IMPACT OF FLOOD ON BUILDINGS

A PROJECT

Submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

In

(Structural Engineering)

Submitted
By

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Under The Supervision

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CERTIFICATE

This is to certify that the work which is being presented in the project title **"Impact of Floods on Buildings"** in partial fulfillment of the requirements for the award of the degree of Master of Technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Sandeep Lamba during a period from August 2014 to May 2015 under the supervision of **Mr. Chandra Pal Gautam** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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DECLARATION

I hereby declare that the research work presented in this Project entitled ***"Impact of flood on buildings"*** submitted for the award of the degree of Master of technology in the Department of Civil Engineering, Jaypee University of Information and Technology Waknaghat, is original and my own account of research. This research work is independent and its main content work has not previously been submitted for degree at any university in India or Abroad.

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ACKNOWLEDGEMENT

I wish to express my sincere gratitude to **Mr. Chandra Pal Gautam,** for his excellent guidance and perennial encouragement and support during the course of my work in the last one year. I truly appreciate and value his profound knowledge, esteemed supervision and encouragement from the beginning to the end of this thesis.

My special thanks are due to **Prof. Ashok Kumar Gupta,** Head of the Civil Engineering Department, for all the facilities provided to successfully complete this work.

I am also very thankful to all the faculty members of the department, especially Structural Engineering specialization for their constant encouragement during the project.

I also take the opportunity to thank all my friends who have directly or indirectly helped me in my project work and in the completion of this report.

Last but not the least I would like to thank my parents, who taught me the value of hard work by their own example. I would like to share this bite of happiness with my mother and father. They rendered me enormous support during the whole tenure of my stay at JUIT, Waknaghat.

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ABSTRACT

This project focuses on both the incorporation of flood loads during the design stage and the assessment of flood vulnerability of reinforced concrete buildings. Vulnerability is expressed as a fraction of ground floor height and assumes that flood water at most immerse the building up to ground floor level. The importance of the outcome arises from the need of a strengthening solution to avoid failure of new or existing structures during floods. To compute the critical effect, the flood was assumed to act along the 18m side and an intermediate 2D frame along 9m side was considered for the study. Three frame models were used, a) bare frame model, without any partition walls, b) frame with light weight partition wall; c) frame with structural infill wall. The infill walls were modeled as a diagonal strut having width 230mm, very low moment of inertia, modulus of elasticity 13800 N/mm2 and Poisson ratio 0.25. The weight of light weight partition walls were considered negligible. Hence, frame models for both bare frame and frame with light weight partition walls were similar but the difference will come in to the picture while applying flood load. The model is analysed in SAP 2000 Software. From the analysis it can be concluded that bare frame is less vulnerable and frame with light weight partition wall result as the most vulnerable, storey drift for the frame with structural infill walls is very low. Soft storied buildings are less vulnerable compared to ordinary buildings and this depends on the free movement of water in between the columns.

LIST OF FIGURES

LIST OF TABLES

CONTENTS

CHAPTER 1

INTRODUCTION

As Structural engineers in the field of civil engineering, we are often asked to measure residential buildings exposed to flood events. Whether the flooding is due to the storm surge from a hurricane, heavy rainfall events that result in riverine flooding, or failure of a bridge, the effects on residential buildings have many common structural concerns.

Floods are one of the most far flung and destructive natural disasters occurring in the world and with the increase in constructions along river courses and engrossment of population around floodplain areas, flood-induced damages have been endlessly increasing. Thus, floods are posing a great scouge and challenge to planers, design engineers, policy makers, and to the governments. Structural and non-structural measures can be used to handle floods. Structural measures include a set of works aiming to reduce one hydraulic parameters like runoff volume, peak discharge, rise in water level, duration of flood, flow velocity, etc. Nonstructural measures involve a wide range of measures to reduce flood risk through flood forecasting and early warning systems and posing land use regulations and policies. The futuristic buildings can be considered as a symbol of modern civilization. Buildings are usually constructed based on the guidelines given by the standard code books (like IS: 456:2000, for India).

Unfortunately, the code consider the seismic loads and wind effects alone, while accounting the dead and live design loads, and exclude the flood loads. This implies the necessity to bring out corrective measures that can be adopted to reduce vulnerability before damages occurrences.

This study focuses on both the incorporation of flood loads during the design stage and the assessment of flood vulnerability of reinforced concrete buildings. Vulnerability is expressed as a fraction of ground floor height and flood water at most immerses the building up to ground floor level. The importance of the outcome arises from the need of a strengthening solution to avoid failure of new or existing structures during floods.

1.1 How does floodwater enter a building?

Floodwater will always follow a path of least resistance and will enter a building at the weakest points in the construction, particularly through masonry and construction joints, and any voids and gaps.

The following summarizes the main entry points. Current building regulations and traditional construction do not require the use of materials and design details that can withstand long-term immersion in flood water.

Water could enter via:

- Brickwork and Block work
- Party walls of terraced or semi-detached buildings if the attached building is flooded
- Expansion joints between walls where different construction materials meet or between the floor slab and wall
- Suspended timber ground floors via the interface between timber and mortar for built-in joists or along the interface between timber and metal plate where a joist hanger is used.
- Water will be absorbed through the exposed end grain of a built-in timber joist.

Specific features encourage air flow and therefore may provide a pathway for water.

Routes include:

- Vents, airbricks
- Inadequate seals between windows, doors and frames
- Door thresholds
- Cracks and openings due to settlement, poor construction, and services all provide

Water entry routes, such as:

- Cracks in external walls
- Flaws in wall construction

- Cracks and gaps at the interface between brick, stone and block units and their bedding mortar due to inadequate bonding. These can be as a result of movement caused by thermal expansion/contraction, moisture or settlement
- Damp proof course (d.p.c.), where the lap between the wall damp proof course and floor membrane is inadequate
- Services entries e.g. utility pipes, ventilation ducts, electricity and telephone cables
- Gaps in mortar in masonry, stonework and block work walls, usually at perpends. Other entry routes include:
- Seepage from below ground through floors and basements
- Sanitary appliances from backflow from surcharged drainage systems

1.2. Forces due to flood

The physical forces which act on the buildings include hydrostatic loads (Fig.1.), hydrodynamic loads (Fig.2.), and impact loads, and these loads can be aggravated by the effects of water scouring soil from around and below the foundation (FEMA, 2001).

The *hydrostatic loads* are both lateral (pressures) and vertical (buoyant) in nature. The lateral forces result from differences in interior and exterior water surface elevations. As the floodwaters rise, the higher water on the exterior of the building acts inward against the walls of the building. Sufficient lateral pressures may cause permanent deflections and damage to structural elements within the building. The buoyant forces are the vertical uplift of the structure due to the displacement of water, just as a boat displaces water causing it to float. These uplift forces may be the result of the actual building materials, or due to air on the interior of a tightly built structure. When the buoyant forces connected with the flood exceed the weight of the building components and the connections to the foundation system, the structure may drift from its foundation. The water flowing around the building during a flood creates *hydrodynamic loads* on the structure. These loads are the frontal impact loads from the upstream flow, the drag on the sides of the building, and the suction on the back face of the building as the floodwaters flow around the structure. The magnitude of the hydrodynamic loads depends on both the velocity of water and the shape of the structure. Like the hydrostatic pressures, these lateral pressures may cause the collapsing of either walls or floors.

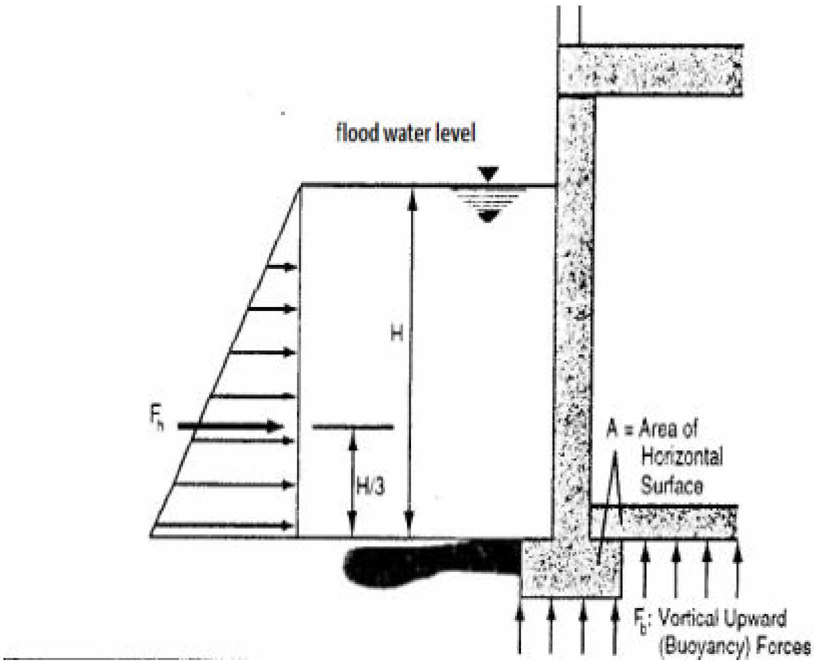


Figure 1 Schematic sketch of hydrostatic force (FEMA, 2001)

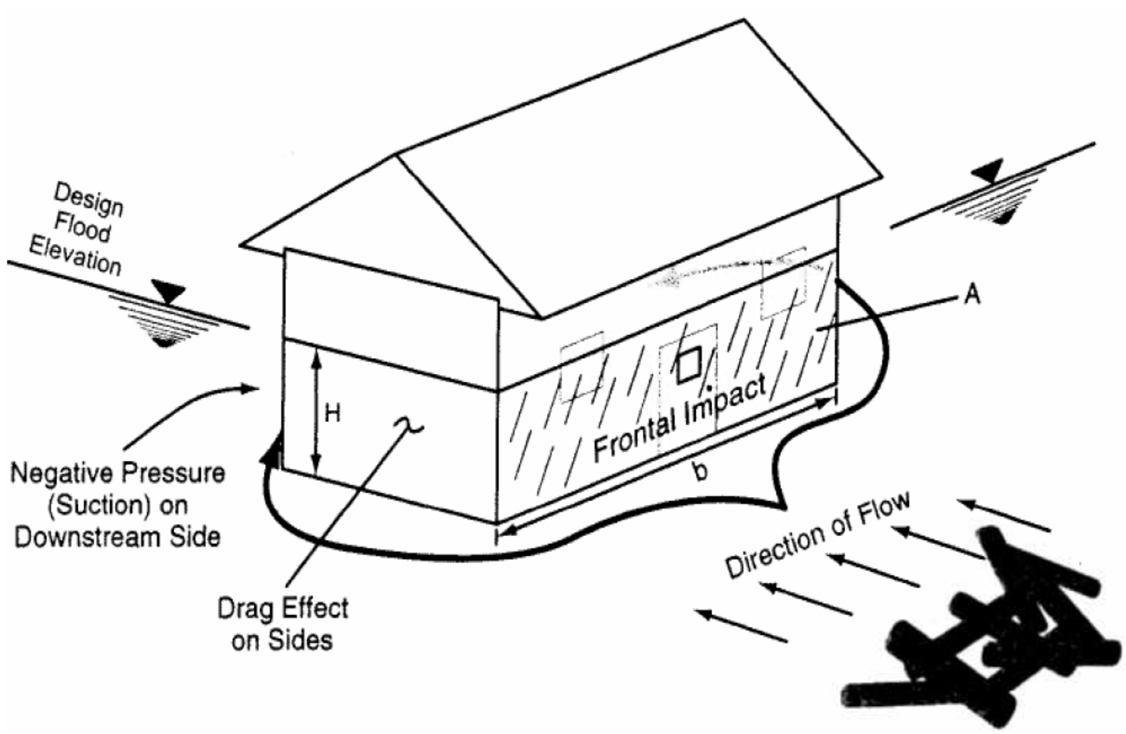


Figure 2 Schematic sketch of hydrodynamic force (FEMA, 2001)

Impact loads during floods may be the direct forces associated with waves, as typically encountered during coastal flooding, or the impact of debris floating in the waters, including logs, building components, and even vehicles. Impact loads can be destructive because the forces associated with them may be an order of magnitude higher than the hydrostatic and hydrodynamic. Floating debris can have devastating effects, as they apply large and/or concentrated loads to the structural elements of the building.

