

# Study of Tank with Inclined Braced Staging

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**ABSTRACT:** The responses of an intze tank with unbraced staging, inclined bracing (single-inclined brace and cross brace) at alternate levels of staging and inclined bracing throughout the height of staging have been compared. The models have been analysed in accordance with the draft of IS 1893 (part 2) using the finite element software STAAD.Pro. The displacement of the tank reduced significantly when the staging had inclined braces. The study also found that the position of the inclined bracing in the staging (with and without bracing at ground level) had a considerable effect on the response of the tank.

**KEYWORDS:** Intze tank; Braced staging; STAAD.Pro

## I. INTRODUCTION

Liquid storage tanks are important structures and it is imperative that these structures remain functional following an earthquake. Hence it is necessary to understand the behaviour of the tanks under seismic loading.

In this study single-inclined braces and cross braces had been incorporated to the staging of the tank at alternate levels and their response had been compared with that of a tank with unbraced staging and single-inclined brace and cross brace throughout the height of staging.

## II. RELATED WORK

Hydrodynamic pressure has also been applied to the tank container in addition to the hydrostatic pressure since it was observed that the response of the tank was more when hydrodynamic pressure acted in the tank when compared to the response of tank with only hydrostatic pressure [1].

Radial braced staging has been known to cause the least displacement in the tank when compared to un-braced and horizontal-cross braced staging configurations [2], [3]. In another study it was reported that unbraced staging displaced 5 to 6 times more than that of braced staging [4].

Tank with single-inclined brace and cross-brace throughout the height of staging had been studied previously for three heights of staging [5] and it was found that for all the heights the displacement of the tank with braced configurations was significantly less than the tank with unbraced staging. But for the tank with staging height of 20m, the total seismic weight of the was found to be about 180kN and 360kN more than unbraced staging for single-inclined braced and cross braced staging configurations respectively. If the bracing is positioned at alternate levels of staging the weight of the staging would reduce considerably. Hence tank staging with bracing at alternate levels has been studied to find the type of staging configuration which would reduce the displacement of the tank without increasing the weight of the structure significantly.

## III. METHODOLOGY

### MODEL OF THE LIQUID AND TANK

The liquid in the tank is divided into two liquids; one which moves with the wall of the tank container called impulsive liquid with mass  $m_i$  and the other that moves relative to the wall of the container called the convective liquid with mass

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$m_c$ . The pressure exerted on the wall and base of the container by these liquids is called as hydrodynamic pressure. The elevated tank is treated as a two degree of freedom system, where one mass constitutes the impulsive mass along with the structural mass of the tank and the other constitutes the convective mass. The spring mass parameters depend on the aspect ratio of the tank and have been calculated using the draft of IS 1893 (part 2) [6] and the IIT-GSDMA guidelines [7].

### LATERAL STIFFNESS OF STAGING

In this study the staging stiffness was calculated as the ratio of the force applied at the centre of gravity (CG) of the tank and the corresponding displacement. The link between the CG and the top of the staging was considered to be infinitely stiff having a very large elastic modulus and a large cross section and force of 10kN had been assumed to act at the CG of the tank.

### BASE SHEAR AND OVERTURNING MOMENT

The two modes have different time periods and hence their seismic coefficients ( $A_h$ ) are also different which is given by  $A_{hi}$  and  $A_{hc}$  for impulsive and convective modes respectively and are calculated using equation (1). Where  $Z$  is the seismic zone,  $I$  is the importance factor,  $R$  is the response reduction factor and  $S_a/g$  is the average response acceleration coefficient.

$$A_h = \frac{Z I S_a}{2 R g} \quad (1)$$

The base shear is calculated as the product of the seismic weight and base shear coefficient. The impulsive ( $V_i$ ) and convective ( $V_c$ ) base shears are calculated using the equations (2) and (3).

$$V_i = A_{hi} (m_i + m_s) g \quad (2)$$

$$V_c = A_{hc} m_c g \quad (3)$$

Where  $m_i$ ,  $m_s$  and  $m_c$  are the impulsive, structural and convective mass respectively and  $g$  is the acceleration due to gravity. The equations for bending moment at the base of staging for the two modes ( $M_i^*$  and  $M_c^*$ ) are given in (4) and (5).

$$M_i^* = A_{hi} [m_i (h_i^* + h_s) + m_s h_{cg}] g \quad (4)$$

$$M_c^* = A_{hc} m_c (h_c^* + h_s) g \quad (5)$$

Where  $h_i^*$  and  $h_c^*$  are locations of impulsive and convective masses including the effect of pressure on the base of the container;  $h_s$  and  $h_{cg}$  are height of staging and CG of the container from the bottom of the staging respectively.

