diagrid models, with Zone III seismicity, medium soil, and consistent consideration of impulsive and convective liquid effects.

Fig. 2. Project-level analytical outputs: (a) three-dimensional diagrid model and (b) representative maximum story-displacement plot.

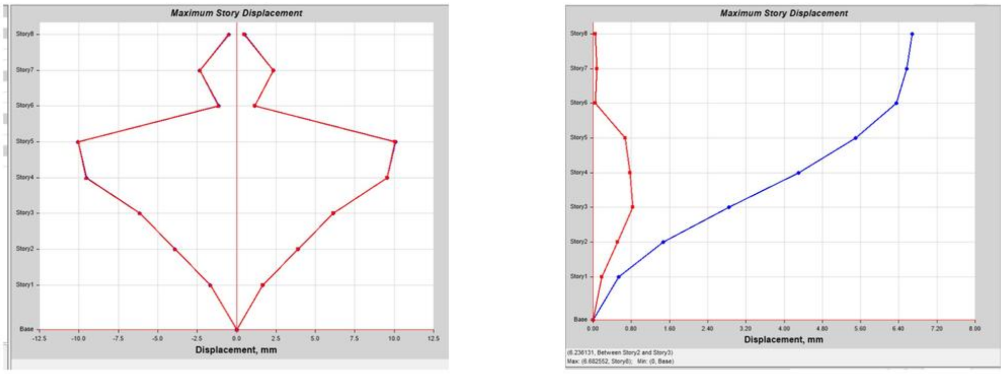
III. Comparative Results

A. Lateral Displacement Response

Lateral displacement is the clearest serviceability indicator for elevated-tank staging because it directly reflects the lateral stiffness of the support system. Table II shows that the diagrid staging reduces maximum displacement consistently across the critical wind and seismic load cases. Under the critical seismic load combination LC-10, the displacement decreases from 42.1 mm in the conventional staging to 32.6 mm in the diagrid staging, corresponding to a 22.6% reduction.

TABLE II: Selected Story-Displacement Results

Critical load case	Conventional displacement	Diagrid displacement	Reduction
LC-3 (Wind, full tank)	38.4 mm	29.7 mm	22.7%
LC-5 (EQx, full tank)	34.8 mm	27.1 mm	22.1%
LC-9 (Critical wind)	44.2 mm	34.1 mm	22.9%
LC-10 (Critical seismic)	42.1 mm	32.6 mm	22.6%



(a) Opposite-direction story response

(b) Comparative displacement profile

Fig. 3. Story-response plots used to compare displacement distribution and opposite-direction lateral response.

The response plots confirm that displacement grows progressively with height, as expected for a tank support acting as a tall lateral-force-resisting system. The conventional staging shows a more pronounced curvature in the displacement profile, whereas the diagrid response is smoother and lower in magnitude, indicating a stiffer and more uniform transfer of lateral demand through the inclined-member network.

B. Base Shear, Overturning Moment, and Member Forces

The diagrid system also improves global seismic force demand. At LC-10, base shear reduces from 168.2 kN to 136.4 kN and overturning moment falls from 3412.4 kN-m to 2776.3 kN-m. For the empty-tank seismic cases LC-7 and LC-8, base shear reduces from 98.4 kN to 81.6 kN in both principal directions, corresponding to a 17.1% reduction. The most dramatic improvement, however, is observed in the peak member bending moment, which drops from 218.6 kN-m in the critical conventional member to 38.4 kN-m in the critical diagrid member. This confirms that the diagrid layout shifts the response toward axial-force action and away from flexure-dominated behaviour.

TABLE III: Comparative Structural Performance Indicators

Performance parameter	Conventional	Diagrid	Improvement
Max. lateral displacement (LC-10)	42.1 mm	32.6 mm	22.6% lower
Max. base shear (LC-10)	168.2 kN	136.4 kN	18.9% lower
Max. overturning moment (LC-10)	3412.4 kN·m	2776.3 kN·m	18.6% lower
Max. member bending moment	218.6 kN·m	38.4 kN·m	82.4% lower
Fundamental period (Mode 1)	0.847 s	0.714 s	15.7% lower
Buckling safety factor	3.1	4.2	35.5% higher
Base shear (LC-7/LC-8, empty tank)	98.4 kN	81.6 kN	17.1% lower

The decrease in bending demand is significant because it has a direct influence on detailing complexity, reinforcement congestion, and crack control. The reduction in maximum axial force is smaller than the reduction in bending moment, which is physically consistent with the load-transfer mechanism of a triangulated system: the diagrid does not eliminate axial demand, but it redistributes the total lateral action more efficiently.

