PROGRESSIVE COLLAPSE ANALYSIS OF RC FRAME WITH SHEARWALL STRUCTURE SUBJECTED TO TSUNAMI HAZARD

[1]Aqib Parmar,[2]Dr K.B.Parikh,[3]Dr Y.K.Tandel

[1]P.G Student,[2]Associate Professor,[3]Assistant Professor
[1]Applied Mechanics Department,
[1]Government Engineering College, Dahod,India

Abstract: Tsunamis are the deadliest event which causes huge devastation to life as well as property. The catastrophic Tsunami of 26th December 2004 reveals the importance of a structure which can act as vertical evacuation structure or a structure which can effectively resist the disastrous effect of Tsunami. As progressive collapse is rare event and it needs an abnormal loading to initiate the local damage, the effect due to Tsunami can be one of the prime cause which can initiate progressive collapse of building. In this paper Tsunami forces are evaluated with the help of FEMA P-646 and are applied on the 14 storiedshearwall building. The critical column members are removed from the ground storey and progressive collapse analysis is performed according to GSA-2013.

***IndexTerms* - Progressive Collapse, RC Frame with Shear wall, Nonlinear Static Analysis, Tsunami Forces**

I. INTRODUCTION

Tsunami is characterised by shallow open ocean wave which is generated by sudden change in the ocean geography like vertical or horizontal movement of seabed which causes waterbed to rise above normal sea level and when it propagates to coast it causes widespread destruction. Normally Tsunamis are caused by the earthquake but it can also occur due to volcanic eruptions, underwater landslides, or meteor impact. The vertical deformation of underlying seabed causes the water lying on the surface of seabed to gain potential energy. This potential energy gained by the waterbed will be converted into kinetic energy with the help of gravitational force. With this kinetic energy it can travel upto 100s of kilometre with high speed. The Tsunami can have wavelength which exceed 200 Km in the deep ocean. In deep ocean the height of the Tsunami seldom exceeds 0.5 m and this causes it to be unnoticed by the onboard people on ship. The typical depth of ocean can be upto 8 to 10 km and according to the equation of wave speed i.e, $v = (gh)^{1/2}$ with the above typical depth of the ocean Tsunami can travel upto 280 m/s to 313 m/s. As it approaches the shallow water it speeds drastically reduces. Speed on the coast reduces drastically due to shallow depth of water and it travels at 10 – 20 m/s. As it approaches the coast its height increases due to a phenomenon known as shoaling. Along with water Tsunami comes with large amount of debris and other floating objects which can cause detrimental effect on structure. The structure which is designed for the lateral forces may be prominent to failure or can collapse due to the worst damaging effect due to Tsunami. The damage can be either due to progressive collapse of the structure.

Progressive collapse can be inferred as a type of chain reaction in which the failure of vertical load bearing element could cause partial or total collapse of the structure. The removal of one or more vertical load bearing element can initiate progressive collapse of the structure. Once the vertical load bearing element is removed then the building's weight or unbalanced gravity load will be transferred to the neighboring beam element or column element. If the element has enough capacity to transfer the unbalanced gravity load then the structure can resist the progressive collapse. But if it is not then structure will be prone to progressive collapse in terms of partial collapse or total collapse of structure. The members will fail until the additional load has not been stabilized. There are three approaches to resist the progressive collapse of structure. Tie Force method, Local Resistance method and Alternate Load Path method. The Tie Force method is classified under Indirect Design method and Local Resistance method and Alternate Load Path method is classified under direct design method. GSA-2016 suggests only Alternate Load Path method whereas UFC 4-023-03 (DoD 2016) suggests Tie Force method, Load Resistance method and Alternate Load Path method. Amongst the three method listed Alternate Load Path method is the most preferable method for the design of progressive collapse resistance. The concept behind this method is that the structure should be able to tolerate the local damage and structure should be able to reach the equilibrium state after the removal of load carrying element. There are three methods to analyse a structure i.e, Linearstatic method, Nonlinearstatic method and Nonlinear dynamic method. In this paper 14 storied structure is subjected to Tsunami forces for the runup measured during the 26th December 2004. The Tsunami forces are calculated according to runup measured i.e, 12m, 9m and 6m with the help of FEMA P-646. The load bearing columns as well as shearwall are removed form the first storeyof the structure. Nonlinearstatic method is employed for the progressive collapse analysis of the structure with the help of software ETABs 16.2.1.