1.3. Flood Actions on Residences

This study’s mandate is to investigate flood characteristics not previously examined in detail in order to contribute new knowledge and techniques. Such characteristics include forces, pressures, chemical reactions, and other impacts which a flood could impose on a residence. Collectively, they are termed “actions” for this study and refer to something to which a structure responds. Flood actions describe acts which a flood could do to a residence, potentially causing damage and failure. Full analysis of flood actions will permit losses from potential flood events to be calculated more comprehensively. This Chapter defines and quantifies flood actions on residences and suggests a hierarchy for selecting those actions which should be examined in more detail.

1.4 Overview of Flood Actions

1.4.1. Introduction

This Section provides an overview of qualitative and quantitative characteristics of flood actions. The material is illustrative, not comprehensive.

1.4.2 Hydrostatic Actions

Two forms of hydrostatic action exist: lateral pressure and capillary rise.

$\Delta P = \rho_{wg(fdiff - y)} = \Delta P$hydrostatic at y=0 – ρ_{wgy} for b $\leqslant_{diff}$ y $\leqslant$ f

$\Delta P = 0$ for $y > f_{diff}$

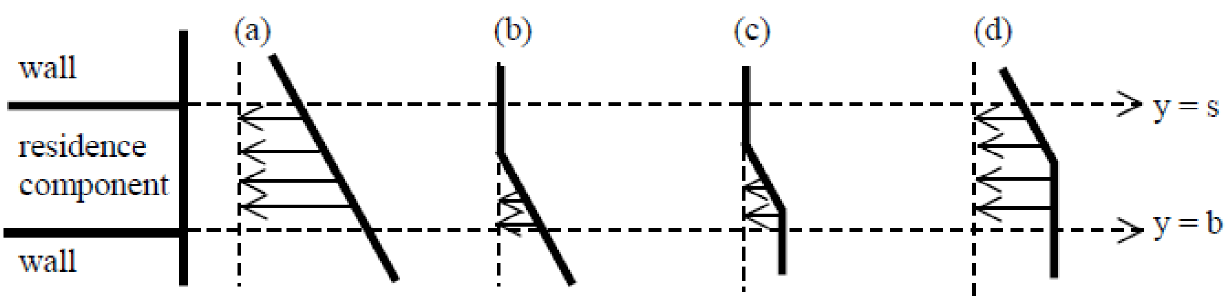


Figure 3 Pressure Distributions on Residence Component in Each Situation

Depending on the specific flood situation and residence component being considered, this basic equation has four variations (Figure 3):

(a) Water covers the entire residence component on one side yielding a linear pressure over the entire residence component.

(b) Water rises partway up the residence component on one side.

(c) Water rises partway up the residence component on both sides, but to different y values each side.

(d) Water entirely covers the residence component on one side and rises partway up the other side.

Whether the water level is greater on the outside or inside, the same ΔP is imparted to the residence component—which may be the wall itself. If ΔP were from the inside and were relatively small, a strong wind could conceivably prevent failure by balancing the pressure. Localized wind pressure is highly variable meaning that in most such cases, the residence component would fail at some point anyway.

Capillary rise inside a residence's components which water has contacted would cause damage at a height above f or that reached by waves. Hoffmann and Niesel (1995) write "capillary effects occur in pores between about 0.1 and 100m diameter" and they indicate that the pore sizes of masonry units and render fall within that range. They note that "accessible pore volume and portion of capillary-active pore sizes" are important parameters to consider in determining height of capillary rise through a material. For a brickwork wall, Hoffmann and Niesel (1995) provide a series of equations requiring several empirical parameters for calculating maximum rise height, but no such calculations are carried out. Huelman and Corrin (1997) suggest 0.45 m as an approximate upper limit for capillary rise following a flood, depending on the residence's materials.

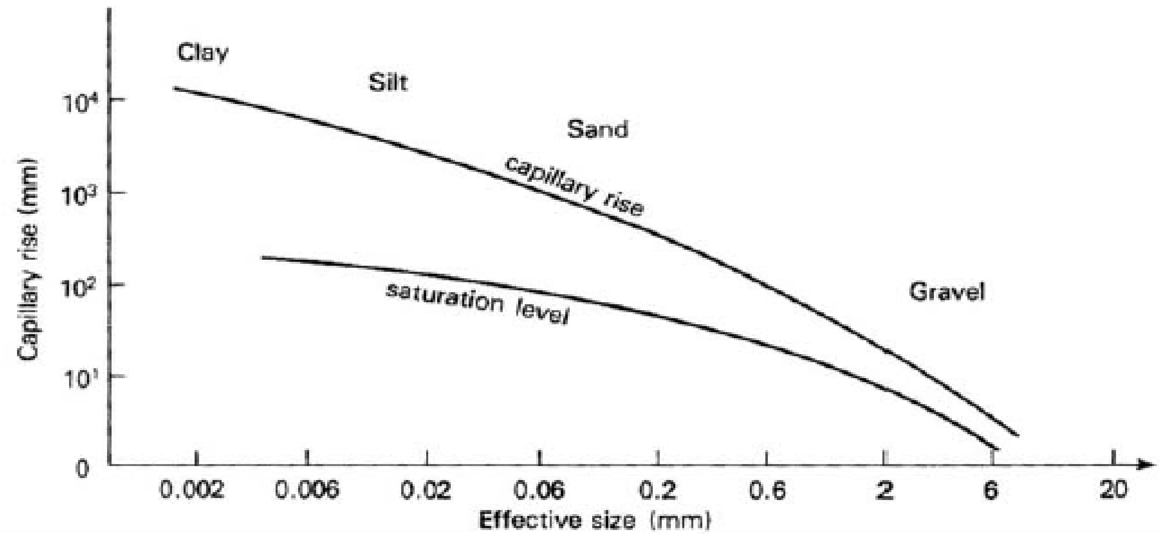


Figure 4: Capillary Rise in Soil (modified from Whitlow, 1983)

Capillary rise may also occur in soil, above the water table. Residences which encounter capillary water may absorb it resulting in damage. As illustrated in Figure 4 modified from Whitlow (1983), soil saturated with capillary water may occur up to 0.5 m above the water table. Partial saturation with capillary water may occur more than 10 m above the water table for fine soils such as clay.

1.4.3 Hydrodynamic Actions

Five forms of hydrodynamic actions exist: three from velocity (including turbulence) and two from waves.

The lateral pressure imparted by water flowing around a residence may be taken as ΔP = ½ρv2 for a first-order approximation. This value represents the dynamic pressure due to steady flow of an in viscid, incompressible fluid with negligible heat transfer and shaft work. This pressure occurs at the stagnation point of a fluid flowing around a bluff body, but may be used for ΔP over a residence wall or component as a first-order approximation.

Localized changes in v, and therefore ΔP, occur when water flows around corners of a residence or through gaps. v tends to increase, creating suction forces and producing higher impacts due to local v. A residence which withstands the ½ρv2 direct pressure may succumb to the local variations or may be affected by resulting erosion.

Turbulence is irregular fluctuations in v, in either or both the magnitude and the direction. Eddies, vortices, surface choppiness, gusts, and rapid but short-lived changes in f or f_{diff}, all Figure 4: Capillary Rise in Soil (modified from Whitlow, 1983) distinct from waves, may result. Turbulence can be highly variable over short spatial and temporal scales making quantitative prediction difficulty.

'Non-breaking waves' peaks and troughs will respectively increase and decrease the pressures and total force exerted on a residence. Peaks can add a maximum force approximately equivalent to the hydrostatic force while troughs may decrease the total force by up to 40%— beyond these limits, the wave would break (USACE, 1984). The exact change in total force depends on the ratio of wave height to water depth which is less than about 0.70 for nonbreaking waves (USACE, 1984). ΔP at any point on the residence component will obviously change in proportion to the depth of water raised or lowered by the wave's peak and trough respectively. The rate of change of forces and pressures depends on the wave's period.

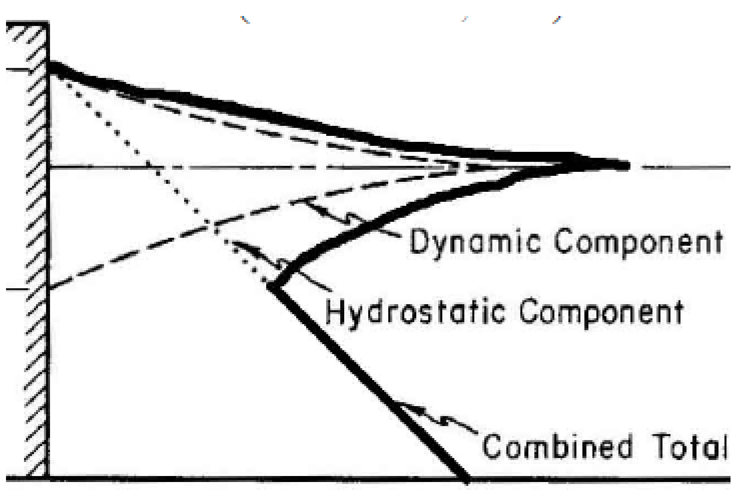


Figure 5: The Pressure Function of a Breaking Wave (From USACE, 1984)

Waves breaking in, over, through, or near a residence can impart large pressures compared to other hydrodynamic actions. Lewis (1983) records that in Chiswell in coastal, southern England, "in December 1978 and in February 1979 waves overtopped the [shingle] bank with such force that several buildings were damaged". For breaking waves, the pressure function is illustrated in Figure 5. The peak dynamic pressures of breaking waves can be "as much as 15 to 18 times those calculated for nonbreaking waves [but these values] should be used with caution and only until a more accurate method of calculation is found" (USACE, 1984). Lloyd and Harper (1984) use USACE's (1984) method to calculate ΔP generated by breaking waves for different scenarios. For f = 0.5 m, peak dynamic pressure is just under 50 kPa; for most variations at f = 2.5 m, peak dynamic pressure is above 500 kPa.

1.4.4 Erosion Actions

Moving water may cause erosion by scouring away soil from the sides or bed along which the water flows. Baker (1988), Bull (1988), Carter (1988), Hamill (2001), Komar (1988), Nelson *et al.* (2000), Rooseboom and le Grange (1994), and Whitehouse (1998) describe erosion and scour analysis. Their work is summarized in this paragraph. Two principal phenomena occur: entrainment of sediment in water and horizontal movement of the entrained sediment. The main water parameters involved in such analysis are f, v, and ρ_w, although volumetric flow rate and kinematic viscosity are considered at times. The main sediment property is an index representing grain diameter but sediment density and grain cross-sectional area may be included. Bed roughness, which changes due to erosion, is a factor too. The erosion mechanisms usually cited are lift and drag forces, but turbulence may produce instantaneous upward forces large enough to cause entrainment. Turbulence underneath waves, such as the orbital velocity, may lead to sediment entrainment and transport too.

Water seeping through soil may physically move the soil. Ubell (1995) and Whitlow (1983) describe the seepage action which occurs as water infiltrates through soil. Ubell (1995) writes "The seepage force acting on the soil particles will cause them to move if not opposed by other greater forces acting in the opposite direction". Water may destabilize soil on slopes causing landslips which would destabilize residences or damage them from direct impact.

1.4.5 Buoyancy Action

The buoyancy force is a function of the submerged volume of the object, in this case the residence. This volume equals the volume of water which the residence displaces, i.e. A×f. Thus, the buoyancy force is $\rho_w gAf$. This buoyancy force is an uplift force which could result in the residence, or parts of it, floating. Hydrodynamic actions or the hydrostatic lateral pressure may then displace the floating residence or parts, potentially causing damage, destabilisation, or complete destruction (FHRC, 1983; Black, 1975; Sangrey *et al.*, 1975). Buoyancy could also affect lighter structures such as shacks or sheds, thereby contributing to debris, along with residence components such as pipes or fuel or water storage tanks.

