EFFECTIVE ORIENTATION AND CRITICAL IMPACT PREDICTION FOR RC STRUCTURE UNDER EVENT OF TSUNAMI DRIVEN DEBRIS

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ABSTRACT

The recent investigation of the 11 March, 2011 Japan Tsunami had shown the importance of debris. It has been revealed that the drifted objects by tsunami like wooden log, cars, small sized ships, shipping containers etc increased damages on the buildings and structures. This debris with weight and pressure creates sudden impact forces in the structure which acts horizontally with higher force value and damages the structural configuration or structural members. The observation shows that, many hotel building near shoreline are constructed in such a way that the people inside hotel gets maximum scenario of the sea. This requirement if fulfilled only by keeping longer side parallel to the shoreline. Debris may hit the structure exactly on the same point at the available water level or may be it differs by some margin in hitting the structure as above or below the water level. This study highlights, weather the existing orientation of building is feasible or not by applying the tsunami forces on the longer side and then we change orientation by keeping shorter side parallel to shoreline. Comparatively decision is taken on the basis of the forces generated in the structural elements. In another case we apply the impact force on different locations on one of particular column element, which is most critical column (corner) of a building. The study concludes, Small masses converted to large impact when speed of waves increases. Orientation by keeping shorter side always parallel to shoreline is effective in reducing magnitude of forces in tsunami event and impact occurred above water level is more vulnerable than still water level. These predictions are very much useful for planning of buildings near shore line which sustain all possible tsunami forces.

Keywords: Tsunami, Debris, Wooden Log, Impact Force, Displacements, Hydrodynamic Force, Coast Line Structures, Orientation, Impact Analysis Etc.

I INTRODUCTION

The 26th December 2004, tsunami severely affected communities situated along the coast line of the Indian Ocean including Sri Lanka, Thailand, The Maldives Islands and the littoral zones of several West African countries. The 26 December 2004 earthquake, which was 4th strongest earthquake recorded since 1900 (M 9.1) generated below the sea bed and resulted in vertical displacement of the sea floor. The displacement triggered a tsunami that killed almost 2, 30,000 people and cause billions of dollars in form of damage. People living on the coastline near the epicentre of the earthquake had very little time to move higher ground to escape. Asian tsunami took around 2 hrs to reach coast of Tamil nadu, Kerala, West Bengal etc. The tsunami heights observed in these states were ranges from 2 m to 5.5 m.

The Tohuku earthquake and ensuring tsunami in Japan is one of the most catastrophic events in the history of tsunami event. On March 11, 2011 a Moment Magnitude of 9.0 earthquakes struck off the northern coast of Japan. The earthquake was so close to coast that, the little time was available for people to react. The infrastructure of hundreds of cities and villages in the Indonesia, Thailand, Japan, India and Sri Lanka like countries was severely affected by the impact of the tsunami waves. Many of the structures was completely damaged and collapsed. Some of them toppled down due to high pressure tsunami waves. The coastal population has increased significantly over the past several decades. The increased coastal population led to increased coastal development, which led in turn to greater number of structures at risk from coastal hazard. The earthquake and tsunami are inevitable forces of nature, so it is better to be prepared for them, so that the damage to the infrastructure can be minimised.

1. 1 Need for Study

The recent investigation of the 11 March, 2011 Japan Tsunami had shown the importance of debris. It has been revealed that the drifted objects by tsunami like wooden log, cars, small sized ships, shipping containers, floating wooden building etc increased damages on the buildings and structures. These debris having tremendous weight ranges from 400 kg to 3500 kg, along with the water pressure hits the structural component which obstacle in their travelling path and creates sudden impact forces in the structure. These forces acts horizontally with higher force value and damages the structural configuration or structural members.

The wooden structure immediately collapsed in tsunami or sometimes floats with tsunami waves and due to heavy weight reinforced concrete structures remains at their place but, affected severely. March 2011 tsunami in Japan showed that, the height of waves rises up to 16m above sea level. These kinds of waves generate tremendous pressure and lead to collapse of reinforced concrete structures also, so proper analysis and design of RCC structures in tsunami prone areas governs an importance. Currently, there are no clearly established procedures to address tsunami-induced forces. In December 2004 tsunami, Tamil nadu state is worst affected by tsunami. One important element that needs significant improvement is the estimation of the lateral resistance of onshore structures against tsunami-induced forces and also the quantification of impact forces generated various water borne debris. Proper attention must be paid to the detailed design of structural members exposed to the above mentioned forces.

