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SEISMIC ANALYSIS OF ELEVATED STEEL WATER TANK WITH OR WITHOUT BASE ISOLATION

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Abstract

Liquid storage tanks are one of the many important structures that demand grater safety against natural disaster like earthquakes. Water tanks and particularly the elevated storage reservoir is considered as main lifeline elements which be able to maintain the expected performance i.e., Operational during and after earthquakes. Specific concentration must be paid while designing the water tank to avoid the potential damage associated with the failure of tanks and to supply water. In this paper seismic response of a Steel elevated service reservoir of 743 m3 capacity had been evaluated. Steel water tank was designed as per the Indian code IS: 805-1968 (Reaffirmed 2006). Particular attention had been paid to the consideration of internal fluid sloshing phenomena, Total water mass was divided into two masses convective and impulsive mass. The Non-linear time history analysis on the tank model with or without the base isolation under the seismic event named as Bhuj had been performed in ETABS software. Also, two types of staging and bracing combination were considered which were Seismically strong as per the literature i.e., X and Inverted V braced frame. Elevated steel water tank was isolated with Laminated lead rubber bearing and two different isolating position were considered 1) Between Superstructure and Substructure 2) Between Staging and tank. After analysis results were obtained in the form of Base shear and Tank deformation.

Keywords: Seismic Analysis, Elevated steel Water Tank, ETABS software, Base Shear, Tank deformation, Bracings.

1. INTRODUCTION

Earthquakes are one of the dangerous and hazardous kind of natural disaster which not only leads to loss of human life but also causes economical loss. Due to earthquakes millions of lives are lost which never be affordable, hence utmost care is needed while designing any structure, especially important structures like elevated structure which are more likely to get affected by such disaster. From various natural calamities quakes gain first place in vulnerability. The life can't be recovered but property losses are often recovered to some extent after an earthquake. During course of history, it has been seen that high raised structure are most prone to seismic damages like community towers, tall buildings and elevated tanks.

1.1. Water Tank

Water storage tanks are used to store water for fire protection and potable drinking water within a designated area or community. Elevated tanks allow the natural force of gravity to produce consistent water pressure throughout the system. Based on the intended application and needs of the distribution area, elevated water tanks can be engineered using a broad range of shapes, sizes, and materials.

Storage tanks are among the most important structures that serve multiple purposes for society and industry, generally tanks are used to store chemicals, oil, liquefied gas, also to store water for supplying to households as drinking purpose, for industries as a coolant and irrigational water for agricultural farming in some areas, also they use for firefighting and for emergencies.

One of the basic needs of all human being is water, so for that need there are various types of water tank depending upon their size, shapes and position.

I. Depending upon shape there are Intze, Circular, Conical, and rectangular water tank.
II. Depending on position there are Elevated, Underground and Ground supported water tank.
III. Depending on material there are Reinforced concrete, steel and Prestressed concrete tanks.

Fig 1.1 Photograph Steel Water Tank

From all types of water tank elevated water tank which is also called as Elevated Service Reservoir (ESR) typically comprises of a container and a supporting tower (also called as staging) cover large area of distribution of water and ESR are specially constructed to maintain high pressure during supply of water at required locations. These tanks are most prone to get affected by earthquake forces, since large concentrated fluid mass is at the top which is supported by some staging system. The seismic performance of these tanks has been a matter of special importance, beyond the economic value of the structure, due to the requirement to remain functional after a major earthquake event. Water supply is essential immediately following destructive earthquakes, not only to cope with possible subsequent fires, but also to avoid outbreaks of disease. Another reason is the potential danger associated with the failure of tanks containing highly inflammable products, which can lead to extensive uncontrolled fire, while possible spillage of such contents might cause extensive environmental damage and affect populated areas. To overcome this problem base isolation can be provided to the tanks.

Fig 1.2 Elevated water storage tanks (ESR)

1.2. Base Isolation

Base isolation is a method in which the structure (superstructure) is separated from the base (foundation or substructure) by introducing a suspension system between the base and the main structure. Base isolation is simply defined as decoupling or separating the structure from its foundation. In layman terms, base isolation can be understood by comparing it to suspension system used in automobiles.