1.4.6 Debris Actions

Three forms of debris actions exist: static actions, dynamic actions, and erosion. Debris refers to solids in the flood, so chemical, nuclear, and biological actions may be relevant too. At times, the solids may be such a prominent part of a flood wave that the flow is no longer considered to be a water flood. Costa (1988) provides one example of a simple rheologic classification of flows (Table 1). Mainali and Rajaratnam (1991) and Newson (1989) each provide more complicated schemes focused on the higher sediment concentrations. LACOE (1997) illustrates the immense impacts which debris flows may have on residences as well as on lives and landscapes.

Flow	Sediment Concentration Flow In Entire Flow		Bulk Density (kg/m3)	Major Sediment-Support Mechanism
	by Weight	**by Volume**		
Water Flood	1%-40%	0.4%-20%	1,010-1,330	Electrostatic forces, turbulence
Hyper concentrated	40%-70%	20%-47%	1,330-1,800	Buoyancy, dispersive stress, turbulence
Debris Flow	70%-90%	47%-77%	1,800-2,300	Cohesion, buoyancy, dispersive stress, structural support

Table1: A Simple Classification Scheme for Flows (From Costa, 1988)
(Assuming silt and clay content < 10%.)

Static debris actions would occur due to sediment accumulating externally or internally to a residence. USACE (1984) writes "the forces exerted on a wall by soil backfill depend on the physical characteristics of the soil particles, the degree of soil compaction and saturation, the geometry of the soil mass, the movements of the wall caused by the action of the backfill, and the foundation deformation". In a flood, the soil backfill would be sediment deposited by the flood. USACE (1984) and Thorley (1969) provide equations for the different forces exerted in a form for which the force imposed equals 0.5ρsoilgy2Ч. y represents the height of the soil backfill or deposited sediment. Ч is determined from soil properties and scenario geometry such as the verticality of the residence component subject to the forces. USACE (1984) and Thorley (1969) provide data tables for calculating Ч.

Dynamic debris actions would occur when debris moved by water impacts a residence. The impact could be from outside, such as a cow or car. The impact could also be from inside, such as a couch or table floating and hitting the ceiling, an internal wall, or a window. Dynamic debris actions may be either forces or pressures. An example of a force, concentrated and applied with shock, is a log floating in moving water which impacts a residence. Likewise, Lewis (1999) states that during storm surges in Chiswell in southern England, “waves hurl stones and pebbles, causing their own impact damage to roofs and windows”. An example of a pressure applied over a relatively long duration is a hyper concentrated or debris flow flowing around a residence.

Debris could cause severe erosion, such as pebbles and saturated computers being dragged along with the flow and gouging out soil from the sides or bed of the flow channel.

1.4.7 Non-Physical Actions

Three forms of non-physical flood actions exist: chemical actions, nuclear actions, and biological actions. Some overlap exists between physical flood actions and non-physical flood actions.

Flood damage to residences is frequently estimated by considering only the chemical actions which occur when water contacts an object. An example of a chemical (contact) action is rusting. Physical consequences may result too, such as timber floor boards warping. Additionally, flood-induced humidity may cause damage, even if flood water does not contact the damaged residence (Crichton, 2002). The chemical (contact) action would be from water vapour rather than water.

Flood water may be contaminated with sewage, petrol, oil, paint, household cleaners, or industrial chemicals. Any corrosiveness or flammability in the contaminants could result in chemical damage to residences. A full propane tank or a vehicle’s petrol tank colliding with a residence may result in an explosion. Additionally, the vapour from flood water contaminants may cause damage even if the contaminated flood water does not contact the damaged residence.

Water is a good conductor of electricity. This chemical action in the form of energy is frequently fatal in floods and has the potential to produce electrochemical reactions which damage residences; for example, by breaking down render or paint.

Nuclear actions would be much rarer, occurring, for example, if nuclear fuel becomes a contaminant. One possibility for eastern England is the nuclear power plant sited just above the shingle beach at Sizewell, Suffolk. A highly improbable but catastrophic event during which a storm surge severely damages this structure has a small potential for imparting nuclear actions during the flood.

Biological actions include microorganisms which thrive in damp conditions, particularly moulds and fungi. Floods could also bring animals in contact with residences which normally would not be encountered, such as jellyfish. Macro vertebrates—including fish, alligators, crocodiles, sharks, and snakes—may impart significant physical forces on residences if these animals are brought by a flood into the proximity of residences.

1.4.8 Summary and Interactions

To summarize, the proposed typology for flood actions on residences is:

1. Hydrostatic actions (actions resulting from the water's presence):
   - Lateral pressure from f_{diff}.
   - Capillary rise.

2. Hydrodynamic actions (actions resulting from the water's motion):
   - Velocity: moving water flowing around a residence imparting a hydrodynamic pressure.
   - Velocity's localized effects, such as at corners.
   - Velocity: turbulence.
   - Waves changing hydrostatic pressure.
   - Waves breaking.

3. Erosion Actions (water moving soil; the water's boundary becomes dynamic and moves into the adjacent solids).

4. Buoyancy action: the buoyancy force.

5. Debris actions (actions from solids in the water):
   - Static actions.
   - Dynamic actions.
   - Erosion actions.

6. Non-physical actions.
   - Chemical actions (including contact).
   - Nuclear actions.
   - Biological actions.

1.4.9 Conclusions

The flood actions on residences which are most relevant and most applicable to analysis for loss prediction are the combination of lateral hydrostatic pressure and lateral hydrodynamic pressure imparted by instantaneous fdiff and instantaneous v respectively along with damage from water contact due to f. Focusing on these three actions produces a first-order analysis of the physical vulnerability of residences to floods. The uncertainties in this analysis, introduced by not directly considering other actions including waves and corrosion, may be reduced once more data and experience are available by incorporating the other actions into the analysis. Meanwhile, a significant contribution to knowledge and a clear advancement of flood damage prediction and analysis are attained by considering in detail the flood actions of fdiff, and v plus f where needed. A method for using the three principal actions to predict residence failure has been proposed involving the development of vulnerability matrices.

CHAPTER 2

Literature review

1. FEMA (2001) published a manual focusing on the retrofitting of family residences subject to flooding without wave action. The measures include elevation of the structure in place, relocation of the structure, construction of barriers, dry flood proofing and wet flood proofing. The analyses necessary to determine flood-related hazard factors are also presented. Kelman (2002), in a dissertation on Physical Flood Vulnerability of Residential Properties in Coastal Eastern England, examined the lateral pressure from flood differential depth between inside and outside a residence.

2. Kelman and Spenc (2004) categorized flood actions on buildings as energy transfers, forces, Pressures, or the consequences of water or contaminant contact.

3. Messener and Meyer (2005) argued that the challenge consists in understanding the interre- lations and social dynamics of flood risk perception, preparedness, vulnerability, flood damage and flood management, and to take this into account in a modern design of damage analysis and risk management.

4. Sagala (2006) examines the physical vulnerability to flood and people's coping mechanisms in flood prone residential areas in Naga city of Philippines. Six structural types of buildings were chosen and for each type of vulnerability curves (flood depth/damage) were plotted. Results indicate that buildings with plywood walls and wooden floors are the most vulnerable while the type with hollow block walls and concrete floors is the least vulnerable.

5. Arulselvan et al. (2007) conducted an experimental investigation on the influence of brick masonry infill in a reinforced cement concrete frame and validated outcomes by comparing them with theoretical results obtained by finite element analysis. Until the cracks developed in the infill, the contribution of infill to both stiffness and lateral

stiffness was found to be very significant. The strains measured in infilled beams and columns were 20% less than bare frame beams up to failure of brick walls.

6. Haugen and Kaynia (2008) presented a method for prediction of damage in a structure impacted by a debris flow of known magnitude. The method uses the principles of dynamic response of structures to earthquake excitation, and fragility curves proposed in HAZUS for estimation of the structural vulnerability, by the damage state probability. The model was tested on a debris flow in Italy and it gave probabilities between 34% and 66% for reaching the damage levels which actually occurred for five out of six structures.

7. Kreibich et al. (2009) investigated the importance of flow velocity, water depth and combina- tions of these two parameters on various types of damages to buildings and roads. A significant influence of flow velocity on damage to roads was found, in contrast to a minor influence on monetary losses and business interruption. The energy head is suggested as a suitable flood impact parameter for reliable forecasting of structural damage to residential buildings.

8. Lopez et al. (2010) developed a methodology to estimate flood vulnerability to buildings, in either riverine or coastal settings, based on the aggregated damage to individual building components. Building vulnerability is modelled based on analytical representations of the failure mechanisms of individual building components.

9. Geotechnical Problems of Cultural Heritage due to Floods **(**Ivo Herle1; Vladislava Herbstová2; Michael Kupka3; and Dimitrios Kolymbas4) this paper gives an overview of different phenomena which can be encountered in the ground during water flooding. Refurbishment and protection measures are introduced and accompanied by particular references. Rising groundwater during the flood is responsible for various effects which can cause additional deformations of the ground surface or landslides and thus damage valuable objects founded on the ground.

10. Procedure for Site Assessment of the Potential for Tsunami Debris Impact (Clay Naito, M.ASCE1; Christina Cercone, S.M.ASCE2; H. R. Riggs, M.ASCE3; and Daniel Cox4.) The paper work provides a framework that can be used to classify potential debris types, quantify the debris potential for a given site, and then translate the debris and debris potential to impact loads on structures. Result, The inundation depth at the point of debris origin, surrounding building height, building construction, and topography control the dispersion of debris. For debris sources surrounded by steel or concrete industrial buildings and a low relative inundation depth, the dispersal will be minimized, whereas for high inundation depths, planar topography, and frangible construction, the dispersal may be high. A method to calculate delivery potential given a debris source and inundation zone is developed. The method provides a reasonable approach to identify regions with a high likelihood of debris impact.

11. Impact of Flood on a Simple Masonry Buildings (Shiyun Xiao1 and Hongnan Li, M.ASCE2) In this paper, the impact action of a flood on rural mountain buildings is systematically studied. First, based on the one-dimensional Saint-Venant water equation explicit-difference scheme, a new explicit-difference scheme is deduced to establish the evolutionary routing model of a flood. A computational formula about the impact loading of the flood model is deduced. Secondly, an impact experiment of a flood on buildings is carried out in a large wave-current tank. The numerical results are compared with the experimental results.

1. The impact pressure increases with increasing water height both in the vertical direction and in the horizontal direction.
2. During the impact process, the mortar element becomes a failure first, and then, more mortar and brick elements become failures. Finally, the right wall is damaged, because the door and the right window decrease its stiffness.

CHAPTER 3

Methodology

The present work focuses on the assessment of flood physical vulnerability of building expressed as a factor of ground floor height. The influence of design variation zones or boundary conditions has been also investigated.