This study focuses on the forces generated by the water born debris on a structure or structural elements. Study also highlights the Performance of the structure against these sudden impact forces on vertical members. We studied the effect of orientation of buildings which situated along the shore line against the maximum impact forces; also we try to predict the position of impact force which creates maximum damages in the structures.

II TSUNAMI INDUCED FORCES AND CODES

2.1 Hydrodynamic force (F_D)

$$F_D = \frac{1}{2}\rho\, C_D\, A\, u^2 \qquad (1)$$

Where,

F_D = Total drag force in direction of flow (KN),

C_D = Drag coefficient,

A = Projected area of the body normal to the flow direction (m^2),

u = Bore velocity or flow velocity at location of structure (m/s),

B = Breadth of the structure in the plane normal to direction of flow (m),

h = Flow depth (m) and

(hu^2) = Combination represents the maximum momentum flux per unit mass

$$(hu^2)_{max} = gR^2\left(0.125 - 0.235\frac{Z}{R} + 0.11\left(\frac{Z}{R}\right)^2\right) \qquad (2)$$

Where,

g = acceleration due to gravity (m/sec^2),

R = design runup elevation (m) and

Z = ground elevation at the base of the structure (m)

2.2 Impact force (F_i)

The estimation of impact force is governed by stiffness of both the debris and structure elements. The water born debris (woods, logs, cars, ships, etc) may have their own stiffness (stiffness depends on the dimensions of the member). This debris hits the structure or structural element in their travelling path and creates tremendous impact in the structure. This impact is absorbed or reduced by the stiffness of individual structural systems. *FEMA P646* considered the stiffness of these two objects in the calculation as effective stiffness.

$$F_i = C_m\, u_{max}\, \sqrt{K\, m} \qquad (3)$$

Where,

C_m = Added mass coefficient,

u_{max} = Maximum flow velocity carrying the debris at the site,

m = Mass of the debris (Kg) and

k = The effective stiffness for the debris and impacted object.

It is recommended that the added mass coefficient be taken as Cm = 2

$$u_{max} = \sqrt{2gR\left(1 - \frac{z}{R}\right)} \qquad (4)$$

u_{max} Depends upon the location of building and topography of the shoreline, this velocity is for light weight debris, which can move rapidly with water.

Here,

g = Acceleration due to gravity = 9.81 N/sce^2

R = Design run-up height = $1.3 \times R^*$

Z = Ground elevation at the base of structure

The velocities of water borne objects are assumed to be the same as the flood velocity. The object is assumed to be at or near the water surface level when it strikes the building. Unlike other forces, impact forces are assumed to act locally on a single member of the structure at the elevation of the water surface, as shown in Fig.1

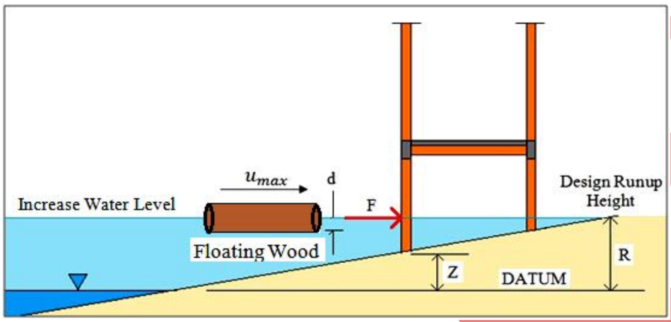

Fig. 1 Phenomena and location of debris impacting a structure

The magnitude of the debris impact force depends on mass and velocity. Smaller (lighter) debris requiring little or no draft to float and can travel at higher velocities but larger (heavier) debris requiring larger depths to float, so travel with less velocities. Use of maximum flow velocity without consideration of the depth required to float large debris would be unnecessarily conservative. Debris impact forces should be evaluated considering the location of the structure and potential debris in the surrounding area. For example, locations near yacht marinas or fishing harbours should consider possible impact from boats that break their moorings

The equation given by *FEMA* requires the mass and stiffness properties of the debris. The approximate values of *m* and *k* for common waterborne debris are listed in *Table 1* Mass and stiffness properties for other types of debris will need to be derived or estimated as part of the design process.