C. Modal Characteristics and Structural Efficiency

The fundamental period decreases from 0.847 s for the conventional system to 0.714 s for the diagrid system. The shorter period indicates greater lateral stiffness, and the mass-participation levels remain high in the first two translational modes. This confirms that the diagrid does not achieve lower displacement by shifting the response into torsion or higher-mode irregularity; instead, it achieves improvement through more efficient primary lateral resistance. The structural performance index correspondingly improves from 0.063 to 0.068, indicating about 8% higher stiffness per unit staging mass.

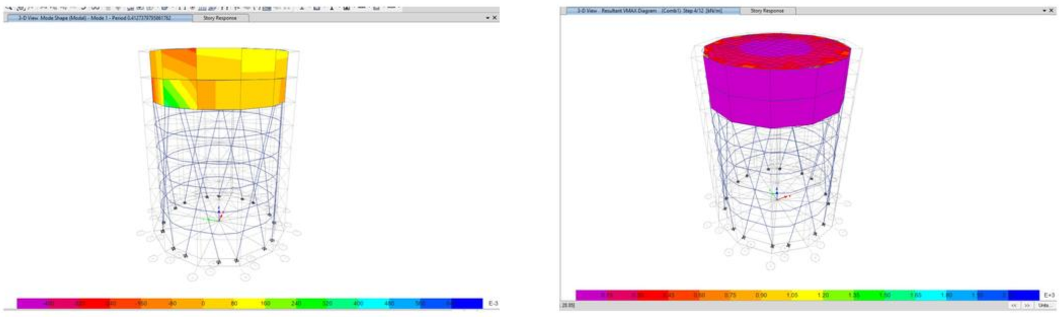
D. Material Quantity and Direct Cost

The structural advantages of the diagrid system are accompanied by measurable economy in material usage. Total concrete in the staging decreases from 34.6 m³ to 28.4 m³, while total reinforcement falls from 12,840 kg to 10,920 kg. Even after accounting for an additional connection-related cost of ₹45,000, the direct staging cost reduces from ₹14,72,420 to ₹12,29,760.

TABLE IV: Material Quantity and Direct Cost Comparison

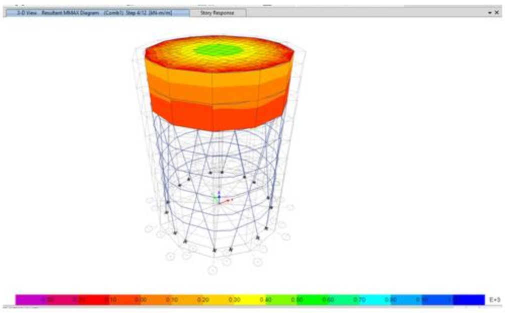
Item	Conventional	Diagrid	Difference / saving
Total concrete volume (staging)	34.6 m³	28.4 m³	17.9% lower
Total reinforcement (staging)	12,840 kg	10,920 kg	14.9% lower
Formwork area	312 m²	298 m²	4.5% lower
Direct staging cost	₹14,72,420	₹12,29,760	₹2,42,660 saved

The total direct saving of approximately ₹2.43 lakh corresponds to about 16.5% of the conventional staging cost. This is an important outcome because many structurally improved alternatives fail to gain practical acceptance if they increase project cost significantly. In the present case, the diagrid alternative is both structurally stronger and economically preferable.