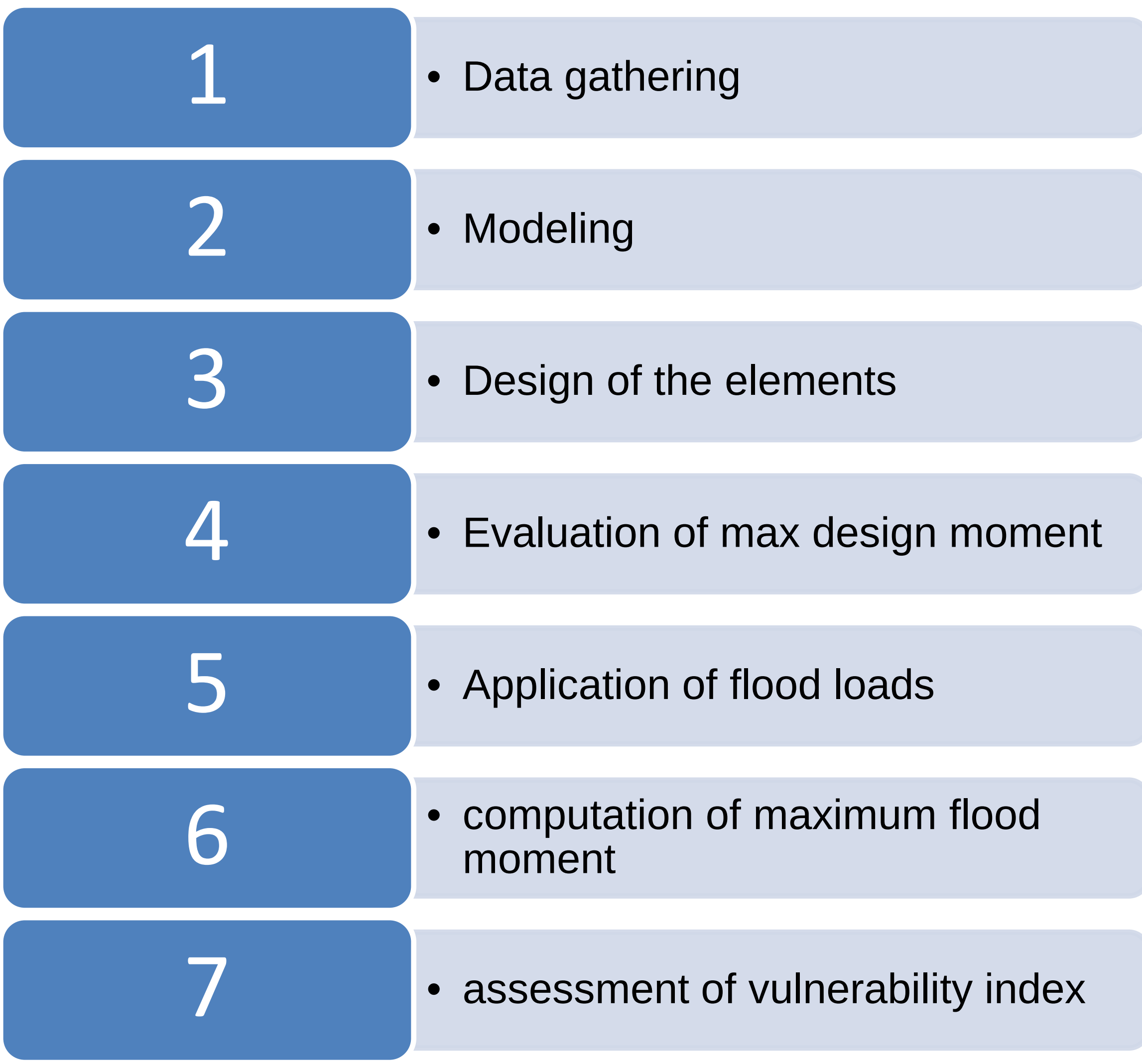
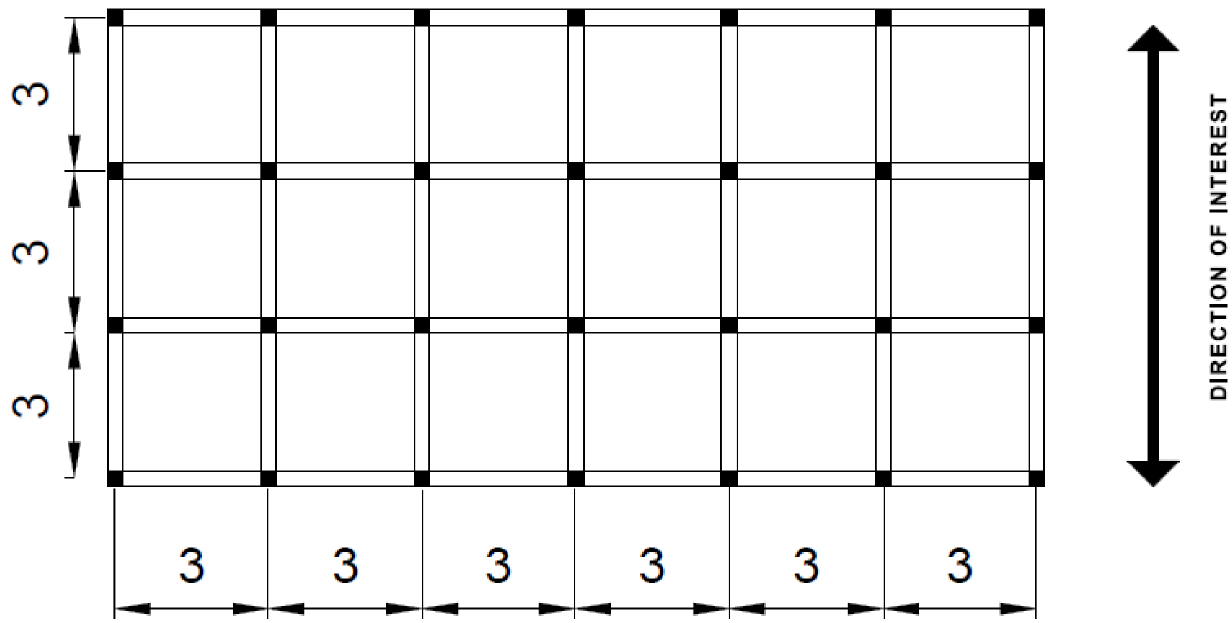


Figure 6 The steps of the methodology

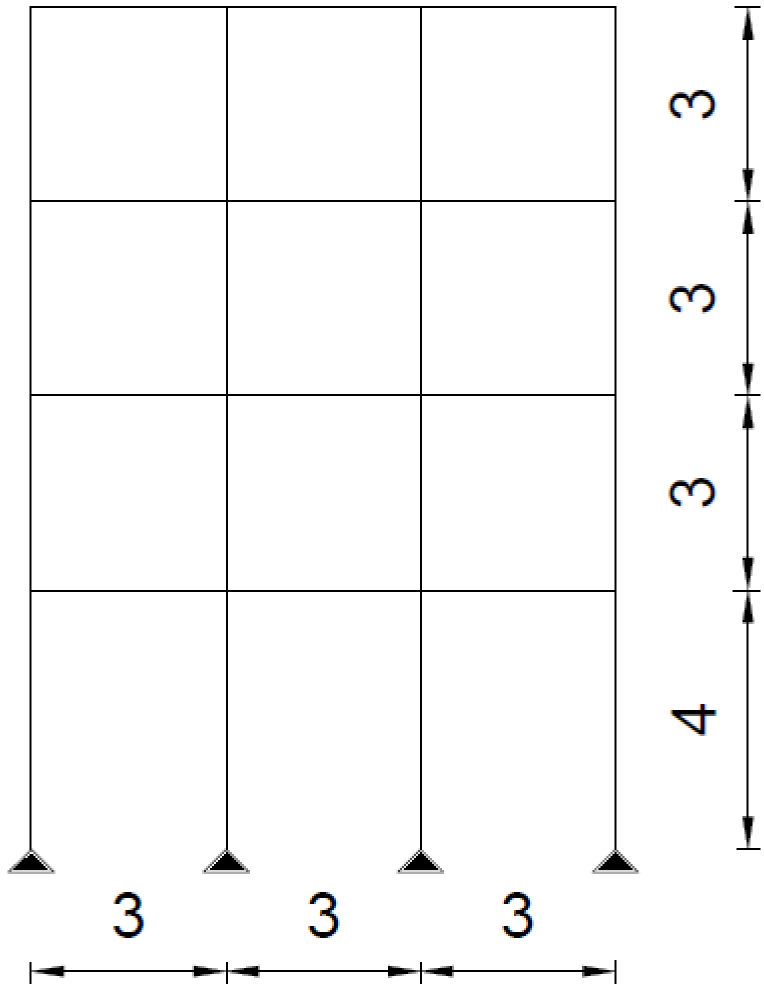
3.1. Building details

The building configuration used for the study is regular, with plan dimensions 9m×18m. Table 1 lists the data associated with a four storey reinforced concrete building considered for the analysis, while the plan and elevation of the building are shown in Fig.4. and Fig.5., respectively. In Fig.4,the direction of interest refers the perpendicular direction of flood.



Note:-all dimensions in meter.

Figure 7 Plan of considered building



Note:-all dimensions in meter.

Figure 8 Elevation of frame

Ground floor height	**4m**
Remaining floors height	**3m**
No. of bays in X direction	6
No. of bays in Y direction	3
Bay width	3m in both X and Y directions
Column size	300mmx300mm
Beam size	250mmx300mm
Masonry wall thickness	230mm
Slab thickness	120mm
Unit weight of the concrete	25 kN/m^3
Unit weight of masonry	20 kN/m^3
Elastic modulus of steel	2×108 kN/m^2
Yield strength of steel	415 N/mm^2
Young's modulus of concrete	25×106 kN/m^2
Poisson ratio of concrete	0.2
Compressive strength of concrete	20 N/mm^2
Young's modulus of masonry	13.8×106 kN/m^2
Poisson ratio of masonry	0.25
Floor finish load	0.5kN/m^2
Terrace water proofing (TWF) load	1.5kN/m^2
Live load on roof	1.5kN/m^2
Live load on floor	3kN/m^2

Table 2 Reinforced concrete building details

3.2. Modeling

To compute the critical effect, the flood was assumed to act along the 18m side and an intermediate 2D frame along 9m side was considered for the study. Three frame models were used, a) bare frame model, without any partition walls (Fig. 6.); b) frame with light weight partition wall; c) frame with structural infill wall (Fig. 7.). The infill walls were modelled as a diagonal strut having width 230mm, very low moment of inertia, modulus of elasticity 13800 N/mm2 and Poisson ratio 0.25. The weight of light weight partition walls were considered negligible. Hence, frame models for both bare frame and frame with light weight partition walls were similar but the difference will come in to the picture while applying flood load.