## IV. MODEL DESCRIPTION

### MODEL PROPERTIES

An example from the IIT-GSDMA guidelines [7] has been used for the study. An intze tank of capacity 250 m<sup>3</sup> with an internal diameter ( $D$ ) of 8.6m, supported by 6 columns has been modelled. The dimensions of the components of the tank are as follows:

- Top dome = 120mm thick
- Top Ring Beam = 250mm x 300mm
- Cylindrical Wall = 200mm thick
- Bottom Ring Beam = 500mm x 300mm
- Circular Ring Beam = 500mm x 600mm
- Bottom Dome = 200mm thick
- Conical Dome = 250mm thick
- Free board = 300mm
- Column = 650mm dia.
- Braces = 300mm x 600mm
- Height of staging = 20m

The tanks have been analysed for seismic zone II. A response reduction factor of 2.5 had been adopted as the frame was assumed to be a special moment resisting frame (SMRF) and an importance factor of 1.5 had been considered as per IS 1893 (Part 1) [8].

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## SPECIFICATION OF STAGING

Type1 (t1) and type2 (t2) are the configurations with inclined bracing at alternate levels of staging and the configuration with bracing throughout the height of staging is type3 (t3) as shown in figures 1(a)-(c). Type1 configuration does not have bracing in the ground level whereas type2 has bracing at the ground level.

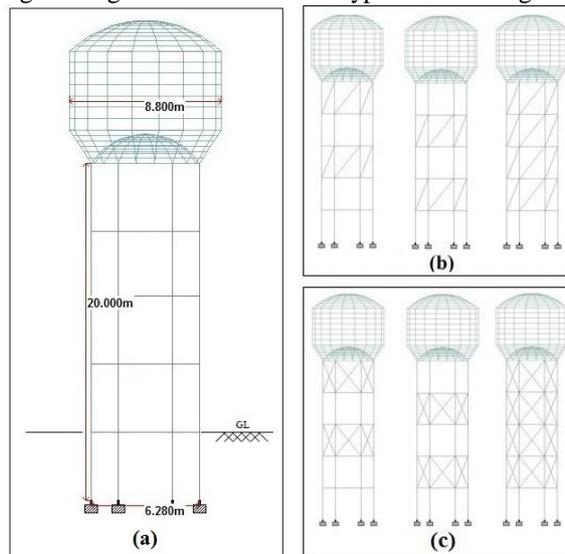


Figure 1: (a) Elevated Intze tank with unbraced staging (u); (b) Tank with type1, type2 and type3 configurations of single-diagonal braced staging system (b-t1, b-t2 and b-t3 respectively); (c) Tank with type1, type2 and type3 configurations of cross braced staging system (c-t1, c-t2 and c-t3 respectively)

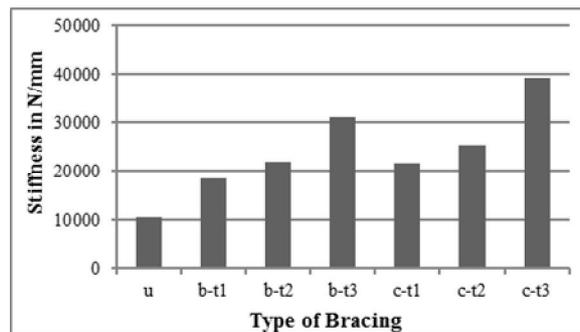


Figure 2: Variation of Staging Stiffness for different configurations

The stiffness of the staging configurations is shown in figure 2. When compared to unbraced staging, type1 single-diagonal bracing (b-t1) was 74% more stiff and the same type of cross braced staging (c-t1) was 105% more stiff than unbraced staging. The stiffness of the type2 configuration of single braced (b-t2) and cross braced (c-t2) staging further increased by 20% and 16% respectively compared the type 1 variant.

Even though type1 and type2 of single- inclined braced staging configurations (b-t1 and b-t2) have the same seismic weight, the type2 configuration had 20% more stiffness than type1. Similarly the tank with type3 of single-diagonal braced staging, type1 and type2 of cross braced staging systems weighed the same but their stiffness varied greatly.

## LOADS AND LOAD COMBINATION

Self-weight of the tank, hydrodynamic pressure and hydrostatic pressure have been applied in the tank for full tank condition and for empty tank condition only self-weight has been considered. From the recommendations of the code [6] and guidelines [7], the pressures due vertical excitation and inertia of the wall have also been considered. The load due

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to the liquid and self-weight together are considered as the dead load. The load combinations considered in the analysis are:

- 1.5 (DL ± EQ<sub>x</sub>)
- 1.5 (DL ± EQ<sub>y</sub>)
- 0.9 DL ± 1.5 EQ<sub>x</sub>
- 0.9 DL ± 1.5 EQ<sub>y</sub>

Where EQ<sub>x</sub> and EQ<sub>y</sub> are the response quantities due earthquake load in the two horizontal directions x and y and DL is the dead load.

