Criticality of a Structural Column When Subjected to an Impact Load from Water Born Debris in Tsunami Event

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ABSTRACT

Tsunami is a rare event, but when it strikes the shore line it not only destroys the structural objects but also affected more on human lives. Tsunami resistant buildings, where the lower level is elevated by means of RC columns to allow the free flow of tsunami waves, recently constructed in many tsunami prone countries. However these columns are very vulnerable to impact due to water-borne massive debris. Tsunami field survey observations showed the building destruction is often exacerbated by the impact of tsunami water-borne massive objects such as automobiles, wooden logs, boats, empty storage tanks and shipping containers. This paper emphasis, the impact of tsunami water-borne massive objects (debris) on RC buildings which are located in the vicinity of the shoreline in Tsunami-prone coastal areas in India A G+3 frame model building is analyzed using software SAP2000v14 prior to impact simulation. Linear static analysis is conducted to investigate response from structural elements due to impact of wooden log. The study concludes, Small masses converted to large impact when speed of waves increases. Corner column of a building and impact above the water level is proved to be more vulnerable. Such buildings need an effective protection against debris to control simulation of heavy forces in structural columns.

Keywords: coast-line structures, columns, debris, displacements, hydrodynamic force, impact force, Tsunami, Tsunami runup, wooden log, etc.

1. Introduction

The 26th December 2004, tsunami had worst 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 26th 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 epicenter 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 recent Tohuku earthquake and ensuring tsunami in Japan is one of the most catastrophic events in the history of tsunami events. On March 11, 2011 a Moment Magnitude of 9.0 earthquakes struck off the northern coast of Japan. This earthquake generated a tsunami that rose up to 41m above sea level and killed over 20, 000 peoples. 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 damaged caused by the tsunami clearly reveals inadequate design of columns, joints as well as retaining structures. The recent investigation of the 11th March 2011 Japan Tsunami had been revealed that the drifted objects by tsunami like wooden log, cars, small sized ships, shipping containers, floating wooden buildings etc increased damages on the buildings and structures

This paper focuses on the forces generated by the water born debris on structural elements. Study also highlights the critical position of column in the structural system when wooden debris hits the structure, this paper also emphasis on the critical location of impact load on a critical column of a structure. Fig.1.1 shows the recent photograph of tsunami driven debris in form of cars and floating wooden logs in Japan 2011. This cars and woods float with water and strike the structure. Under this paper we studied the impact from wooden logs only.

"Fig.1.1 Cars and wooden material as debris in 11th March 2011, Japan Tsunami "
(Source-www.graphicschool.webs.com)

1.1 Coastline Survey of Tamil Nadu State

We focused on Tamil Nadu coastline, in our study. This is the state which was affected more in the 26th Dec 2004 tsunami. The topography of Tamil Nadu coast indicates, the coastal line has flatter slope which has an elevation of 0.6 m to 1.5 m with respect to the sea level. This means tsunami waves can travel very rapidly and gain maximum speed, thus increasing the level of damage and loss of human life in nearby areas. Fig.1.2 shows exact view of the shoreline in *Kalpakkam (Tamil Nadu)* Details of tsunami run-up surveys along the coast of Tamil Nadu is given in Table 1. This survey gives the idea about the maximum tsunami inundation in one particular area for calculation of tsunami forces for design of tsunami resistant structures in future.

"**Fig. 1.2** Kalpakkam (Tamil Nadu) in past 1980" *(Source – PWD Government of Tamil Nadu)*

On 26th Dec 2004 tsunami event, Tamil Nadu state faces waves of varying heights, these waves travel at a speed of 8.33m/sec. They carries fisherman boats, automobiles, wooden logs etc along with them and can reach max 1.2 km inland. An earthquake of M 8 or more in Indian Ocean will cause waves of 10-15 m in Tamil Nadu and Kerala. The structures located in this region must be properly designed to sustain not only earthquake but also the tsunami effect.