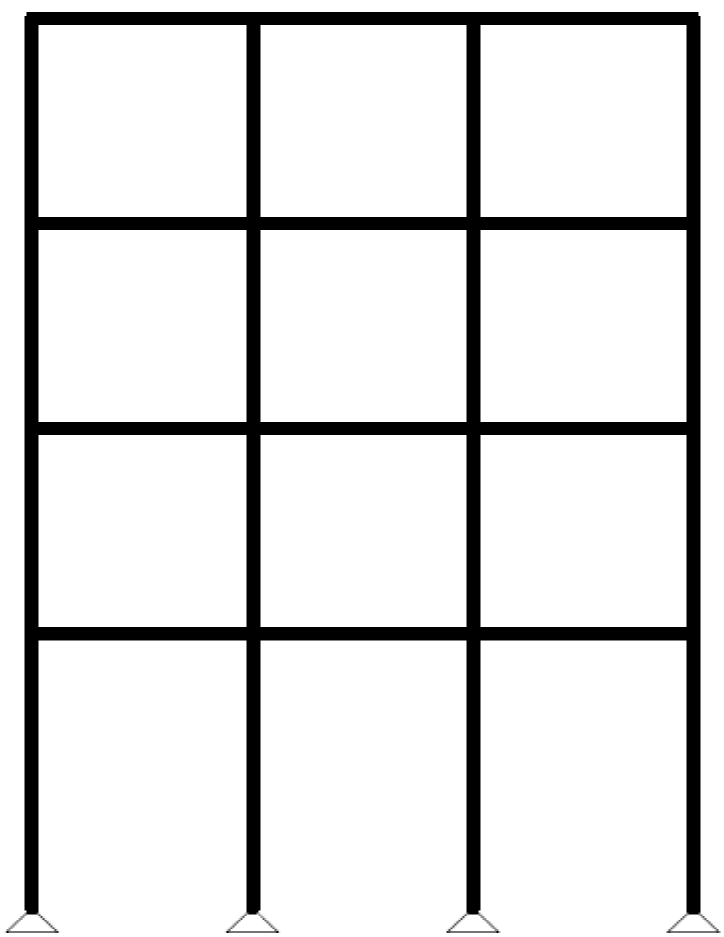


Figure 9 Bare frame SAP model

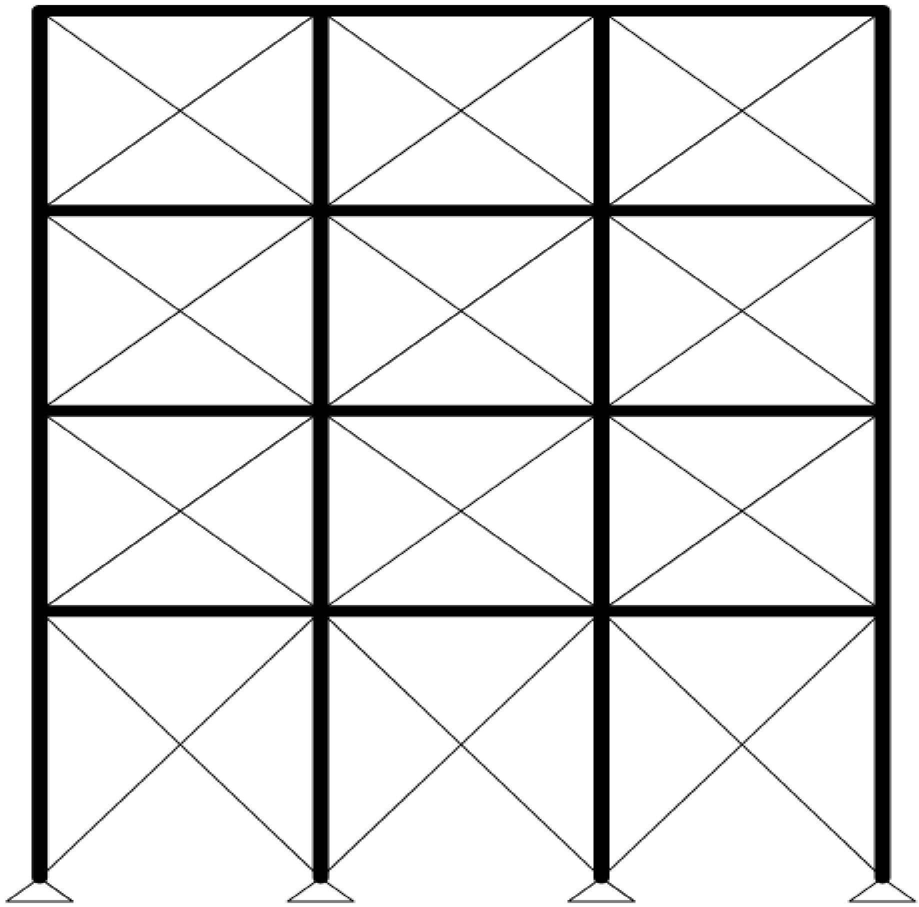


Figure 10 Frame with structural infill walls

3.3. ANALYSIS

The procedure consists of linear static and linear dynamic analysis. When the linear static or dynamic procedures are used for seismic evaluation, the design seismic forces, the distribution of applied loads over the height of the buildings, and the corresponding displacements are determined using a linearly elastic analysis. The various steps involved in SAP model analysis are the following:

- Modeling of frame sections.
- Defining and assigning material properties and section properties.
- Assigning support conditions.
- Defining and assigning load patterns and load cases.
- Assigning load combinations.
- Setting up of analysis option.
- Running analysis.
- Inferring the results.

The load combinations considered for the study are:

a) 1.5 (DL + IL) b) 1.2 (DL + IL ± EL)

c) 1.5 (DL ± EL) d) 0.9 DL ± 1.5 EL

Analyses were carried out for six different conditions of seismic zones, flood duration, flood water height, flood forces, frame models, and support conditions, to obtain the maximum design moment, flood moment and lateral displacements.

3.4. Calculation of design moment

The earthquake load calculations were made for all the zones and all the models analysed, and designed for IS 456:2000. Here, the earthquake zones are considered to demonstrate the different structural variations but not the multi-hazard conditions (Table 3). The design moment is lower for fixed support condition than hinged condition.

Seismic zone	II	III	IV	V
Seismic intensity	Low	Moderate	Severe	Very severe
Z	0.1	0.16	0.24	0.36

Table 3 Zone factor (Ref. IS 1893-2002)

3.5. CALCULATION OF FLOOD LOADS

Flood loads are assumed to act as:

a) Hydrostatic loads;

b) Impact loads as equivalent static loads;

c) Impact loads as dynamic loads, considering the duration of flood.

The hydrostatic loads consist of both lateral pressures and buoyancy forces. Lateral pressure is calculated using the formula $P_s = \gamma\ h_f$ (in kN/m2), where $\gamma = 9.81\ kN/m^3$ for water, and hf is the water depth in meters. Since lateral hydrostatic loads are acting as triangular loads, the resultant hydrostatic load (F_f) acts at $h_f/3$ distance from ground level. Buoyancy force has a significant effect either if the building is surrounded by water or in submerged condition. Here, the flood is considered as slow moving; hence the effect of buoyancy is neglected. Impact loads are velocity dependent loads. As no codes or design books are available for incorporating the impact effects, the magnitude of these loads is arbitrarily considered as a factor of hydrostatic force acting laterally as UDL over the surface. Table 4 shows the magnitude of flood loads acting on the column for the frame models.

h_f (m)	F_f (kN)	Impact UDL (kN/m)	
		$0.2\gamma h_f$	$f0.2\gamma h_f$
2	5.89	0.59	1.18
3	13.24	0.88	1.77
4	23.54	1.18	2.35

Table 4 Flood loads on frame models

The flood loads are assumed as dynamic loads by considering the duration of flood t_d. The dynamic displacement and dynamic flood moment are found using a deformation response factor (R). R is the ratio dynamic to static displacement caused by the flood force. The dynamic flood load is assumed as a rectangular pulse (Fig.11.).

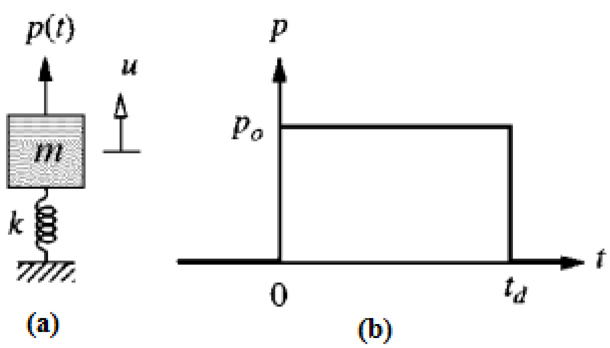


Figure 11. a) SDF system (b) Rectangular pulse load (Chopra, 2009)

The governing equation is:

$$m\ddot{u} + ku = p(t) = \begin{cases} p_0 & t \le t_d \\ 0 & t \ge t_d \end{cases} \tag{1}$$

The R value obtained after solving the equation 2 is (Chopra 2009):

$$R = \frac{u}{u_{st}} = \begin{cases} 2\sin \pi \frac{t_d}{T_n} \\ 2 \end{cases} \quad \frac{t_d}{T_n} \leq \frac{1}{2} \tag{2}$$

Where

u is the dynamic displacement,

u_{st} is the static displacement,

t_d is the flood duration

Tn is the fundamental natural time period of the structure.

The t_d/T_n ratios and corresponding R values used are shown in Table 5. R = 1 indicates the flood as static while R = 2 indicates suddenly applied flood load. Since the flood assumed for the study is slow moving, R will always lies in between 1 and 2.

td/Tn	**1/6**	¼	**1/3**	½
R	1.000	1.413	1.732	2.000

Table 5 Deformation response factor

3.6. Calculation of flood moment and height

Afterwards, analyses have to be carried out for different frame models in each zone with different boundary conditions, and the maximum flood moment in each case must be evaluated. The safe flood height is the height of flood up to which the structure is safe. It is obtained by plotting the moment due to hydrostatic force versus flood height: height corresponding to the design moment gives the safe flood height (h_f, safe).

The vulnerability index is assessed as a factor of ground floor height. It indicates the extent of damage that a flood can cause if the water reaches up to ground floor height. It is calculated using the equation (3).

$$\text{Vulnerability index}=\frac{ground\ floor\ height - safe\ flood\ height}{ground\ floor\ height} \qquad (3)$$

CHAPTER 4

RESULTS

The analysis was carried out for three frame models under different conditions of:

Flood loadings: static, equivalent static and dynamic loads;

Support conditions: hinged and fixed;

Seismic zones;

Flood water height: 2m, 3m and 4m;

Flood duration: $T_n/6$, $T_n/4$, $T_n/3$ and $T_n/2$.

For each zone, earthquake loads were assessed for all the zones and all the models designed for IS 456:2000. The earthquake zones (Table 6) are considered to demonstrate the different structural variations but not the multi-hazard conditions. The maxima design moments for both the bare frame and the frame with light weight partition walls are similar, since the weight of partition wall is considered as negligible. The sizes of frame sections, selected according to these moments, are given in Table 7. For the frame with structural infill, the infill walls were modelled as diagonal structures. After applying flood loads, for different frame models and in each zone, for hinged support condition, the maximum flood moment in each case was evaluated. Assuming flood heights of 2m, 3m and 4m from ground level, maxima moments were also obtained (Table 7). Because of the free movement of water in between the columns of the bare frame, the flood moment for bare frame model is very low if compared to the other models.

Zone	Bare frame	Light weight infill	Structural infill
II	33.58	33.58	64.99
III	45.05	45.05	92.58
IV	62.29	62.29	128.78
V	86.43	86.43	184.10

Table 6 Maximum design moments in kN-m

Frame model	Column size	Beam size
Bare frame	300X300	250x300
Light weight infill	300x300	250x300
Structural infill	350x350	300x350

Table 7 Frame cross-sections in mm

hf (m)	Bare Frame	Light weight infill	Structural infill
2	5.80	32.18	30.50
3	9.65	97.46	83.98
4	20.59	205.94	165.67

Table 8 Flood moment due to hydrostatic force (no impact factor) in kN

Impact force is assumed to act as UDL, and its value is arbitrarily taken as a factor of hydrostatic force. The impact factors considered are 0.1 and 0.2. For all the models, the moments are linearly increasing as impact load increases, because impact force is considered as a factor of hydrostatic load (Table 9). Non-linearity will come only while considering flood duration. Flood is assumed to act as dynamic rectangular load with flood duration td and the maximum flood moment obtained in each case is shown in Table 10.

h_f (m)	Bare frame		Light weight frame		Structural infill	
	0.1γhf	0.2γhf	0.1γhf	0.2γhf	0.1γhf	0.2γhf
2	5.76	5.76	36.70	41.40	33.65	37.19
3	10.70	11.95	109.97	122.26	92.53	101.15
4	22.56	24.99	229.49	252.91	180.08	193.76

Table 9 Moment due to hydrostatic and equivalent static impact forces in kN-m

zone	Bare frame				Frame with partitions			
	R=1	R=1.413	R=1.732	R=2	R=1	R=1.413	R=732	R=2
II	33.59	47.40	58.19	67.19	64.98	91.75	112.49	129.86
III	45.04	63.68	77.98	90.07	92.67	131.08	160.47	185.36
IV	62.29	88.09	107.86	124.58	128.55	181.87	222.74	257.19
V	86.44	122.16	149.66	172.89	184.04	260.38	318.86	368.15

Table 10 Flood moment due to dynamic flood forces in kN-m

Frame type	R=1	R=1.413	R=1.732	R=2
Bare frame and Frame with light weight infill	0.0449	0.0672	0.0898	0.1346
Frame with masonry infill	0.0091	0.0140	0.0184	0.0275

Table 11 Duration of flood (t_d) in sec

The fundamental frequency and duration of flood will be the same for both the frames. Also, the flood moment obtained is the same for frame with structural and non-structural partitions, because the contact area of flood water is the same for both frames. The safe flood height is obtained by plotting the moment due to hydrostatic force versus flood height. For example, for a frame with light weight partition wall in Zone II, design moment is 33.58 kN-m (Table 5) and its maximum moment due to hydrostatic loading is shown in Table 12. From the graph, the safe flood height corresponding to design moment 33.58 is 2.0276 m.