## V. RESULTS

### BASE SHEAR AND OVERTURNING MOMENT

The base shears of impulsive and convective modes had been combined using the method of square root of sum of squares (SRSS). The variation of base shear with soil type is shown in figures 3 and 4 for full tank and empty tank conditions respectively.

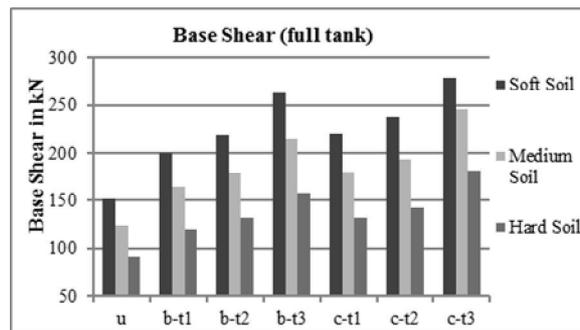


Figure 3: Variation of Base Shear with soil type for full tank condition

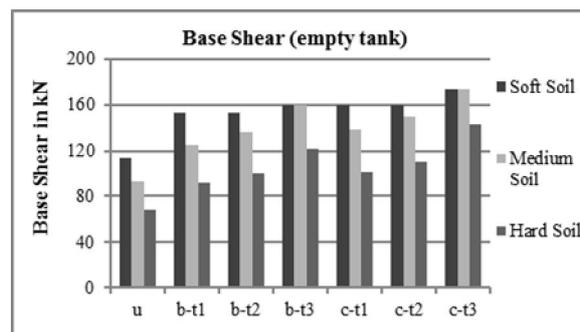


Figure 4: Variation of Base Shear with soil type for empty tank condition

The base shears of the tank with three types of single-diagonal braced and cross braced staging configurations was found to be 1.3 to 2 times more than that of unbraced staging for both full tank and empty tank conditions. From the figure of base shear for empty tank it can be seen that the base shears of tank with configurations b-t1 and b-t2 and configurations b-t3, c-t1 and c-t2 follow a pattern similar to that of their seismic weights and have the same base shear.

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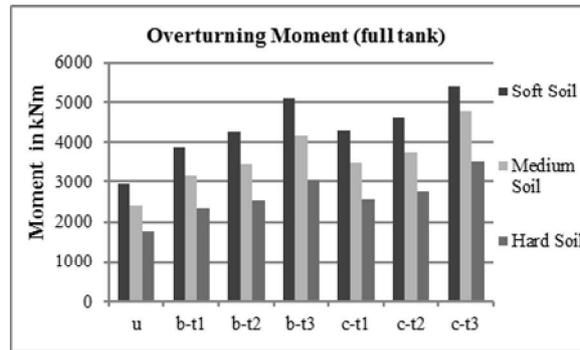


Figure 5: Variation of Overturning Moment with soil type for full tank condition

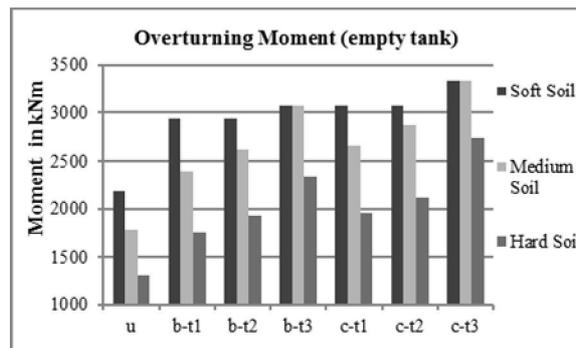


Figure 6: Variation of Overturning Moment with soil type for empty tank condition

The variation of overturning moment of the tank at the base of staging with soil type is shown in figures 5 and 6. The variation follows the same pattern as that of base shear where an increase of 1.3 to 2 times had been noted for the configurations with inclined braced when compared to the unbraced staging system.

## DISPLACEMENT OF THE ROOF OF TANK

The variation of maximum displacement of the models with soil type is shown in figure 7. The displacement is the maximum of all the values obtained from the load cases considered.

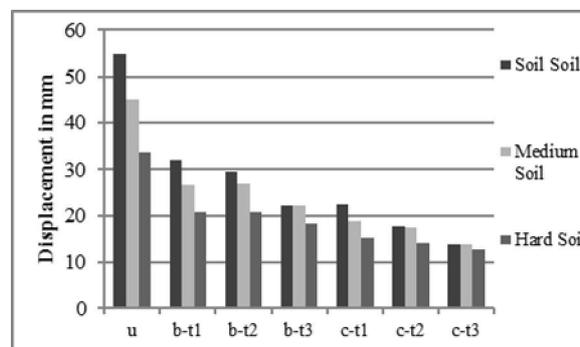


Figure 7: Variation of Maximum Displacement of the roof of tank with soil type for different staging configurations

On an average, the displacement of the tank with type1 and type2 of single-diagonal braced staging decreased by 42% and 46% respectively for soft soil, 40% for medium soil and 38% for hard soil when compared to unbraced system. In

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case of type1 and type2 of cross braced configuration, it decreased by 59% and 68% respectively in soft soil, 60% in medium soil and in hard soil it reduced by 57% when compared to that of unbraced staging.