"**Table 1** Details of tsunami runup surveys along the coast of Tamil Nadu" *(Source – R. K. Chadha)*

Sr. No	Location	Runup Elevation (m)	Lateral Inundation (m)
1.	Pulicat	3.2	160
2.	Pattinapakam	2.7	145
3.	Kovalam	4.3	180
4.	Kalpakkam	4.1	360
5.	Periakalapet	3.9	170
6.	Puttupatanam	2.6	-
7.	Devanaampatn	2.5	700
8.	Parangipettai	2.8	400
9.	Tarangambadi	4.4	400
10.	Nagapattinam	5.2	800

2. Tsunami Induced Forces and Code provisions

There is very little guidance provided by structural design codes for the forces induced by tsunami and their effects on coastal construction.
A set of generalized equations were created from currently available building codes and published literatures, which contain information and recommended equations on flooding, breaking waves and providing a brief description, along with the existing analytical and empirical formulae to calculate each of the components. These forces are lateral hydrostatic force, buoyant force, hydrodynamic force, surge force, impact force, and breaking wave forces. This study deals with only two types of loading on structure due to tsunami; these are hydrodynamic forces and impact forces. *FEMA P646* and *CCH* give effective empirical formulae to calculate these forces.

2.1 Hydrodynamic force (F_D)

When the water flows around a structure, hydrodynamic forces are applied to the structure as a whole and to individual structural components. These forces are induced by the flow of water moving at moderate to high velocity, and are a function of fluid density, flow velocity and structure geometry.

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

Where,
F_D = Total drag force in direction of flow (KN),
C_D = Drag coefficient,
A = Projected area of the normal to the flow direction (m^2),
u = 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)

A high-speed tsunami bore travelling inland carries debris such as floating automobiles, floating pieces of wooden buildings, drift wood, small boats, ships or any object transported by floodwaters, induces significant forces on a building, leading to structural damage or collapse. Estimating its magnitude is the most likely cause of error in the calculation because there are numerous variables that could affect this type of force.

These variables could range from an accurate estimate of the objects weight and duration of impact. The velocity and location of the waterborne object can be assumed equal to the flood velocity and the water surface level, respectively.

The estimation of impact force is governed by stiffness of both the debris and structure elements. The water born debris (wooden 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.

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

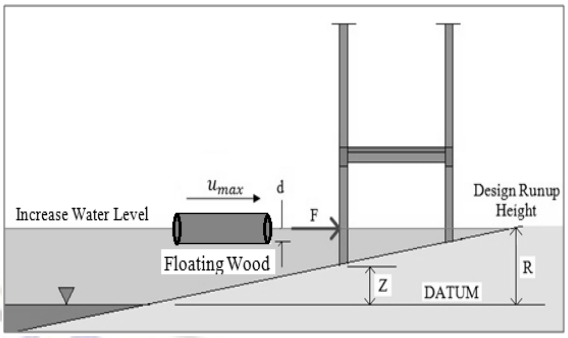
Where,
C_m = Added mass coefficient,
u_{max} = Max flow velocity carrying the debris at the site,
m = Mass of the debris (Kg) and
k = The effective stiffness for debris and impacted object.
It is recommended that the added mass coefficient be taken as Cm = 2

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

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 runup height = 1.3 × 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.2.1

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.



"Fig. 2.1 Schematic presentation of location of debris impacting a structure"

Debris impact forces should be evaluated considering the location of the structure and potential debris in the surrounding area. For example, it is likely that floating debris would consist primarily of driftwood, logs and pier pilings for most coastal towns, whereas for some large port areas, the debris could be shipping containers. Locations near yacht marinas or fishing harbors 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 2 Mass and stiffness properties for other types of debris will need to be derived or estimated as part of the design process.

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.2.2 shows the application of above forces on a building or structural element.

"**Table 2** Mass and stiffness of some water born debris *(FEMA P646)"*

2.4 Dimensions and mass of debris

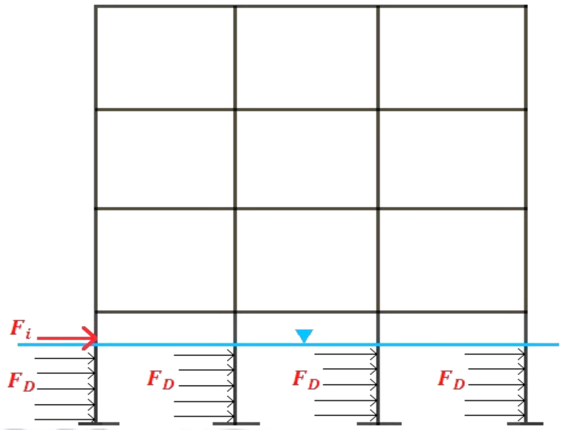
Sr. No	Type of debris	Mass, (Kg)	Effective Stiffness (N/m)
1	Lumber or Wooden Log	450	2.4×10^{6}
2	Family cars	1500	3.10×10^{7}
3	Small boats	1550	3.05×10^{7}
4	20-feet Shipping Containers	2200	1.5×10^{9}
5	40-feet Shipping Containers	3300	6.5×10^{9}