Sr. No	Type of debris	Mass, (Kg)	Effective Stiffness (N/m)	Sr. No	Type of debris	Mass, (Kg)	Effective Stiffness (N/m)
1	Lumber or Wooden Log	450	2.4×10^6	4	20-feet Shipping Containers	2200	1.5×10^9
2	Family cars	1500	3.10×10^7	5	40-feet Shipping Containers	3300	6.5×10^9
3	Small boats	1550	3.05×10^7				

Table 1 Mass and stiffness of some water born debris *(FEMA P646)*

2.3 Recommendation by FEMA P646

Debris impact forces F_i are short duration loads, due to impact of large floating objects with individual structural components. Since large floating objects are not carried by the leading edge of the surge, the effect of the debris impact is combined with hydrodynamic drag forces, F_d but not impulsive (Surge) forces F_S. Although many floating objects may impact a building during a tsunami event, the probability of two or more impacts occurring simultaneously is considered small. Therefore, only one impact should be considered to occur at any point in time. Both the individual structural component and the overall structure must be designed to resist the impact force in combination with all other loads (except impulsive forces). *Fig.2* shows the application of above forces on a building or structural element.

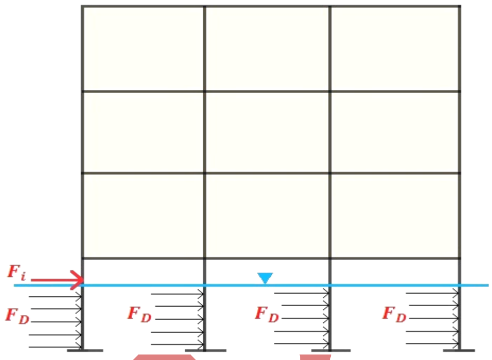

Fig. 2 Application of design forces on building

2.4 Dimensions and mass of debris

The nature of debris depends upon the location of building and surrounding area. If building is located in ship yard area then most probable debris are shipping containers, wooden houses collapse due to water pressure and moves with water as impact missile, in a city area the family cars floats with water and hits the structure *(observed in Dec. 2004 Asian Tsunami and 11 March 2011 Japan Tsunami).*

III. MODELLING PARAMETERS

To study the behaviour of structural elements of a building when subjected to tsunami water born debris impact loading in a tsunami event, a G+3 storey building is considered. The building is a Hotel Building which is situated very close to shore line *(600 m from shore line)*, keeping longer side parallel to shoreline.

The study focuses on the point, weather the designed building as an earthquake resistant structure can resist the impact of tsunami driven debris and the adequacy in the behaviour of structural elements particularly columns on ground floor. We will use a *SAP2000 v14* for analysis of the structure against debris impact forces. Static linear analysis is carried out for different cases. Displacement and base shear of structure for different types of debris studied. From geological investigation, the coastline along Tamil nadu has a flatter slope. The ground elevation available near shoreline is only 0.6 m – 1.5 m. For study purpose we keep the ground elevation as 1 m (Z =1 m).

3.1 Model Configuration

Plan dimension of structure = 20 m × 12 m

No of bays in X-direction = 4

No of bays in Y-direction = 3

Spacing of bays in X-direction = 5 m

Spacing of bays in Y-direction = 4 m

Height of all typical floors = 3.4 m

Height of ground floor (Parking) = 2.5 m

Height of parapet wall = 1 m (all around the periphery of roof floor)

No of Columns = 20

Type of foundation – Isolated footing

3.2 Loadings Considered in Analysis

Loadings and loading combinations are considered as given in *IS 1893-2002 (Part-I)*

1. Dead Load
2. Live Load on Typical floors – 4.5 KN/m^2
3. Live Load on Terrace – 2 KN/m^2
4. Tsunami waves parallel to longer side

The parameters essential for tsunami analysis based on location of structure are listed in Table 3 with reference to *FEMA P646*.