In context of seismic design of structures, base isolation can be replaced with seismic isolation i.e., the structure above the ground, which is most affected during earthquake is separated from the effects of earthquake forces by introducing a mechanism that will help the structure to hover. The concept of base isolation is quite easy to grasp. It can be explained as a bird flying during an earthquake is not affected. In simple words if structure is floating on its base, the movement of ground will have no effect on the structure.

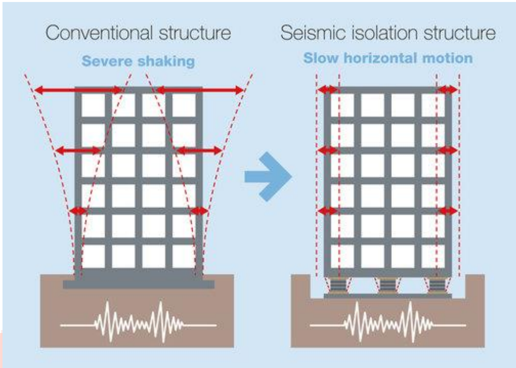

Fig 1.3 Building with and without Base Isolation

Various isolation bearings are designed and employed around the globe for protection of buildings under seismic conditions. Different types of bearings which can be applied to liquid storage tanks are discussed.

i. Elastomeric Rubber Bearings (ERB)
ii. Rubber-based elastomeric Bearings
iii. Laminated rubber Bearings (LRB)
iv. Roller and Ball Bearings
v. Sliding Bearing

1.2.1 Principle of Base Isolation

The basic principle behind base isolation is that the response of the structure or a building is modified such that the ground below is capable of moving without transmitting minimal or no motion to the structure above. A complete separation is possible only in an ideal system. In a real-world scenario, it is necessary to have a vertical support to transfer the vertical loads to the base.

The relative displacement of ground and the structure is zero for a perfectly rigid, zero period structure, since the acceleration induced in the structure is same as that of ground motion. Whereas in an ideal flexible structure, there is no acceleration induced in the structure, thus relative displacement of the structure will be equal to the ground displacement.

No Structure is perfectly rigid or flexible, therefore, the response of the structure will be between the two explained above. Maximum acceleration and displacements are a function of earthquake for periods between zeros to infinity. During earthquakes there will be a range of periods at which acceleration in the building will be amplified beyond maximum ground acceleration, though relative displacements may not exceed peak ground displacements.

Base isolation is the ideal method to cater this, by reducing the transfer of motion, the displacement of building is controlled.

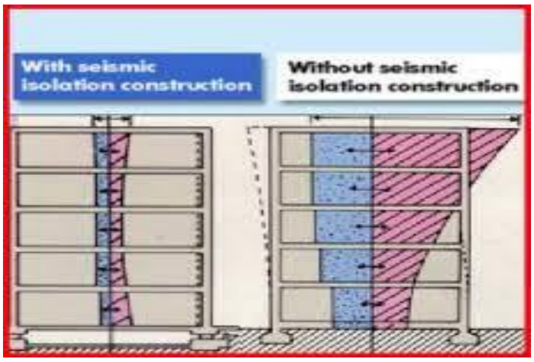

Fig 1.4 Principle of Base Isolation

1.2.2 Basic requirements of an isolation system are:

1. Flexibility
2. Damping
3. Resistance to Vertical or other service loads.

1.2.3 Applications of Base Isolation

1. Base isolation of bridges
2. Base isolation of important buildings
3. Enhancing response of historic structures
4. Isolation in Machinery Field

1.2.4 Advantages of Base Isolation

1. Apart from protecting structures from seismic activities, base isolation also protects them from GSA blast loads as the ability to move reduces the overall impact of the blast on the structures.
2. Base isolated structures are predictable, hence reliability of them is very high as compared to conventional structural components.
3. Need of strengthening measures such as frames, bracing and shear walls in cut down by reducing the earthquake forces transmitted to the building.
4. Simplification of seismic analysis as compared to the conventional structures by allowing reduction in structural elements.
5. In case of large unexpected seismic activities, damage is only concentrated in isolation system, where elements can be easily substituted.
6. Base isolation can also be retrofitted to suitable existing structures. Moreover, the building can remain serviceable throughout the construction.