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).* Table 3 gives mass and dimensions of general observed debris near shoreline of tsunami prone areas

3. Modeling Parameters

To study the behavior 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 behavior 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).



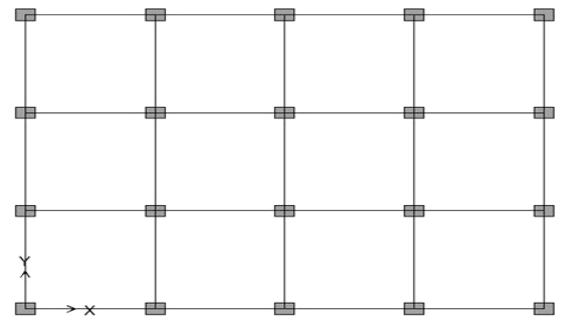
"**Fig. 2.2** Application of design forces on building."

"**Table 3** Dimensions and mass of water born debris" *(www.google.co.in)*

Debris (Wooden Logs)	**Dimensions and Weight (Kg)**
	5.5 m × 0.25 m 6.5 m × 0.30 m 8.5 m × 0.35 m **Weights** 450 to 650 Kg

3.1 Model Configuration

The proposed model plan for study is shown in fig.3.1



"**Fig. 3.1** Model plan considered in the study"

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 5 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 4. 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 $\mathrm{KN/m^3}$ and that of infill wall was 20$\mathrm{KN/m^3}$. The modulus of elasticity of concrete 27386 $\mathrm{N/mm^2}$ and that of infill wall 8800 $\mathrm{N/mm^2}$ *(based on Tamil Nadu State brick quality)*, the poisons ratio for concrete and infill was 0.2 and 0.15 respectively.

Table 5 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.

“**Table 4** Sizes of structural members as per location

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

Table 5 Values of Inundation height and tsunami height for building elevation (Z=1)”

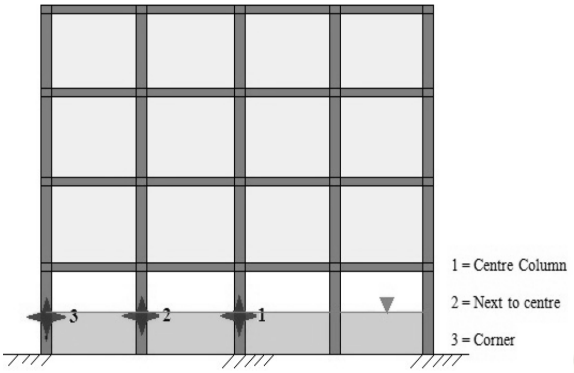
Values of ‘R*’ (m)	**Design values of ‘R’ R = 1.3× R***	**Tsunami Height (m) $H_{max} = R - Z$**
2.5	**3.25**	**2.25**
3.0	3.90	2.90
3.5	4.55	3.55
4.0	5.20	4.20
4.5	**5.85**	**4.85**
5.5	7.15	6.15
6.0	7.80	6.80
6.5	8.45	7.45
7.0	9.10	8.10
7.5	9.75	8.75

4. Structural Problem

Debris travels along with the sea water and acquire same velocity that tsunami wave has. These floating debris can move anywhere without a particular direction. They strike the obstacles in there travelling path and creates tremendous impact on the surface of the obstacle. We didn’t have any idea regarding their location of impact and amount of impact. When debris hits the structure forces are generated in the member and the amount of forces depends upon the location of impact. Here we can locate the critical column in our model by considering impact in all possible 3 ways along longer side.