h_f (m)	Max flood moment (kN-m)2
2	32.15
3	97.60
4	205.85

Table 12 Maximum flood moment for the frame with light weight partition wall in Zone II

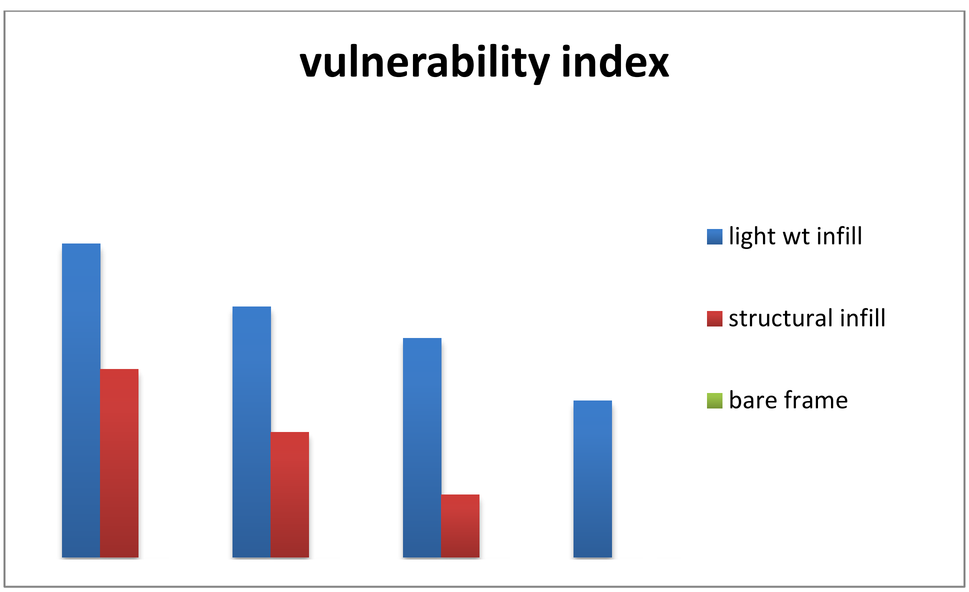


Figure 12 Variation of vulnerability in various zones

The vulnerability index of frame with light weight partition wall is high (49.3%) if compared to the other frames (Fig.11.). For frame with structural infill it only reaches a maximum of 32%, while it is zero for bare frame model. Vulnerability indexes obtained due to hydrostatic and equivalent static impact forces show that the highest values pertain to frame with light weight partition wall (Table 13). Vulnerability indexes obtained due to dynamic flood forces in various zones for different flood duration are shown in Table 14.

zone	Bare Frame		Light weight infill		Structural infill	
	$0.1\gamma h_f$	**$0.2\gamma h_f$**	**$0.1\gamma h_f$**	**$0.2\gamma h_f$**	**$0.1\gamma h_f$**	**$0.2\gamma h_f$**
II	0	0	0.516	0.539	0.345	0.371
III	0	0	0.465	0.485	0.245	0.27
IV	0	0	0.392	0.415	0.132	0.163
V	0	0	0.312	0.339	0	0.027

Table 13 Vulnerability due to hydrostatic and equivalent static impact forces

Bare frame				
R	1	1.413	1.731	2.1
Zone II	0	0.141	0.299	0.333
Zone III	0	0.062	0.231	0.335
Zone IV	0	0.000	0.161	0.271
Zone V	0	0.000	0.084	0.209

Frame with light weight infill				
R	**1**	**1.413**	**1.731**	**2.1**
Zone II	0.494	0.640	0.704	0.745
Zone III	0.430	0.604	0.670	0.715
Zone IV	0.361	0.545	0.631	0.680
Zone V	0.275	0.489	0.580	0.640

Frame with structural infill				
R	**1**	**1.413**	**1.731**	**2.1**
Zone II	0.319	0.520	0.605	0.659
Zone III	0.215	0.445	0.542	0.605
Zone IV	0.102	0.366	0.450	0.552
Zone V	0.000	0.265	0.405	0.485

Table 14 Vulnerability index due to dynamic flood forces

The storey drifts are evaluated from the lateral joint displacements. According to IS 1893-2002 Cl.7.11.1, the maximum storey drift is 0.004 H, where H is the height of the building. In this study, H = 13 m and hence the maximum allowable storey drift is 52 mm. The frame with structural infill wall has low storey drift if compared to bare frame, because infill walls have significant effect in resisting lateral storey drift (Table 15). For the frame with light weight partition wall, storey drift reaches 71.31mm, which is more than that specified for seismic resistant building (Table 16). Hence a frame with non-structural partitions with hinged support is not preferred in flood prone areas.

h_f(m)	Bare Frame	Light weight infill	Structural infill
2	0.635	5.940	0.085
3	2.015	19.695	0.204
4	4.660	46.240	0.454

Table 15 Storey drifts due to hydrostatic forces

Hf(m)	Bare Frame		Light weight infill		Structural infill	
	$0.1\gamma h_f$	$0.2\gamma h_f$	$0.1\gamma h_f$	$0.2\gamma h_f$	$0.1\gamma h_f$	$0.2\gamma h_f$
2	0.805	0.95	7.555	9.365	0.2	0.216
3	2.555	3.130	25.300	30.900	0.260	0.326
4	5.900	7.172	58.78	71.315	0.600	0.755

Table 16 Storey drifts due to hydrostatic and equivalent static forces

The relative cost for any frame model is calculated with respect to the design moment of bare frame model in zone II (Eq. 4):

$$\text{Cost relative}_{\text{zone III,IV,V}} = \frac{\text{DM zone II (bare)} - \text{DM zone II (bare)}}{\text{DM zone II (bare)}} \qquad (4)$$

Where,

$DM_{zoneIII,IV,V}$ = design moments in zones III, IV and V for frame with partitions.

$DM_{zoneII(bare)}$ = design bending moment of bare frame in zone II.

The relative costs for the three frame models are shown in Table 17. The graph of relative cost versus vulnerability index shows that for the frame with light weight partition wall the cost is increasing but the vulnerability is not reducing that much. Moreover, even though the initial cost is higher for frame with structural partitions, its vulnerability is lower if compared to frame with non-structural partitions (Fig.13.).

zone	Bare Frame		Light weight infill		Structural infill	
	DM	Cost relative	DM	Cost relative	DM	Cost relative
II	33.550	0	33.550	0	65	1
III	44.001	0.342	44.001	0.342	92.700	1.700
IV	62.300	0.850	62.300	0.890	128.600	2.900
V	86.400	1.600	86.400	1.570	184.095	4.496

Table 17 Relative cost as a factor of design moment for three frame models

The vulnerability obtained for different flood loading is compared with partitions, zones and flood duration (Fig.14. and 15). Dynamic load with R = 1.413 is used for comparing the results with static results. Frame with light weight infill wall is more vulnerable (64.20%) and bare frame is less vulnerable (14.20%). This is due to the free movement of water in between the columns of the bare frame, so that the contact area of flood water is very low if compared to the other frames. For the frame with masonry infill, vulnerability is less compared to light weight partition, even though the flood moment is the same for both the cases. It is due to the structural action of masonry infill against the lateral flood load. Comparing vulnerability for different flood loadings to seismic zones (Fig.16), for the frame with light weight infill, vulnerability is higher in Zone II (64.20%) and it reduces as zone increases (zone V: 49.20%). For frame with masonry infill, vulnerability is reaching zero as zone varies from II (51.91%) to V (Fig.14.). This is because the design moment of building in zone V is higher if compared to zone II and hence the building in zone V will be more resistive to flood.

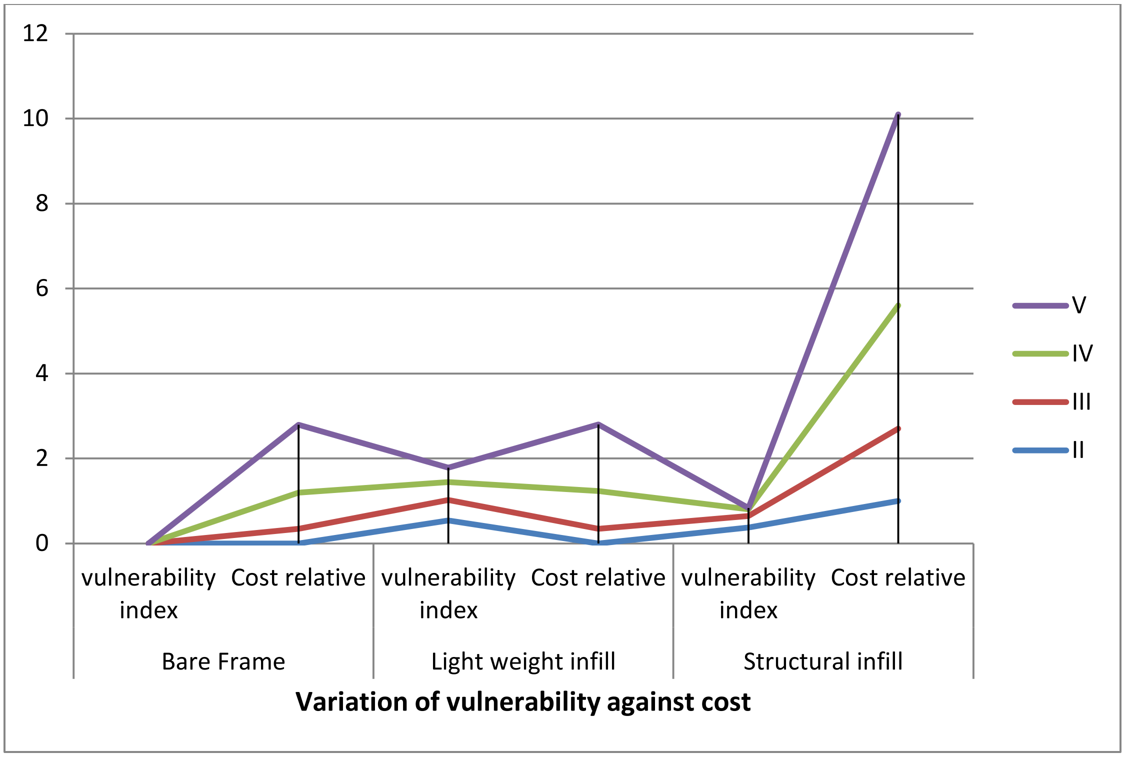


Figure 13 Variation of vulnerability against cost

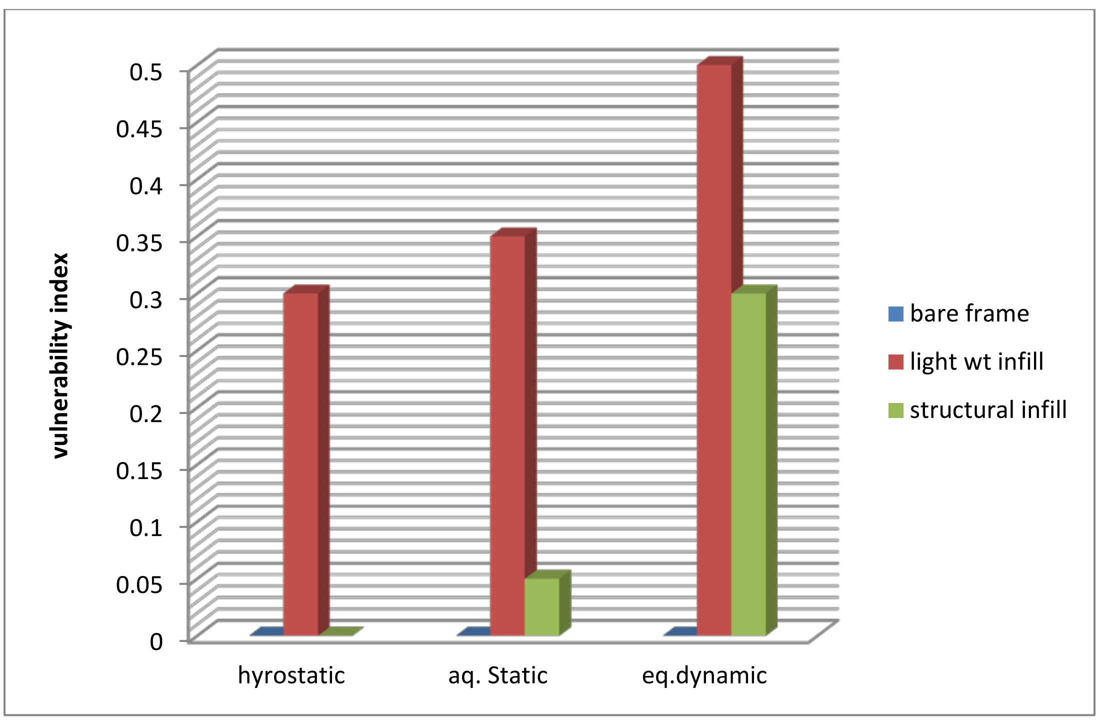


Figure 14 Vulnerability for different frame models in different flood loading conditions in Zone II