II. DESCRIPTION OF STRUCTURAL SYSTEM

2.1Modelling of RC Building

The building modeled is 14 storied RC frame building with shear wall and designed it as SMRF building. The building considered is having 4 bay of 6.5m each and 3 bay of 6m each. The floor to floor height is taken as 3.1m. The dimension of beam is 500mm x 500mm and the column have a dimension of 700mm x 700mm. Shear wall of 300mm thickness is centrally located at the exterior frame in the direction of 6m bay. The thickness of roof and floor slab is 200mm. The structural configuration of column and shearwall are same throughout the building. The dimensions of beam and slab are same for the entire structure. The columns and shearwall is assumed to be fix. The grade of concrete used is M20 and grade of steel used is Fe 415. The typical plan of the structure with shearwall is shown in Figure 1.

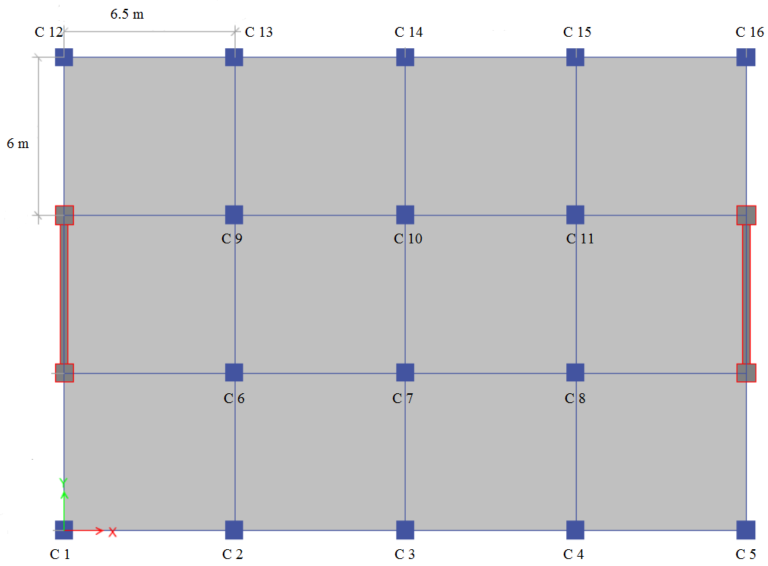


Fig.1 Typical Plan of the Building

2.2 Modeling of Shear wall

300mm thick shear wall is modelled as shell element. The layered option available in ETABs 16.2.1 is used to model the shearwall as multilayer shell element. To represent the nonlinear multilayer shell model for the concrete Mander Stress-Strain relation is adopted with compressive strain at maximum stress is 0.002. For the steel rebar material strain at strain hardening is taken as 0.01 and ultimate strain capacity is taken as 0.09. There are two different layers of reinforcement used in each direction i.e, longitudinal direction and transverse direction of shear wall. Two layers of reinforcement are used to account for upper and lower reinforcement in the crossection.

III. TSUNAMI FORCES

Tsunami is considered as series of waves which has the capability to create the several loading conditions on coastal structure. The different loading conditions are in the form of forces like Lateral Hydrostatic Force, Buoyant Force, Hydrodynamic Force, Impact Force, Additional Load Due to Water Retained on the Floor, Impulsive force, Debris Damming Force.

- Lateral Hydrostatic Force - Lateral hydrostatic forces occur when standing or slowly moving water encounters a building or building component causing a lateral force on its surface.
- Buoyant Force - The buoyant force or vertical hydrostatic forces on a structure subjected to partial or total submergence will act vertically.
- Hydrodynamic Force - This is usually a lateral force caused by the impact of the moving mass of water and the drag forces as the water flows around the obstruction.
- Impact Force - Impact forces are a result from debris such as wood, small boats, automobiles, etc., or any object transported by floodwaters that strikes against a building or its component.
- Additional load due to water retained on the floor –In addition to gravity load, water retained on the floor during drawdown causes additional load on the floor.
- Impulsive Force –Impulsive forces are caused when a leading edge of a surge of water impacts a structure.
- Debris Damming Force –The debris when collected in front of structure either on the entire length of the structure cause damming effect due to debris.

IV. PROGRESSIVE COLLAPSE

To evaluate the progressive collapse of 14 storied symmetrical reinforced concrete building using Nonlinear static analysis for the different column removal case is carried out.According to the GSA-2016 guidelines the external columns are removed near the middle of the short side, near the middle of the long side and at the corner of the building. The shear wall is also removed from the structure. The columns and shear wall are removed from the ground storey of the structure. To account for the nonlinearity in the structure PMM hinges are defined in the column at their both the ends and M3 hinges are defined in the beam at both the ends and at the middle of the beam member. The nonlinear static analysis is carried out with the help of Nonlinear stage construction option available in ETABs 16.2.1 to automate the removal of column and shear wall.