We considered a wooden log as debris, which flows with water and hits the structure at different locations as shown in fig.4.1. We apply the impact at the centre, next to centre and corner column of modeled structure. The critical location among the three is decided based on the shear force, bending moments developed in columns and the displacements of the columns.

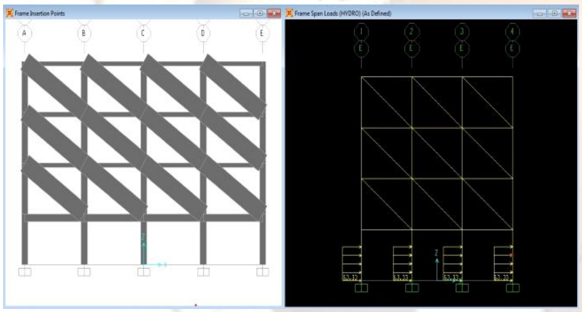
To study the performance point of the structure when subjected to the impact force is one of the important parameter. In that study we can apply the impact force on different locations on one of particular column element, which is most critical from previous results. Debris may hit the structure exactly 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 applied 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 observed the behavior of column with reference to displacements, bending moment and shear forces



"**Fig. 4.1** Different locations of impact in a structure"

4.1 Modeling in SAP 2000 v14

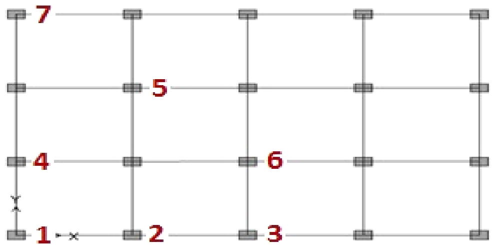
The structure is modeled using *SAP2000 v14*, the structural properties and loading are defined as per *IS 456-2000* and *IS 1893-2002 (Part-I)*. The infill walls are modeled as equivalent diagonal strut. The impact load from debris is applied only on a single element of the structure. This load acts 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 as shown in fig.4.2



"**Fig. 4.2** Modeled building with infill walls and loadings in SAP2000 v14"

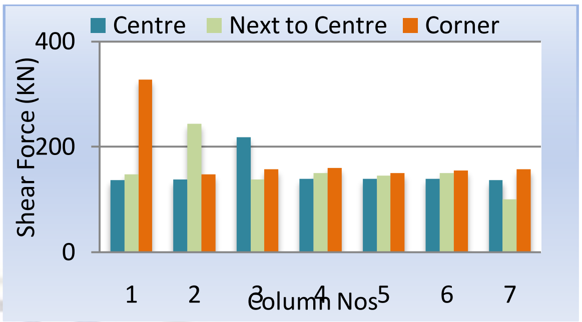
5. Results and Discussions

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.5.1

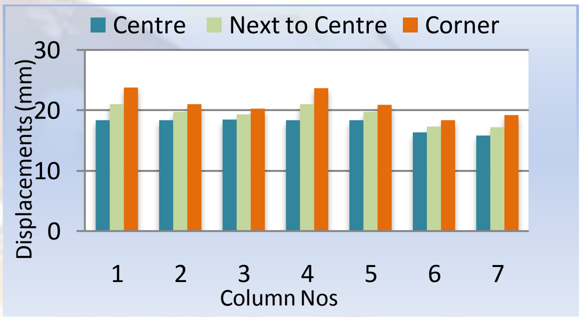


"**Fig. 5.1** Different forces developed for 2.25 m Tsunami"

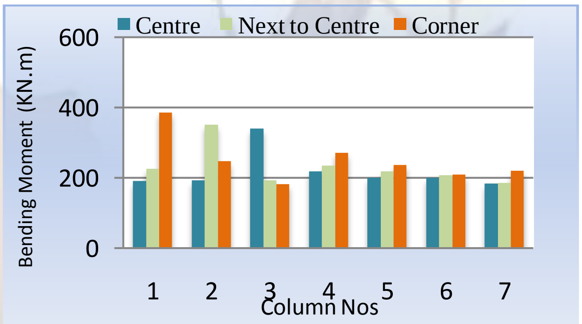
Fig.5.2 to Fig.5.4 shows results for tsunami height 2.25m



"**Fig. 5.2** Shear forces developed in columns for 2.25m tsunami"