1.2.5 Disadvantages of Base Isolation

1. Base isolation can't be done on every structure, for example: it is not suitable for structures resting on soft soils.
2. Becomes less efficient for high rise buildings.
3. Unlike other retrofitting base isolation cannot be applied partially to the structure.
4. Implementation is efficient manner is difficult and often requires highly skilled labors and engineers.

1.3 Objectives

Following are the objectives of this research work:

- The main aim of this research work is to evaluate the response of steel elevated water tank with or without base isolation by Performing Non-Linear dynamic time history analysis.
- To find the effective solution of water storage tank by keeping the constant staging height and water storage capacity.
- Position of isolation: To perform the comparative study for two different isolation position will be considered first is between the foundation and the tank and second is between the staging and tank shell.
- Sloshing effect: In both design and response evaluation process, particular attention is given to the consideration of internal fluid sloshing phenomena.

2 LITERATURE REVIEW

Housner. G. W (1957) developed a model by using an approximate analysis of the hydrodynamic pressures exerted on the walls of rigid tanks subject to unidirectional horizontal seismic ground motion. He assumed the liquid, divided into two-mass system: a part of the liquid at the bottom of the container, known as the impulsive component behaves the same way as solid material while the liquid above it, known as, the convective component participates in sloshing with a different dynamic having long period of vibration. The liquid was assumed to be incompressible and undergo small displacement. Due to its implementation simplicity, the model has been adopted in many codes and standards with certain modifications.

Sandip Maity et.al., (2018) In this research paper massive elevated steel reservoir in Kolkata that is 105 years old had been verified. Total capacity of water tank was 9 million gallon and it was supported on the 28m high staging tower. One of the important features of this tank was it isolated by a series of timber planks between staging and tank shell. Time history analysis on the model of steel elevated water tank with or without timber isolation had been performed by the researcher under the action of three seismic ground motion named as El-Centro (0.319g), Nepal Earthquake Aftershock 2 (0.007g), and Loma Prieta (0.419g). After performing analysis results showed that visco-elastic property of timber coupled with friction damping connection is effective to increase the damage control potential of the structure.

E. Fagà et.al., (2012) In this paper an elevated tank was considered for the case study in order to highlight the problems related to the design and modelling of this type of structure. A cylindrical tank was designed to contain a 226-ton water mass and the tank was 8 m in diameter and it is filled with 4.5 m of water. The steel walls were 10 mm thick. An 18-m high concentrically braced frame structure supports the tank. In this paper special attention was given to the design of sloshing parameter and their implication on the overall dynamic response of the system. For the design of tank two methods had been considered one in accordance with the relevant international codes i.e., the method specified in EN 1998-1:2004 (CEN, 2004) and a second proposed method that allows considering the strength of braces in compression. Structure was evaluated for both linear and non-linear analysis and the different analysis strategies considered were compared and the influence of the design process on the global response was highlighted.

A. Mallika et.al., (2016) In this paper response spectrum analysis was performed to investigate the structural responses like lateral displacements, storey shears, storey drifts and Overturning moments. The bracing patterns studied in the present paper were diagonal, X, V and inverted V-bracings. 10-storeyed building with 3.0 m, 3.6 m and 4.2 m storey heights was considered in zone V for the present study. In the present paper, ETABS software was used for investigating the structural responses of Tall Buildings. And it is concluded that minimum storey drifts were observed in the case of inverted V-braced buildings for all storey heights. Maximum value of overturning moments is less in diagonal-bracing.

Paul P.A. Vimal et.al., (2020) Elevated water tanks in an empty condition, though not important in structural design, becomes an important problem in seismic design. The objective of the research was to investigate the elevated water tanks in empty and in filled conditions and to emphasize the importance of seismic response. Four elevated tanks with various parameters were selected for seismic analysis with the base isolation technique. It was found out that empty tanks were highly vulnerable to earthquake effects, whereas filled tanks can be mitigated by providing base isolation. A simple experimental investigation has also been carried out to validate the analytical results.

Ayman A. Seleemah et.al., (2011) In this paper, the seismic responses of base-isolated broad and slender cylindrical liquid storage ground tanks were investigated. Three types of isolation systems were considered with the corresponding responses of non-isolated tanks. Moreover, a parametric study was conducted to evaluate the effect of tank aspect ratio, isolation period, and friction coefficient of the FPS system on key responses of the tank. It was found that, base isolation was quite effective in reducing the earthquake response of ground liquid storage tanks. Generally speaking, 50–90% reductions in both base shear and impulsive displacement responses were observed. The convective displacement was observed to be 20–70% higher than that associated with fixed base tanks leading to an essential need of increasing the clear height above the liquid surface. Base isolation was found to be more effective for slender tanks in comparison with broad tanks.