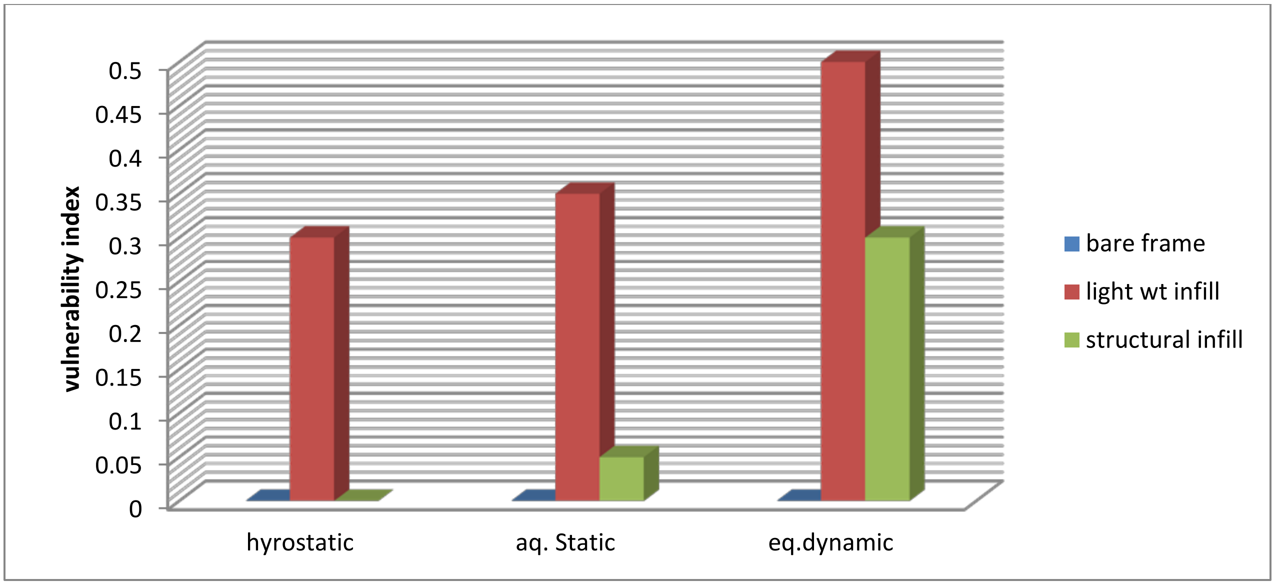


Figure 15 Vulnerability for different frame models in different flood loading conditions in Zone V

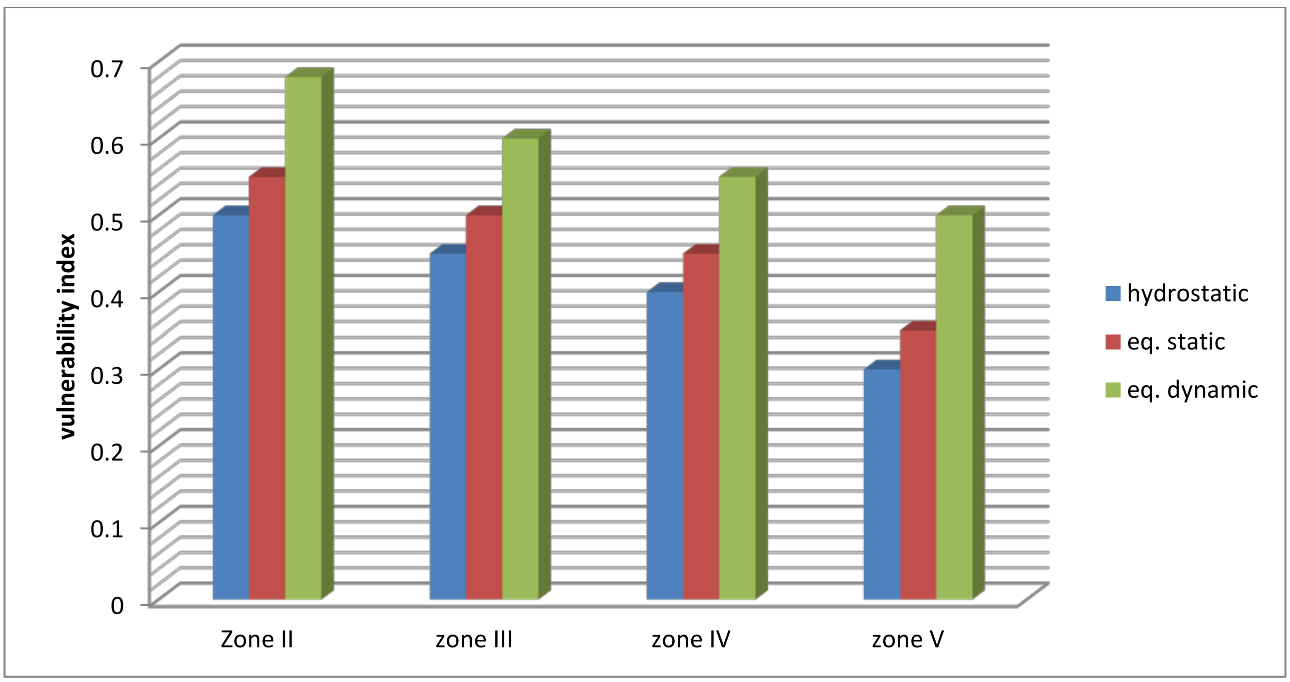


Figure 16 Vulnerability for light weight infill frame under different flood loading conditions in different zones

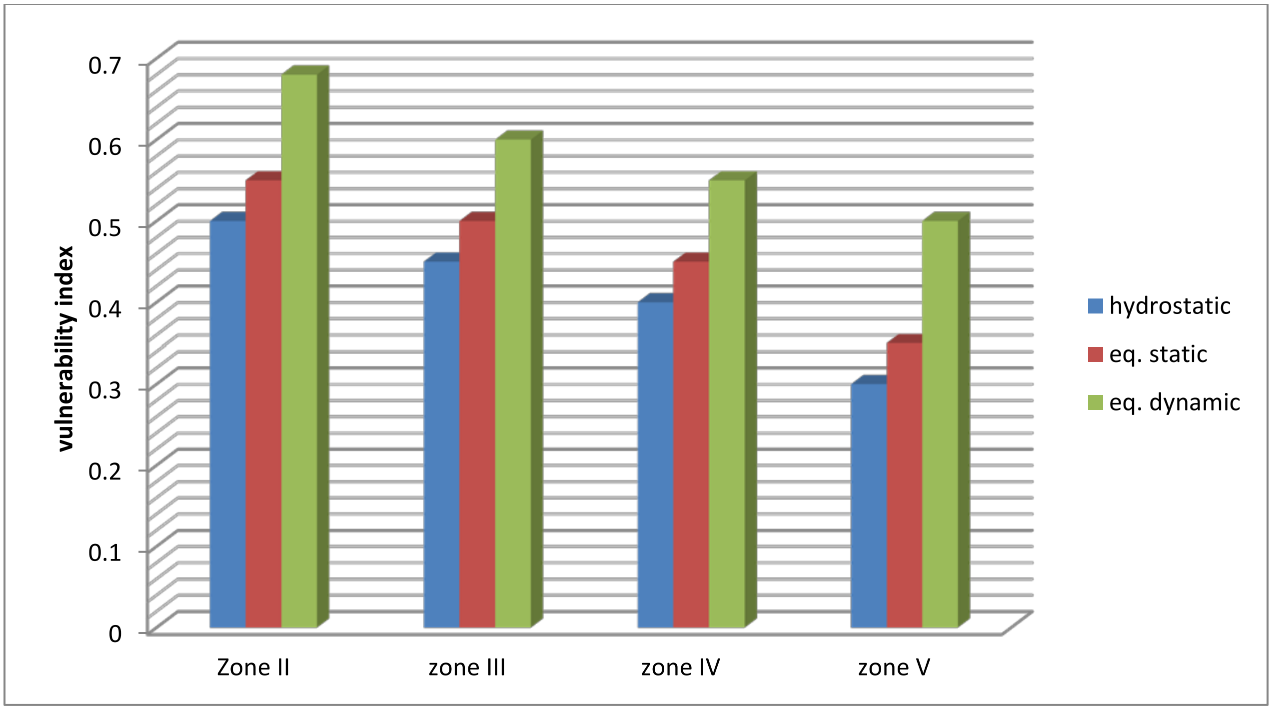


Figure 17 Vulnerability masonry infill frame under different flood loading conditions in different zones.

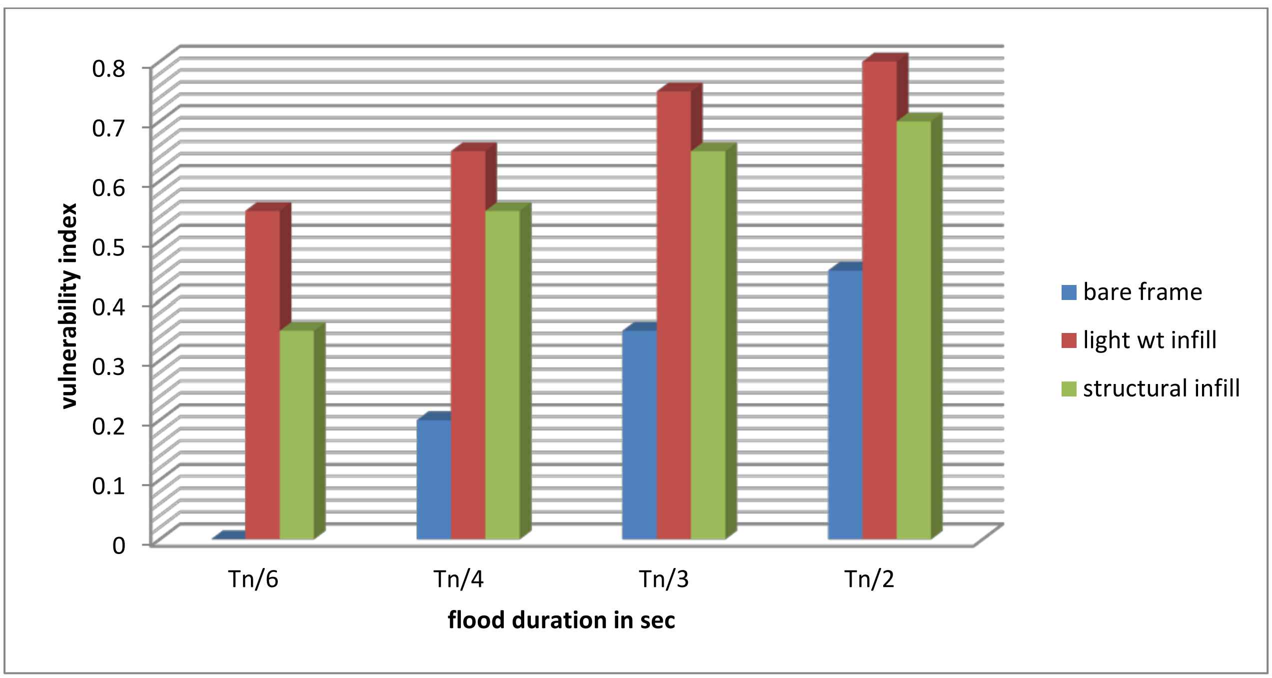


Figure 18 Vulnerability for different frame models under different flood duration in Zone II