V. ANALYSIS RESULTS

5.1 Tsunami

The Tsunami forces are found out with the help of FEMA P-646 and are applied on the structure as described in the FEMA P-646 guidelines. The forces are found out when Tsunami is acting in 6m bay direction of the structure and when Tsunami is acting in 6.5m bay direction of the structure. The Tsunami forces whenapplied on 6m bay is termed as Tsunami Loading Scenario 1 and the forces applied on 6.5m bay is termed as Tsunami Loading Scenario 2.

5.1.1Tsunami Loading Scenario 1

The Tsunami forces are found for the 6m bay of the structure and is applied as per the guidelines provided in FEMA P-646. The evaluated Tsunami forces are tabulated as follow:

Table1FEMA P-646 Forces for 6m Bay

S No.	Forces for 6m bay	12 m Runup	9m Runup	6m Runup
1	Lateral Hydrostatic Force	2217.9 KN	1435 KN	652.3 KN
2	Buoyant Force	2.16 KN/m^2	27 KN/m^2	18.3 KN/m^2
3	Hydrodynamic Forces	Column- 12.24KN/m Shearwall- 17.5 KN/m^2	Column- 8.6 KN/m Shearwall-12.2 KN/m^2	Column- 4.9 KN/m Shearwall- 7 KN/m^2
4	Impact Forces	Wood- 598 KN Container- 7435.2 KN Vehicle- 26.7 KN	Wood-453.1 KN Container-4378.6 KN Vehicle- 26.7 KN	Wood- 224.6 KN Container- 1262 KN Vehicle- 26.7 KN
5	Additional Retained Water Loading on Elevated Floors	2.16 KN/m^2	27 KN/m^2	18.3 KN/m^2
6	Impulsive Force	Column- 27.5 KN/m Shear wall- 26.2 KN/m^2	Column- 19.2 KN/m Shear wall- 18.3 KN/m^2	Column- 11 KN/m Shear wall- 10.4 KN/m^2
7	Damming Effect of Water borne Debris	Column- 12.2 KN/m Shear wall- 17.5 KN/m^2	Column- 8.6 KN/m Shear wall- 12.2KN/m^2	Column- 4.9 KN/m Shearwall-7 KN/m^2

5.1.2Tsunami Loading Scenario 2

The Tsunami forces are found for the 6.5m bay of the structure and is applied as per the guidelines provided in FEMA P-646. The evaluated Tsunami forces are tabulated as follow:

Table2 FEMA P-646 Forces for 6.5m Bay

S No.	Forces for 6.5m bay	12 m Runup	9m Runup	6m Runup
1	Lateral Hydrostatic Force	2403 KN	1555 KN	706.7 KN
2	Buoyant Force	2.16 KN/m^2	27 KN/m^2	18.3 KN/m^2
3	Hydrodynamic Force	Column- 12.24KN/m Shear wall- 17.5 KN/m^2	Column- 8.6 KN/m Shearwall-12.2 KN/m^2	Column- 4.9 KN/m Shear wall- 7 KN/m^2
4	Impact Force	Wood- 598 KN Container- 7435.2 KN Vehicle- 26.7 KN	Wood-453.1 KN Container-4378.6 KN Vehicle- 26.7 KN	Wood- 224.6 KN Container- 1262 KN Vehicle- 26.7 KN
5	Additional Retained Water Loading on Elevated Floor	2.16 KN/m^2	27 KN/m^2	18.3 KN/m^2
6	Impulsive Force	Column- 27.5 KN/m Shearwall- 26.2 KN/m^2	Column- 19.2 KN/m Shearwall- 18.3 KN/m^2	Column- 11 KN/m Shearwall- 10.4 KN/m^2
7	Damming Effect of Water borne Debris	Column- 12.2 KN/m Shearwall- 17.5 KN/m^2	Column- 8.6 KN/m Shearwall- 12.2KN/m^2	Column- 4.9 KN/m Shearwall-7 KN/m^2

5.1.3Baseshear Due to Earthquake and Tsunami Forces

The base shear due to earthquake and Tsunami forces areevaluated for the two Tsunami loading scenario and are plotted as shown below.