M. K. Shrimali et.al., (2002) The response of liquid storage tanks isolated by the sliding systems was investigated under real earthquake ground motion. Total liquid mass was considered as lumped mass as convective mass, impulsive mass and rigid mass. The corresponding stiffness associated with these lumped masses was calculated depending upon the properties of the tank wall and liquid mass. The governing equations of motion of the tank with a sliding system are derived and solved by Newmark's step-by-step method with matrix iterations. A parametric study was also conducted to study the effects of important system parameters on the effectiveness of seismic isolation of the liquid storage tanks. The various parameters considered are (i) the period of isolation (ii) the damping of isolation bearings and (iii) the coefficient of friction of sliding bearings. It had been found that the bi-directional interaction of frictional forces has noticeable effects and if these effects were ignored then the sliding base displacements will be underestimated which can be crucial from the design point of view. Further, the dependence of the friction coefficient on relative velocity of the sliding bearings had no significant effects on the peak response of the isolated liquid storage tanks.

Mahmood Hunar et.al., (2017) In this paper the preliminary design of elements of a circular liquid tank by the API was performed, water tank is provided with different types of stiffeners and analyzed to investigate the effect of type of the stiffener, number of course and location of stiffener on the structural behavior of liquid tanks. With obtained dimensions of elements, tank was modeled in the software ANSYS, and values of maximum stresses and deformation were computed and compared. The stiffeners improve the static, buckling and dynamic behavior of the tank and C section stiffener show better performance. When the number of the courses increase the weight of the tank is reduced meanwhile the structural behavior of the tank does not change so much.

3 NUMERICAL INVESTIGATIONS

For numerical investigation circular steel water tank is considered and it is design as per Indian code. For comparison aspect ratio and water storage capacity of tank is kept constant and by providing isolation at different levels and without isolation system comparison is made. Also, Behavior of isolating system on X braced frame and inverted V braced frame are analyzed. Parameters are discussed on the basis of Tank deformation and Base shear.

3.1 Geometrical configurations:

Overhead steel elevated water tank is designed as per Indian code IS 805:1968 and dimensions of various structural elements presents in steel ESR are as follows:

1.	Shape of tank	Circular
2.	Capacity	743000 m3
3.	Diameter	12m
4.	Height of tank shell	7m (Including freeboard)
5.	Aspect ratio	0.6 (Broad tank)
6.	Depth of foundation	1.5m
7.	staging height	18m
8.	Thickness of shell	8mm
9.	Thickness of top slab	4mm
10.	Thickness of bottom slab	10mm
11.	Gallery thickness	75mm

Table 1. Dimensions of Circular water tank

3.2 Section properties:

The frame sections used in the water tank are defined here along with their dimensions:

1.	Steel Grade	Fe345
2.	Beam	ISHB 350
3.	Column	Double I hollow section B=300mm, D=450mm T=16mm
4.	Ring beam	Double I hollow section B=200, D=300, T=12mm

5.	Bracing	RHS 120x120x5mm
6.	Stiffeners	ISA 70X70X10 mm

Table 2. Section properties of tank

3.3 Modeling in Software

The steel water tank is modeled in ETABS software, ETABS Extended Three-Dimensional Analysis of Building System is one of the latest software which allows non-linear analysis using finite element methods which makes it capable of producing results with higher accuracy. With the inclusion of non-linear dynamic analysis like time history analysis and Equivalent static analysis with modeling of damping effects, it has become more popular in the analysis and design of complex structures. Moreover, the software is very user-friendly and supports design by codes of almost every country.