## VI. DISCUSSION AND CONCLUSION

Tank with radial braced staging, horizontal cross braced staging and staging with shear walls [2] - [4], [9] had been studied previously all of which have been shown to reduce the displacement of the tank and similar results have been obtained in this study by the inclusion of inclined bracing to the staging.

The response of an intze tank with unbraced, horizontal cross braced and radial braced staging configurations with the same dimensions that had been studied for a site with hard soil and seismic zone IV [9]. To compare the staging configurations with those of the other study [9], the models in this study were also analysed for seismic zone IV (figures 8 and 9).

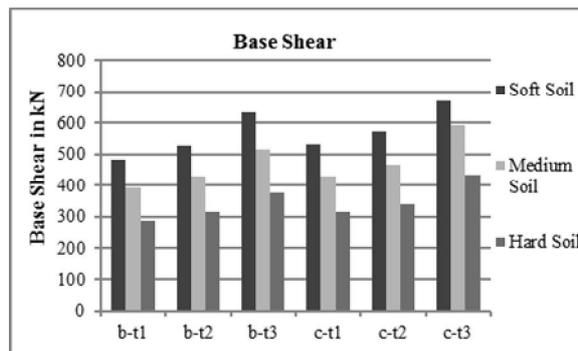


Figure 8: Variation of Base Shear of the tank in seismic zone IV with soil type for full tank condition

On comparing the results, it was found that the base shear and overturning moment was maximum in case of type2 and type3 configurations of both cross braced and single-diagonal braced staging system and the base shear and overturning moment of type1 of both the staging systems were in the same range as that of configurations considered in the other study.

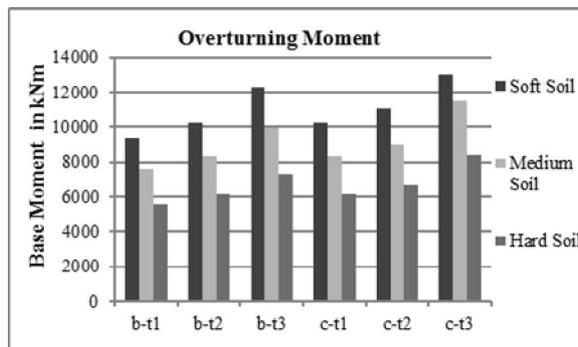


Figure 9: Variation Overturning Moment of the tank in seismic zone IV with soil type for full tank condition

On an average, the displacement of type1, type2 and type3 of single-diagonal braced and cross braced staging configurations was considerably less than the radial braced and horizontal cross braced staging configurations when the tanks were analysed for self-weight of the structure, hydrostatic and hydrodynamic pressures in the container. Hence to reduce the displacement of an elevated tank, staging with cross bracing and single-diagonal bracing can be adopted instead of radial and horizontal-cross bracing.

The tank with type1 and type2 staging configurations of single-diagonal brace and cross braced systems weighed less than their respective type3 systems by 90kN and 180kN respectively and their base shears and overturning moments

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were 15% to 24% less than type3. The displacement of the tank with type1 and type2 staging configurations of single-diagonal braced staging in soft soil varied by 31% and 25% when compared to type3 system, in medium and hard soil it varied by 2mm to 4mm. The displacement of type1 of cross braced staging was 37%, 27% and 17% more than type3 in soft, medium and hard soil respectively and for type2 of cross braced staging the displacement was about 20% more than type3 in soft and medium soil and in hard soil it varied by 1mm.

Though type1 and type2 configurations weighed the same, the stiffness of type2 was approximately 20% and 16% more than type1 for single-diagonal brace and cross braced staging systems respectively and their base shear and overturning moment varied by only 8-9%, the tank with type2 configuration displaced 20% less than type1 for cross braced system and 8% for single-diagonal bracing system in soft soil, the two configurations did not differ much in medium and hard soil. Since the stiffness of the type2 variant is more and it displaces less than type1, amongst the two types type2 configuration can be considered as a potential substitute for unbraced system instead of considering inclined-bracing throughout the height of staging (type3).

When type2 configuration of single-diagonal braced and cross-braced staging systems were compared, it was found that the tank with single-diagonal braced staging weighed about 90kN less than cross braced type and though it had 15% less stiffness, the difference between their base shear and overturning moment was insignificant. Hence, it can be concluded that staging with single-diagonal bracing at alternate levels with bracing at ground level is a better alternative than the other staging configurations considered in this study.

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