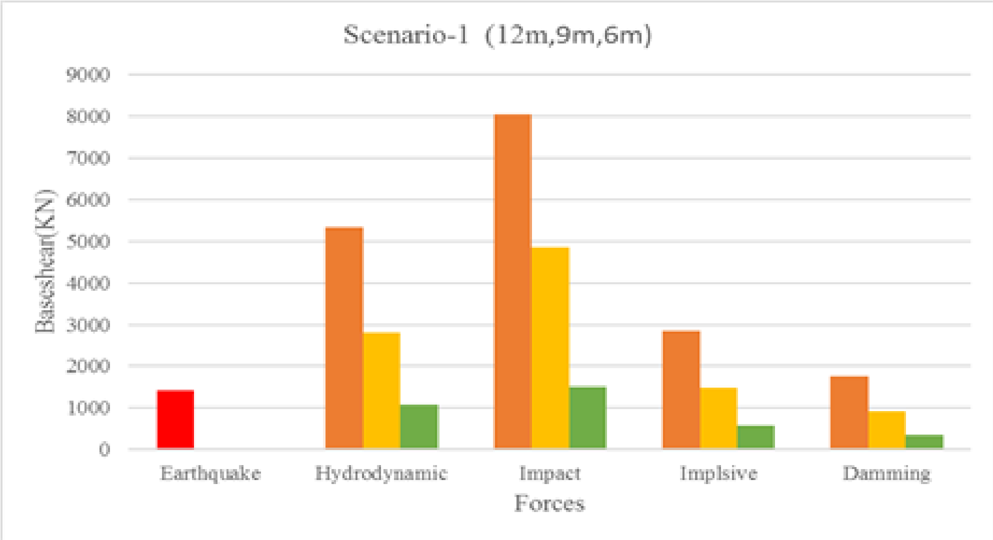


Fig 2Baseshear for Earthquake and Tsunami Forces – Scenario 1

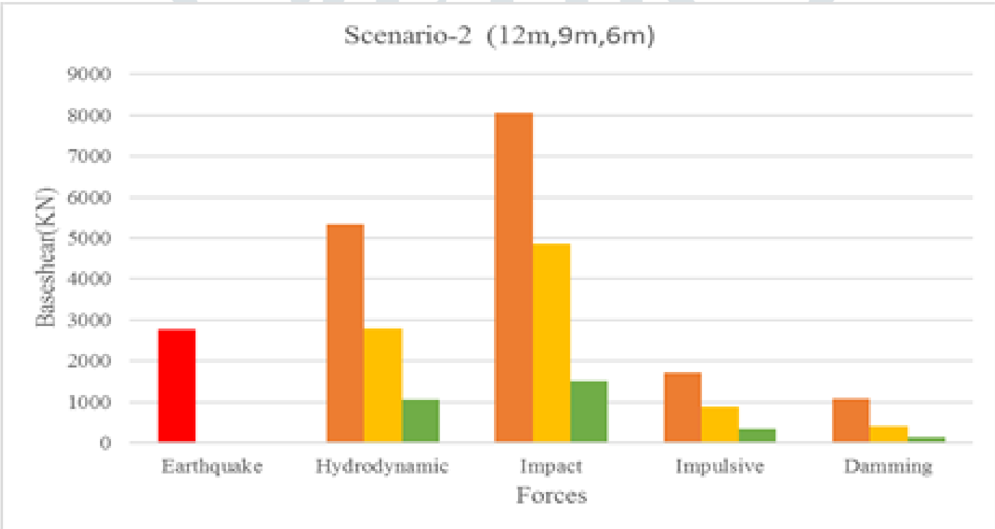


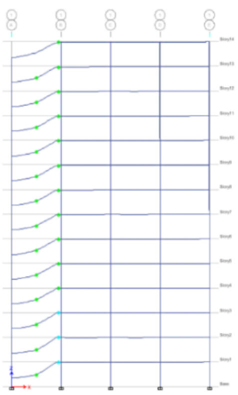
Fig 3 Base shear for Earthquake and Tsunami Forces – Scenario 2

5.2 Progressive Collapse

The progressive collapse analysis is carried out by removing the critical columns and shear wall as per the GSA-2016 guidelines. The columns C1, C3, C5 and Shear wall are removed from the structure.

5.2.1 Column Removal Case - C1

The hinge status of column removal case for C1 is as shown in Figure 4.



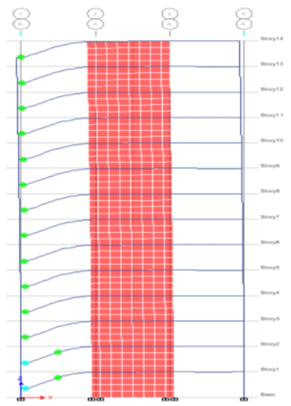


Fig4 Hinge pattern for Column - 1 Removal

5.2.2 Column Removal Case – C3

The hinge status of column removal case for C3 is as shown in Figure 5.