The container is modelled with shell elements while structural elements of the supporting steel tower is beam elements. Tank shell is supported with the 7 columns placed at the vertices of the hexagon and 1 at center as shown in fig. 3.1 and Overall height of staging is divided into 5 intervals at base 2m is kept for isolation. As shown in fig. 3.2

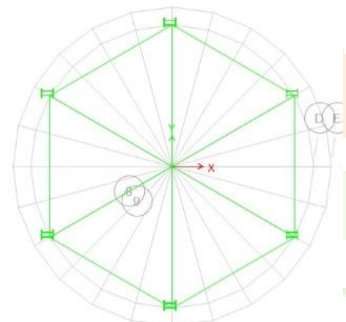

Fig 3.1 Plan of circular water tank

Fig 3.2 Elevation of tank

3.4 Method of Analysis

Time-History analysis is a step-by-step procedure where the loading and the response history are evaluated at successive time increments. Nonlinear time history analysis is the dynamic analysis in which the loading causes significant changes in stiffness. Therefore, this method is one of the most effective for the solution of non-linear response. Non-linear time history analysis utilizes the combination of ground motion records with a detailed structural model therefore is capable of producing results with relatively low uncertainty.

Zone	V
Important Factor	1.5
Soil Type	Medium soft soil
Time history data	Bhuj

Table 3. Seismic parameter

Selection of ground motion data

Performance of the water tank model has been analyzed under the earthquake event named as Bhuj and PGA (0.31g), ground motion records data selected for analysis from COSMOS Consortium of Organizations for Strong-Motion Observation Systems, virtual data.

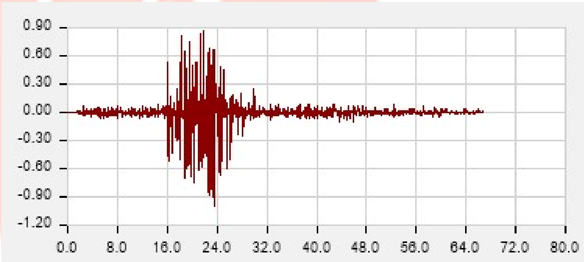

Fig 3.3 Time history graph of Bhuj

3.5 Modeling of Water Inside the Tank

The lumped mass of water inside the tank is represented as two-mass model comprising of convective and impulsive masses (Housner 1963). During seismic excitations, the convective action of the liquid exerts a sloshing effect on the tank wall and impulsive mass moves along with the tank wall. In the tank model, the convective mass is connected to the tank wall by a spring and the impulsive mass is rigidly connected. Different parameters relating to the two masses have been worked out with the help of IITK guidelines which depends upon the overall geometry of the tank.

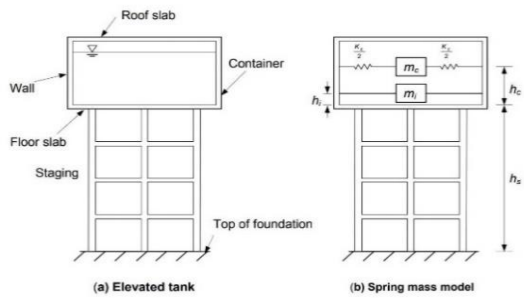

Fig 3.4 Spring Mass Model

Total mass of water insider the tank (m)= Volume x density of water = 757.75 ton

Various parameters of spring mass models for considering the sloshing effect of water as per IITK guidelines obtained are as follows:

mi [ton]	469.8 ton
mc [ton]	287.9ton
hi [m]	2.51 m
hc [m]	4.18 m
Timp [s]	0.22 sec
Tconv [s]	3.64 sec

Table 4. Sloshing model parameters

Where, mi and mc are the impulsive and convective masses in tones, hi and hc are the convective and impulsive height of water in meters, Timp and Tcov are the impulsive and convective time period in seconds.

3.6 Base isolation modeling

The Water tank is isolated with laminated rubber bearing (LRB). The LRB is modeled with linear elastic stiffness (kb) and viscous damping (ξb). Two different positions are considered: (1) between staging and foundation and (2) between base plate of tank and staging. The base mass (mb) is assumed as 5% of the liquid mass.

For Model 1, the stiffness of the isolator can be expressed as,

$$k_b = (M_0 + m_b + m_t)\left(\frac{2\pi}{T_b}\right)^2$$

For Model 2, the stiffness of the isolator can be expressed as,

$$k_b = M_0 \left(\frac{2\pi}{T_b}\right)^2$$

Where T_b = natural period of the isolator (2sec),

and $M_0 = m_c + m_i$, Damping coefficient= 0.1.