3.3 Sizes of Structural Members and Material Specifications

The sizes of structural components to serve as an earthquake resistant structure are prescribed in *Table 2*.

Sr. No	Structural Member	Size	Sr. No	Structural Member	Size
1	Columns on GF	500 mm × 350 mm	4	Beams on Typical Floors	300 mm × 250 mm
2	Columns on Typical Floors	550 mm × 350 mm	5	Thickness of slab	150 mm
3	Beams on Ground Floor	500 mm × 300 mm	6	Exterior and Interior wall thickness	230 mm

Table 2 Location and sizes of the structural elements

The safety of members was checked under *SAP 2000 v14*. This implies the structure constructed near shoreline area is somehow safe against earthquake forces. The concrete and steel used in the study had a grade M30 and Fe 415 respectively. Concrete density was taken as 25 KN/m^3 and that of infill wall was 20KN/m^3. The modulus of elasticity of concrete 27386 N/mm^2 and that of infill wall 8800 N/mm^2 *(based on Tamil Nadu State brick quality)*, the poisons ratio for concrete and infill was 0.2 and 0.15 respectively. *Table 3* gives the possible tsunami height available in the area around the building. Under this study we took only two heights of tsunamis acting on a structure. The first height is 2.25m which is based on 2004 tsunami event and 4.85m which is in future, if tsunami will take place.

Values of 'R*' (m)	Design values of 'R' R = 1.3× R*	Tsunami Height (m) $H_{max} = R - Z$	Values of 'R*' (m)	Design values of 'R' R = 1.3× R*	Tsunami Height (m) $H_{max} = R - Z$
2.5	**3.25**	**2.25**	**4.5**	**5.85**	**4.85**
3.0	3.90	2.90	5.5	7.15	6.15
3.5	4.55	3.55	6.0	7.80	6.80
4.0	5.20	4.20	6.5	8.45	7.45

Table 3 Values of Inundation height and tsunami height for building elevation (Z=1)

IV STRUCTURAL PROBLEM

The observation shows that, many hotel building near shoreline are constructed in such a way that the people inside hotel gets maximum scenario of the sea. This requirement if fulfilled only by keeping longer side parallel to the shoreline. Tsunami generated forces are much larger than the earthquake generated forces proved in this research. Here we can study, weather the existing orientation of buildings is feasible or not by applying the tsunami forces on the longer side and then we change orientation by keeping shorter side parallel to shoreline. The two possible orientation of building is shown in *fig.3*

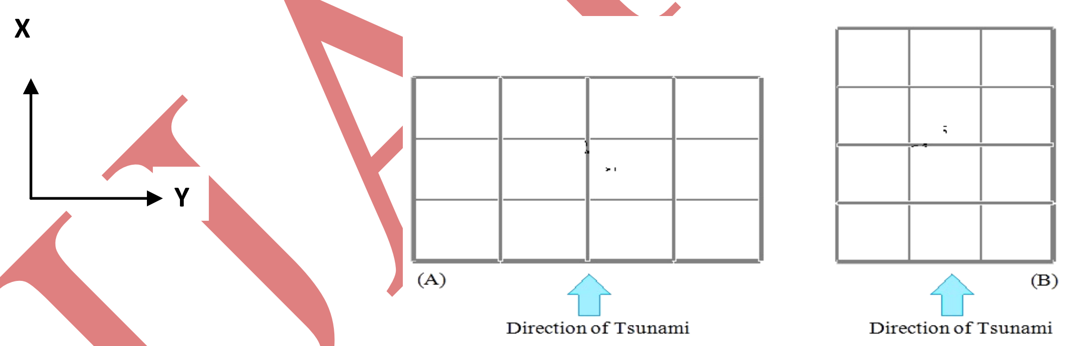

Fig. 3 Orientation of building keeping either longer or shorter side facing tsunami waves

To study the performance point of the structure when subjected to the impact force is one of the important parameter. Debris may hit the structure exactly on the same point at the available water level or may be it differs by some margin in hitting the structure as above or below the water level. *CCH* suggested that the debris with draft may hit the structure 0.5 m above or 0.5 m below the existing water level. We apply the impact load at water level and 0.5 m below and above water level i.e. at 1.75 m and 2.75 m on column element and observe the behaviour of element with reference to axial thrust, bending moment and shear forces. The location of impact are shown in *fig.4*