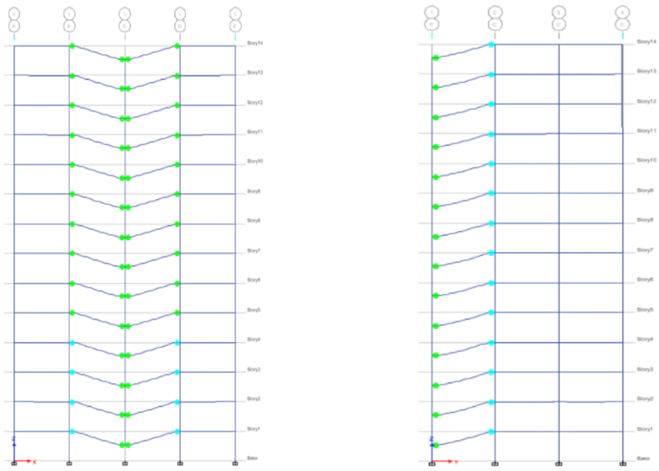


Fig 5 Hinge pattern for Column - 3 Removal

5.2.3 Column Removal Case – C5

The hinge status of column removal case for C5 is as shown in Figure 6.

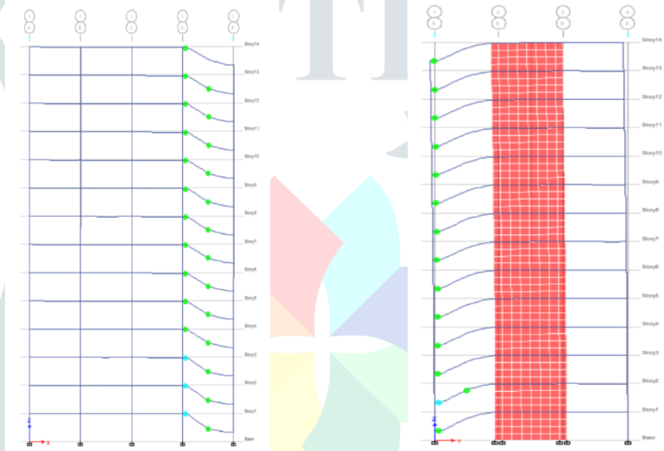


Fig 6 Hinge pattern for Column - 5 Removal

5.2.4Shearwall Removal Case

The hinge status for shear wall removal case for is as shown in Figure 7.

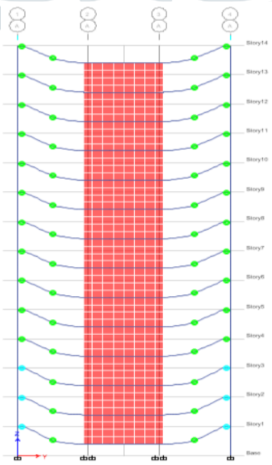


Fig 7 Hinge pattern for Shear wall Removal

VI. CONCLUSION

In this study a 14 storied RC frame shear wall building is subjected to Tsunami forces and is checked forprogressive collapse resistance. The Tsunami forces are calculated for the different runup of 12m, 9m and 6m as recorded at Tamilnadu coast during the 26th December 2004 Tsunami. The forces are calculated in different direction i.e, forces are calculated when Tsunami strikes the face of building with 6m bay and 6.5m bay. The forces are calculated and are applied on the structure according to the FEMA P-646 guidelines. The progressive collapse is carried out by removing the external vertical members' i.e, Column (C1, C3 and C5) and external shear wall is also removed with the help GSA-2016 guidelines. Nonlinearstatic analysis is used to carry out the progressive collapse analysis.

- From the results of base shear it is seen that base shear due to Tsunami force exceeds the base shear due to earthquake hence structural members designed for earthquake force may or may not be adequate to resist the Tsunami force.
- The maximum Tsunami base shear comes out to be 18011.38 KN for the 12m runup for the loading scenario 1 and for the loading scenario 2 the maximum Tsunami base shear comes out to be 16186.22 KN for 12m runup.
- From the nonlinearstatic analysis results the hinges which are formed are within the acceptance limit as specified by ASCE 41-13.
- The GSA-2106 specifies the acceptance limit as Collapse Prevention or when the plastic rotation exceeds by 0.05 radian the member is said to be failed and member is to be redesigned. Most of the hinges formed are within the Immediate Occupancy (IO) and Collapse Prevention (CP).
- None of the hinge has exceeded the acceptance criteria of plastic rotation of 0.05 radian and hence structure can effectively resist the progressive collapse due to column and shear wall removal case.

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