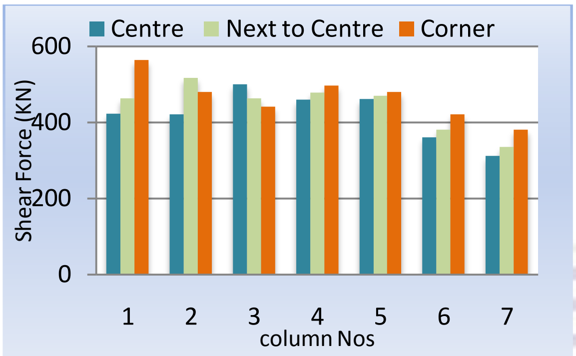


"**Fig. 5.3** Displacements developed in columns for 2. 25m tsunami"

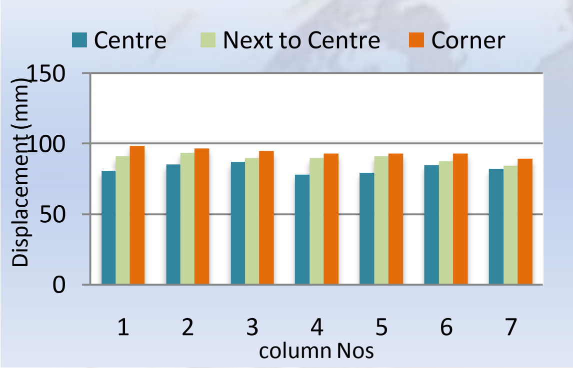


"**Fig.5.4** Bending moments developed in columns for 2.25 tsunami"

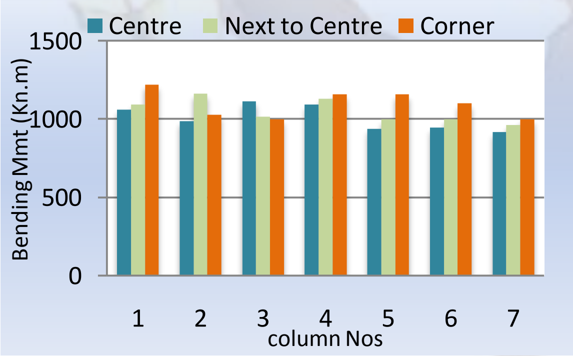
Hydrodynamic forces are acting on every component of structure but impact forces applied on only particular member. We applied impact force on central column of building (3), next to centre (2) and on corner column (1) of a building. The analysis results gave shear force *(SF)*, displacements *(D)* and bending moment *(BM)* generated in selected column against impact forces. When an impact force is applied at central column (No-3 in fig.5.1), all SF, D and BM are maximum only for applied column, but when similar force is applied on corner column (No-1 in fig.5.1), of a building all forces are maximum not only in applied column but also in all columns of a building. Similar results we obtained when the tsunami height is *4.85m* and impact occurs at this water level on different columns considered in the study.



“**Fig.5.5** Shear forces developed in columns for tsunami height 4.85 m”

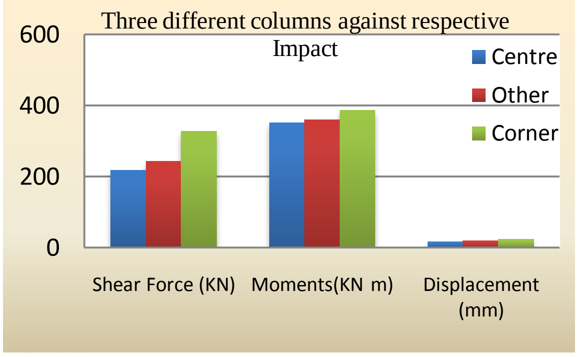


“**Fig. 5.6** Displacements developed in columns for tsunami height 4.85 m”



“**Fig. 5.7** Bending moments developed in columns for tsunami height 4.85m”

The graphical plots clearly indicates when impact occur on corner column (No-1 in fig.5.1) of a building all forces in members are maximum, which implies the corner columns of a building are more critical. We found the percentage increase in the forces in columns for different locations of impact.



“**Fig. 5.8** Forces in three different columns for same impact load (Wooden log)”

The average percentage increase in the forces on corner column over other column is calculated. This increase implies corner columns are more critical than any other column of a building against tsunami generated debris impact.