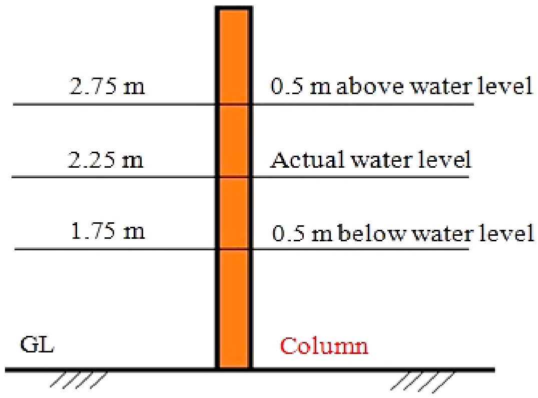

Fig. 4 Different locations of impact on single element

4.1 Modelling in SAP 2000 v14

The structure is modelled using *SAP2000 v14*, the structural properties and loading are defined as per *IS 456-2000* and *IS 1893-2002 (Part-I)*. The infill walls are modelled as equivalent diagonal strut. The impact load from debris is applied only on a single element of the structure. This load acts as a point load in the direction of tsunami waves. Hydrodynamic load is always acting with water on all structural components. This may be acting as a uniformly distributed load on each element of structure.

V. RESULTS AND DISCUSSIONS

For comparison between different components of a structure (Columns), some of the critical columns by primary observations are selected and their locations are shown in the *fig.5*

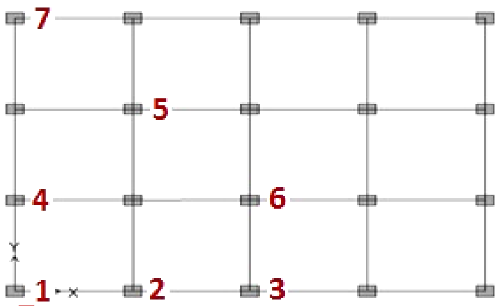

Fig. 5 Location of Different Columns Considered In the Study

5.1 Different forces developed for 4.5 m Tsunami waves (Orientation)

The percentage reduction is different for different forces in columns of a building. Bending moments reduced by *8.36%* for short side orientation. Shear forces reduces by approximately *18%* and displacements are controlled by *23.70%* which is satisfactory as far as safety is considered. *Fig 12* shows the difference in the forces for two different orientations of the building with reference to corner column. The safety of a structure is more when amount of these forces in element due to impact is less. The reduction in the forces is observed, when a building is oriented by keeping shorter side parallel to shoreline.