3.7 ETABS Models

From the problem statement mentioned above following models are proposed for Non-linear time history analysis for earthquake data of Bhuj.

Model 1	Without base isolation, X brace frame
Model 2	Without base isolation, V brace frame
Model 3	With isolation between Superstructure and substructure, X brace frame
Model 4	With isolation between Superstructure and substructure, Inverted V brace frame
Model 5	With isolation between staging and tank shell, X brace frame
Model 6	With isolation between staging and tank shell, inverted V brace frame

Table 5. ETABS Models

4 RESULTS

Non-linear time history analysis on elevated steel water tank with isolation at top, bottom and without isolation for X braced frame and inverted V braced frame on Etabs Software is performed. Results are obtained on the basis of Base shear and Tank deformation.

1) Base shear: It is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity. The variation of base shear in all the models is shown in Fig 4.1

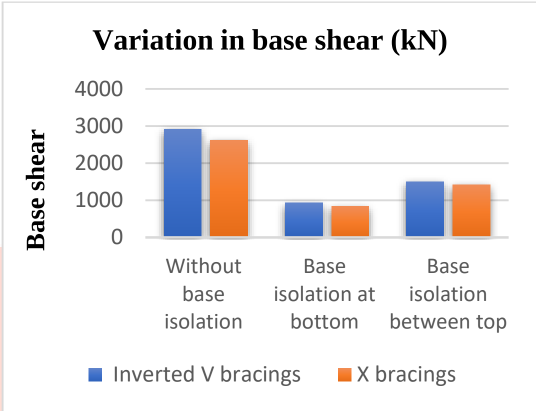

Fig 4.1 Base shear (kN)

2) Tank deformation: Deformation in the walls of the tank is mainly caused due to the action of convective mass of water acting on the tank shell. The variation of tank deformation in all the models is shown in Fig 4.2

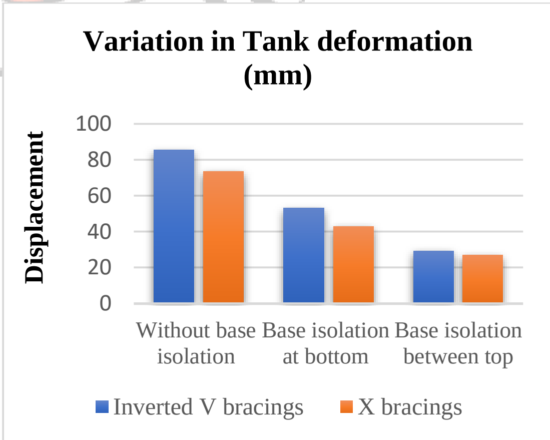

Fig 4.2 Tank deformation (mm)

5 CONCLUSION

Seismic analysis of the elevated steel water tank is important, as the high concentrated mass is supported on the tower. Damage to tanks used for water storage can result in lack of potable water for a community. In this research Steel water tank is analyzed using Indian standard code IS: 805-1968 and time period for impulsive and convective mode is calculated as per IITK Guidelines and concluded that:

1) The performance of the elevated steel water tank with Laminated rubber bearing isolator is found to be effective in reducing the Base shear by 55 - 75 % as compared to non-isolated tanks.
2) Convective motion of the liquid can play major role in the failure of tanks. To reduce the convective mode base isolation techniques can be applied to the actual tanks, it is observed that tank deformation is reduced up to 60 – 70 % as compared to the non-isolated tank.
3) Isolation techniques can be a real need to be implemented to reduce sloshing motion of the liquid. Position of base isolation also plays important role in the seismic performance of the ESR as isolation between tank and staging gives better results as compared to the superstructure and substructure.
4) At seismic ground motion Bhuj, LRB isolator at top of the staging indicates 18 -25 % reduction in value of base shear as compared to at the bottom of the tank.
5) Elevated slender tanks are seismically more vulnerable than broad tanks so it is recommended to provide base isolation at top of the staging for slender tank as the Tank deformation while providing isolation between superstructure and substructure is around 80 % more as compare to the isolation between tank shell and supporting structure.
6) Bracing Structures gives more resistance to lateral deflection and it is also suitable in earthquake prone areas. Comparison with staging pattern shows that performance of X Braced frame shows better seismic response as compared to the Inverted V braces frame.

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