5.2 Critical point for application of the impact load on column.

Under this study we analyzed GF critical column (corner column) against impact load for three different locations on column. The locations are considered 0.5 m above and 0.5 m below the existing water level in tsunami event *(CCH).* The comparative study is based on the forces generated in member such as shear force, bending moments and displacements.

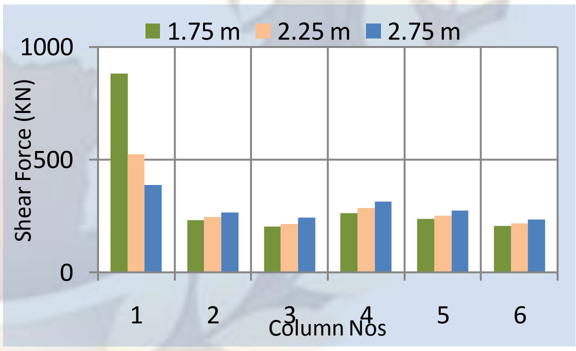
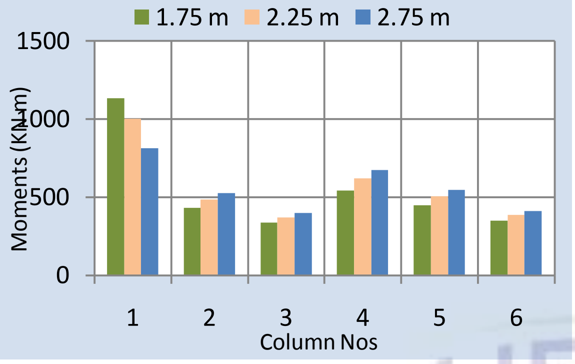
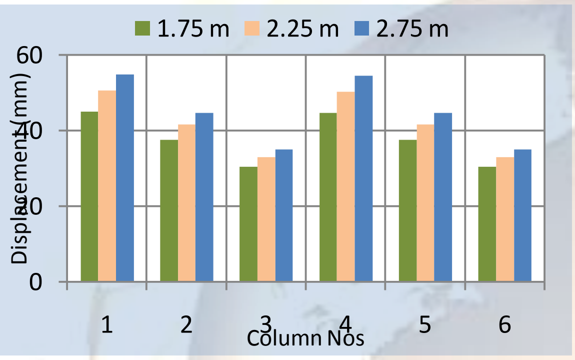


Fig. 5.9 Shear forces in columns for different location of impact”

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 corner column. So we conclude that, for whole structural behavior critical impacting location is 0.5 m above the tsunami water level.



“**Fig. 5.10** Bending moments in columns for different location of impact”

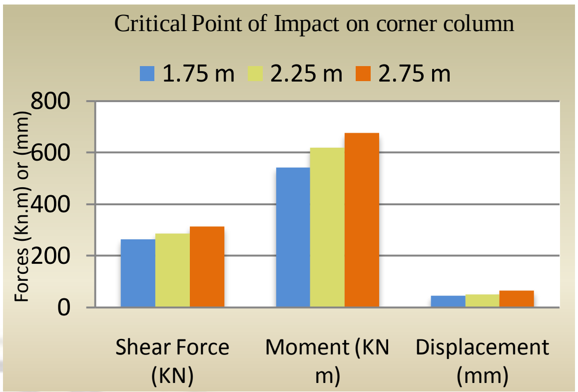


“**Fig. 5.11** Displacements in column for different location of impact”

5.3 Increase in forces when impact is at 0.5 m above water level

We studied the impact location 0.5 m above the tsunami water level on corner column is more critical. This location (2.75 m) acquires more forces not only in corner column but also on other columns of a building. Here we found the percentage increase of forces in column no 4 (Behind the corner column of a building) against impact on corner column at 2.75 m over other two locations of impact (1.75 m and 2.25 m).

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 5.12 shows the difference in the forces at column no-4, for three different impact locations on a single corner column of a building.



“**Fig. 5.12** Forces in column no-4 when impact at corner column”

6. Conclusions

Based on the observations from response of reinforced concrete structural elements to the debris impact loads through different cases the following concluding remarks have been arrived.