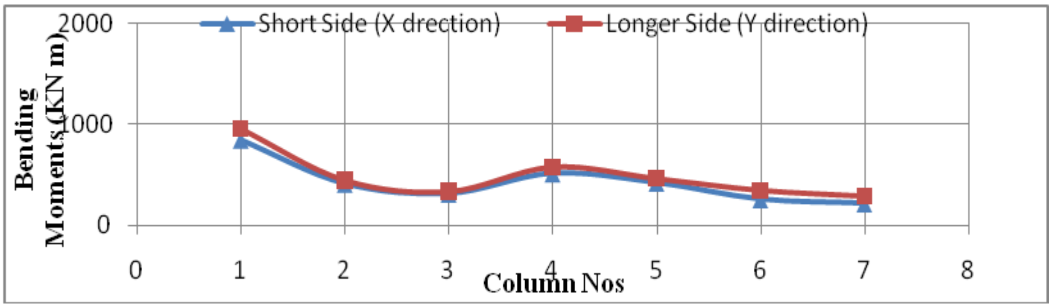

Fig. 6 bending moments in columns for either side orientation of building

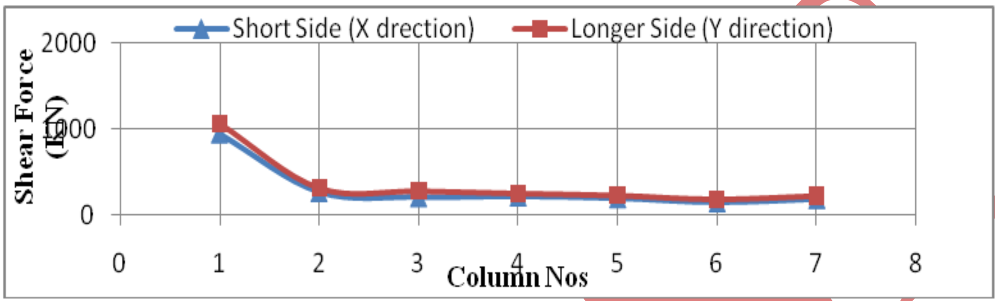

Fig. 7 Shear forces in columns for either side orientation of building

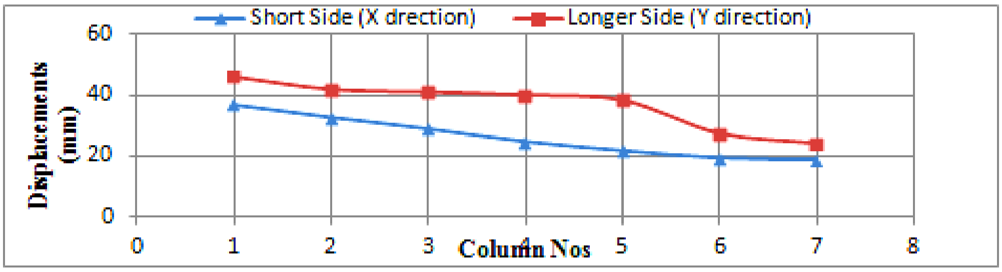

Fig. 8 Displacements in columns for either side orientation of building

5.2 Critical Point for Application of the Impact Load on Column

The results showed that, the forces are maximum when impact at 2.75 m (i.e. 0.5 m above water level). Some forces like shear force and bending moments are maximum when impact is at 1.75 m (i.e. 0.5 m below water level), but this is only for impacted column. When we deal with whole building geometry it was found that, forces in other members are more when impact is at 2.75 m on central column. So we conclude that, for whole structural behaviour critical impacting location is 0.5 m above the tsunami water level. *Fig 13* shows, the percentage increase is different for different forces in column no-4 of a building. The axial forces increased by approximately *9%*, for better structural behaviour they must be as low as possible but should not be zero. The amount of Shear force and displacement increases by same percentage as *12%*, but bending moment in the members increases with little bit higher percentage as *14%*. This increment shows that, when impact location is above water level the forces are increases in all other structural members of a building.