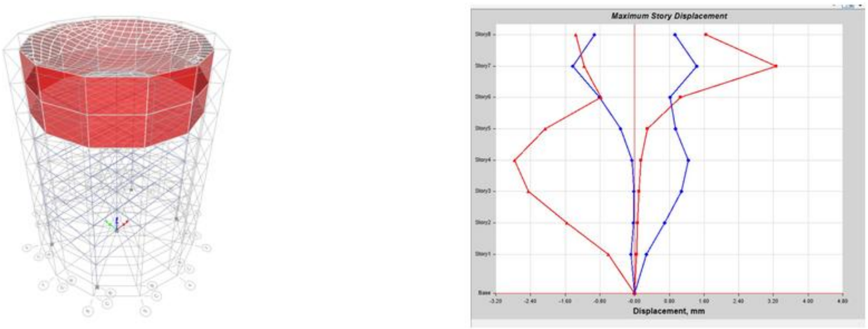
(a) Deformation-related contour

(b) VMAX shell-resultant contour



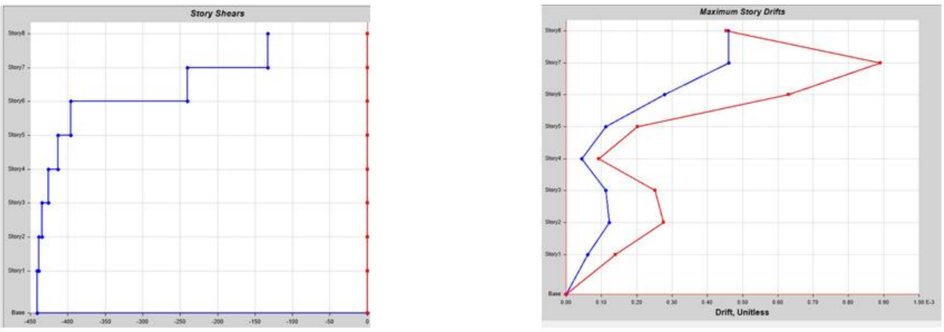
(c) MMAX shell-resultant contour

Fig. 4. Contour-based interpretation of the elevated tank model: (a) deformation-related contour, (b) VMAX shell-resultant contour, and (c) MMAX shell-resultant contour.



(a) Model/shell view

(b) Max. story displacement



(c) Story shears

(d) Max. story drifts

Fig. 5. Showing model, displacement, story shear, and story drift outputs used for final verification.

IV. DISCUSSION

A. Structural Interpretation and Consistency with Earlier Studies

The improvement trends obtained in this study are consistent with the recent elevated-tank literature. Sharma and Verma [9] and Patil and Kulkarni [10] reported diagrid-related displacement reductions in the order of 19–23%, which closely matches the present 22.6% reduction at the critical seismic load case. Likewise, the observed improvement in structural efficiency aligns with the findings of Bose and Chakraborty [13], who showed that lighter but stiffer staging systems achieve higher stiffness-to-mass performance metrics.

The contour images and story-response plots included in the project files strengthen the interpretation of the tabulated results. They show that the tank shell and staging response remain structurally coherent and that the diagrid system provides a lower and smoother displacement profile. These visual outputs are particularly useful when thesis work is distilled into a journal-style paper, because they provide immediate evidence of how the response is distributed rather than relying on numerical tables alone.

B. Practical Implications and Limitations

From a practice-oriented standpoint, the diagrid staging offers three clear benefits: improved serviceability, lower seismic demand, and reduced direct cost. The serviceability benefit is particularly notable because the conventional staging exceeds the H/500 displacement criterion under the critical seismic load case, whereas the diagrid staging remains within the limit. This means that the choice of staging system can directly influence whether the tank satisfies practical design-performance requirements without substantial redesign.

The principal limitation of the present study is that it focuses on a single tank capacity, a single staging height, and one seismic-zone context. The results therefore establish a strong comparative case for the selected configuration rather than a universal rule for every elevated tank. Future work should include parametric variation of capacity, staging height, fill level, soil condition, and diagrid angle, together with nonlinear time-history evaluation for near-fault excitation.

V. CONCLUSIONS

The diagrid staging reduced the critical seismic displacement from 42.1 mm to 32.6 mm, giving a 22.6% reduction in lateral response.

Seismic base shear and overturning moment reduced by 18.9% and 18.6%, respectively, under the critical full-tank seismic case. Under the empty-tank seismic cases, base shear reduced from 98.4 kN to 81.6 kN in both principal directions, confirming that the diagrid system remains advantageous even without stored water.

The peak member bending moment dropped by 82.4%, confirming that the diagrid system shifts the lateral load path toward efficient axial-force action.

The fundamental period reduced from 0.847 s to 0.714 s, indicating a stiffer lateral-force-resisting system without adverse modal redistribution.

Concrete and reinforcement quantities reduced by 17.9% and 14.9%, respectively, and the direct staging cost decreased by approximately ₹2.43 lakh.

For the studied configuration, the diagrid system is both structurally superior and economically viable relative to conventional frame staging.

The findings support the adoption of diagrid staging for elevated water tanks in seismic regions, particularly where displacement control, member-force reduction, and material economy are important design drivers.

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