1) In case when impact is at first floor, the forces in ground floor column are increases with *60%* increase in axial force, *75%* increase in bending moments, *11%* increase in shear forces, but displacements increases only *1.5%*, this means both columns deforms simultaneously with same magnitude.

2) The corner columns of a building are more vulnerable to debris impact forces (Wooden log). When we compare three different columns of a building, axial forces increases by *46%*, bending moments increases by *8%*, shear forces increases by *30%* and displacements increases by *24%* in corner column over other columns.

3) 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, *12%* in both shear force and displacements over other two locations of impact, (at water level and 0.5 m below water level)

4) 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.

5) Small to medium height reinforced concrete frame buildings, with considerably small sizes of structural elements may result in failure of column due to impact forces (negative nature forces are developed)

6) Corner columns may be designed strong enough to withstand earthquake as well as tsunami forces.

References

[1] Saatcioglu M., Ghobarah A. and Nistor I., "Effects of the December 26, 2004 Sumatra Earthquake and Tsunami on Physical Infrastructure", *ISET Journal of Earthquake Technology, Paper No. 457, Vol. 42, No. 4,* December 2005, pp. 79-94.

[2] Anandan. C and Sasidhar. P, "Assessment of the impact of the tsunami of december 26, 2004 on the Near-shore bathymetry of the kalpakkam coast, east coast of India", *Science of Tsunami Hazards,* Vol. 27, No. 4, 2008, pp 26-35.

[3] Nakano. Y, "Design load evaluation for tsunami shelters based on damage observations after Indian ocean tsunami disaster due to the 2004 Sumatra earthquake", *Science of Tsunami Hazards,* Vol. 29, No. 1, 2010, pp 11-20.

[4] Jaiswal R. K., Rastogi B. K and Murty T. S., "Tsunamigenic Sources in the Indian Ocean", *Science of Tsunami Hazards,* Vol. 27, No. 2, 2008, pages 32-42.

[5] Lukkunaprasit P., Ruangrassamee A. And Thanasisathit N., "Tsunami loading on buildings with openings", *Science of Tsunami Hazards,* Vol. 28, No. 5, 2009, page 303-310

[6] Maheshwari B. K., Sharma M. L. and Narayan J. P., "Structural Damages on the Coast of Tamil Nadu due to Tsunami Caused by December 26, 2004 Sumatra Earthquake", *ISET Journal of Earthquake Technology,* Paper No. 456, Vol. 42, No. 2-3, June-September 2005, pp. 63-78.

[7] Apotsos A., Jaffe B. and Gelfenbaum G, "Wave characteristic and morphologic effects on the onshore hydrodynamic response of tsunamis", *Coastal Engineering,* Vol.58, 2011, pp 1034–1048.

[8] Cuomo G., Shams G., Jonkman S. and Gelder P., "Hydrodynamic loading of buildings in flood", *Journal of Coastal engineering*, 2008.

[9] Ghobaraha A., Saatcioglub M. and Nistor I., "The impact of the 26 December 2004 earthquake and tsunami on structures and infrastructures", *Engineering Structures*, Vol. 28, 2006, pages 312–326.

[10] Huang Z., Li Y. and Liu Y., "Hydraulic performance and wave loadings of perforated/slotted coastal structures: A review", *Ocean Engineering*, Vol. 38, 2011, pp 1031–1053.

[11] Government of India, "Preliminary Assessment of Impact of Tsunami in Selected Coastal Areas of India", *Department of Ocean Development Integrated Coastal and Marine Area Management Project Directorate,* 2005, Chennai.

[12] Bryant E., "*Tsunami: the underrated hazard*" 2nd, Praxis publishing Ltd Chichester, UK.2001

[13] Cummins P. R. et.al, "*Tsunami Science four years after the 2004 Indian Ocean Tsunami"* (2008), Bibliotheca verlAG publications.

[14] Murthy T, "*The Indian Ocean Tsunami*" 1st, *Taylor and Francis publications*, 2006

[15] Nouri Y., "The impact of hydraulic bores and debris on free standing structures", *Thesis submitted to University of Ottawa, Canada.* 2008

[16] Guidelines - Federal Emergency Management Agency, FEMA P646

[17] Handbook of Coastal and Ocean Engineering.