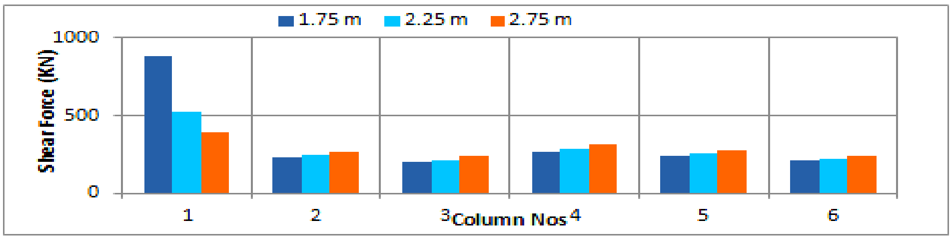

Fig. 9 Shear forces in column for different location of impact

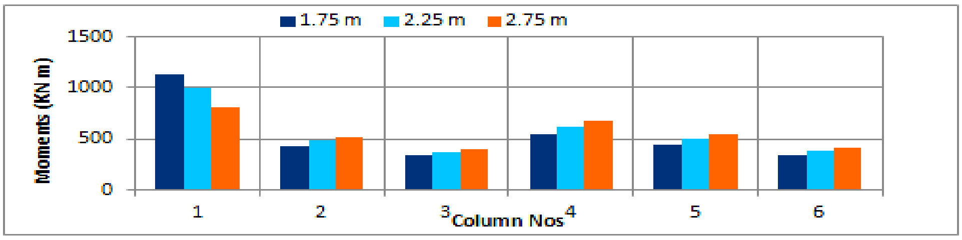

Fig. 10 bending moments in column for different location of impact

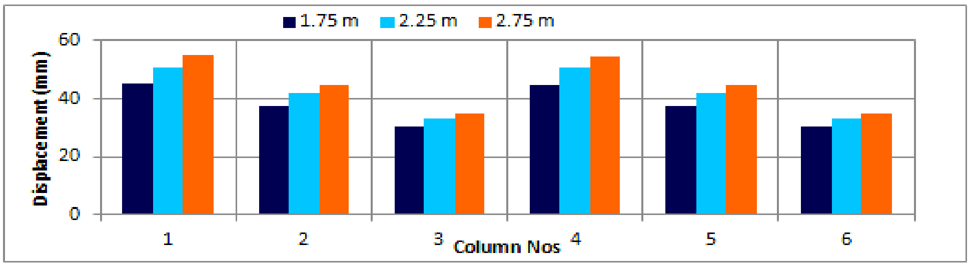

Fig. 11 Displacements in column for different location of impact

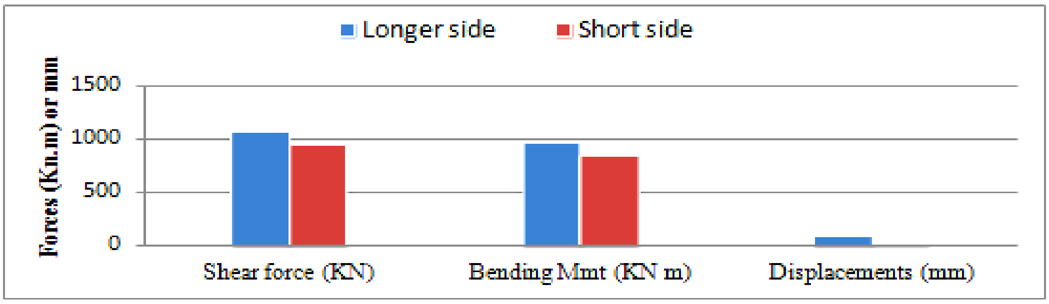

Fig. 12 Different forces developed for 4.5 m Tsunami waves (Orientation)

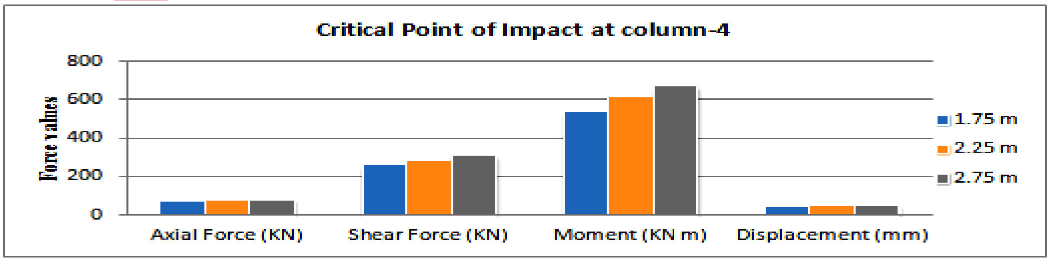

Fig. 13 Forces in column no-4 when impact at corner column

VI CONCLUSIONS

1) The corner columns of a building are more vulnerable to debris impact forces (Wooden log and car/boats). When we compare three different columns of a building, axial forces increases by *46%,* bending moments and shear forces increases by *13%* and displacements increases by *29%* in corner column over other columns.
2) Impact on a central column of a building develops nearly same amount of forces in all columns, this implies that, symmetry of a structure also plays a vital role in reducing the tsunami driven debris impact forces along with hydrodynamic forces.
3) The orientation of building - The effect of tsunami driven forces can be reduced by keeping shorter side of building parallel to shoreline. By doing this shear forces reduced by *18%,* bending moments reduced by *8.36%* and displacements reduced by *24%*
4) The impact at 0.5 m above water level is more critical point on a structural element for application of impact force. Impact at this point increases the forces in all other columns of a building with increase in *9%* in a axial force, *14%* in bending moments and *12%* in shear force and displacements over other two locations of impact, (at water level and 0.5 m below water level)
5) Base shear in a building due to tsunami forces is approximately 84% more than a base shear due to seismic forces (Earthquake).

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