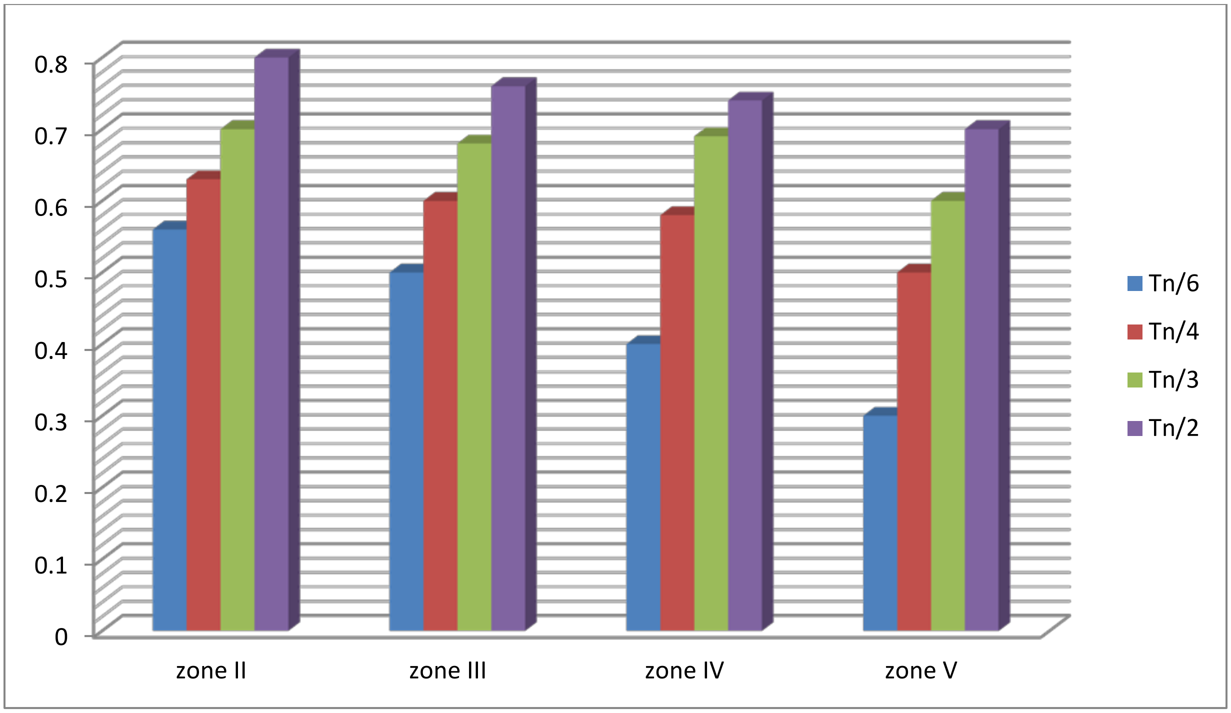


Figure 19 Vulnerability for the frame with light weight infill in different zones

Analyzing different frame models under different flood duration in Zone II (Fig.18.), vulnerability increases with the duration of flood, but it is lower for bare frame (39.31%) if compared to frame with partitions (74.72% for light weight infill and 66% for frame with structural infill). It is due to the free movement of flood water between the columns of bare frame. The results of vulnerability for the frame with light weight infill (Fig. 19.), show that a building in zone V with flood duration $T_n/3$ is less vulnerable (58.42%) than a building in zone II with flood duration of $T_n/2$ (64.23%).

The analysis was carried out for all the cases, keeping the support of columns as fixed. The earthquake load calculations were made for all the zones and all the models analysed and designed as per IS 456:2000, for each zone and maximum design moments (Table 18). The maximum moment is lower for the fixed support condition, so the cross sections required is lower when compared to hinge support condition. The sizes of frame sections are given in Table 19. Fig.21 shows the variation of flood moments for different frame models due to hydrostatic force. The flood moments parabolically increase as flood water height increases.

zone	Bare frame	Light weight infill	Structural infill
II	16.1400	16.1400	33.6500
III	25.3325	30.6600	49.5
IV	30.6600	30.6600	69.5439
V	42.7198	42.7198	100.8070

Table 18 Maximum design moment in kN-m

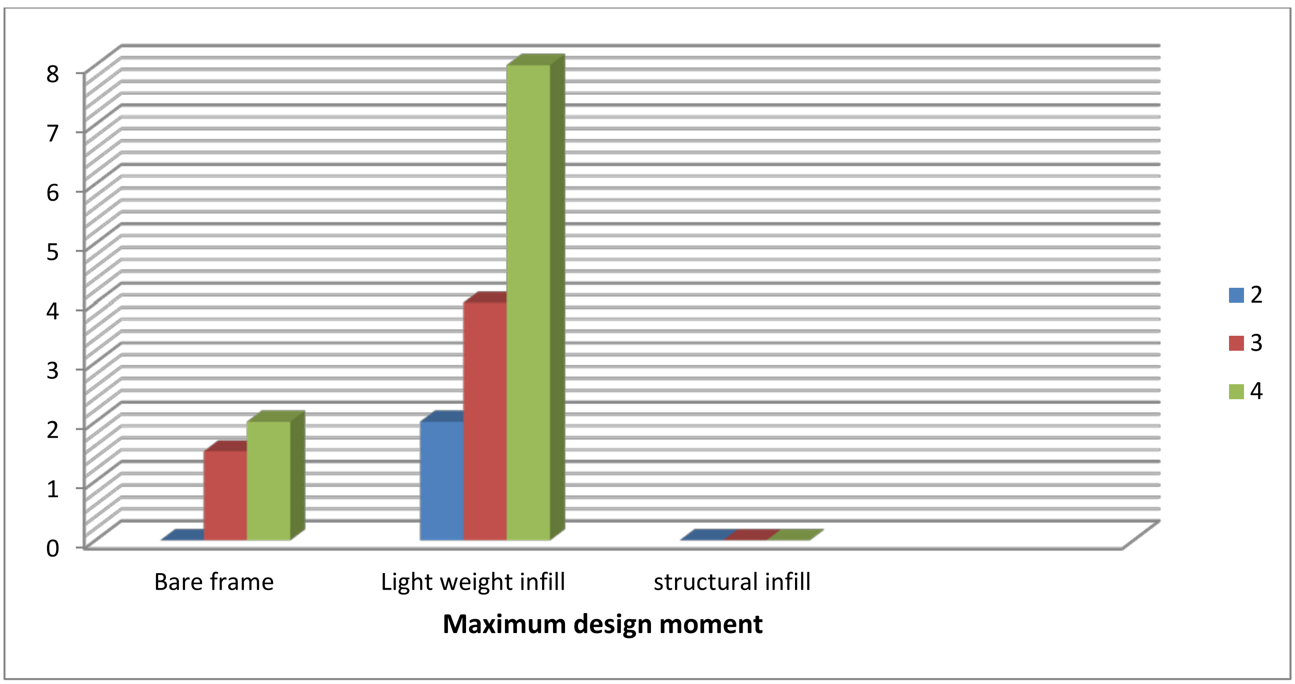


Figure 20 Maximum design moment

Frame model	Column size	Beam size
Bare frame	250 x 250	250 x 300
Light weight infill	250 x 250	250 x250
Structural infill	300 x 300	250 x250

Table 19 Frame cross-sections in mm

The maximum moments obtained from the analysis for fixed support condition are shown in Table 19. For all frame models, the moments linearly increase as impact load increases. This is because, for the present case, impact force is considered as factor of hydrostatic load. Nonlinearity will come only while considering flood duration. The duration of flood load (td) considered for various R values for hinged support condition are shown in Table 20 and the flood moments due to dynamic flood loads in various zones for fixed support condition are

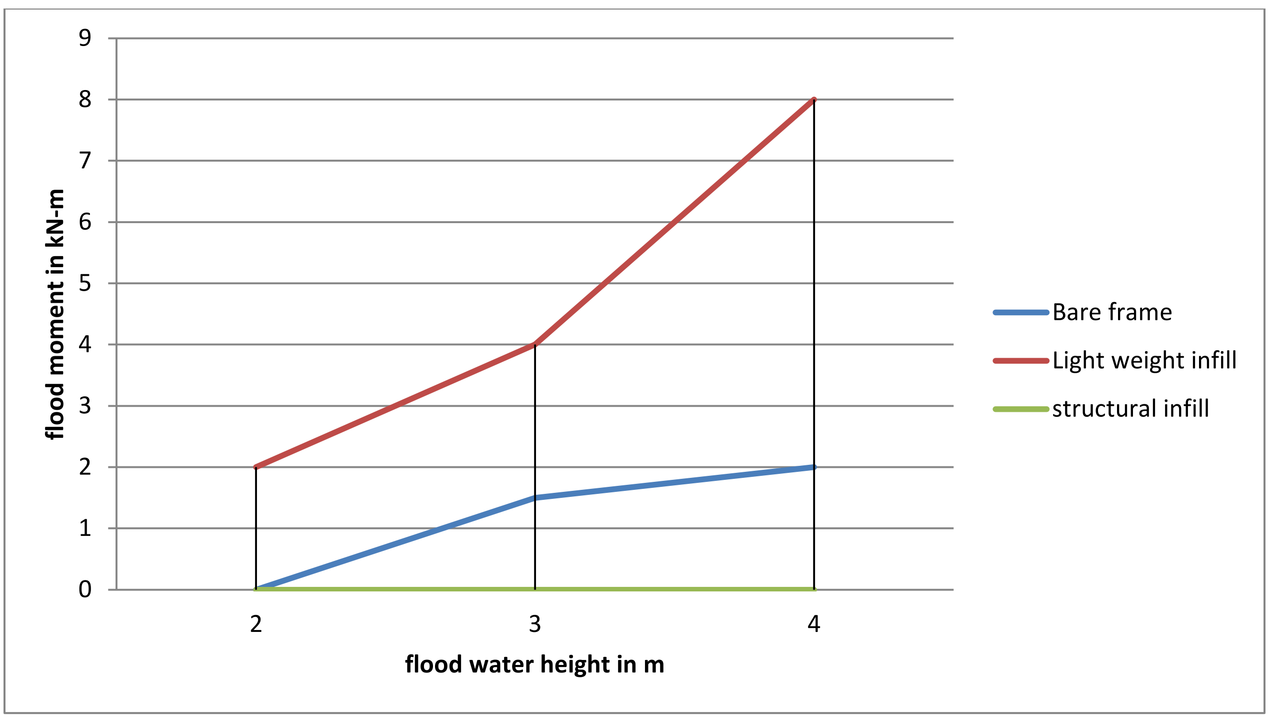


Figure 21 Variation of flood moment to hydrostatic force (without impact factor)with water height

Shown in Table 22.Vulnerability for the bare frame is zero in all the seismic zones but it is nonzero for frame with partitions (Fig. 21.). This is due to the free movement of water in between the columns of the bare frame, so that the contact area of flood water will be low if compared the other frames. The vulnerability of frame with light weight partition wall is very high (60.32%), while for frame with structural infill it reaches 44.61% and it is not present for bare frame model.

Vulnerability indexes obtained due to hydrostatic and dynamic impact forces for fixed support condition are shown in Table 23 and 24, respectively.

h_f (m)	Bare frame		Light weight frame		Structural infill	
	0.1γhf	0.2γhf	0.1γhf	0.2γhf	0.1γhf	0.2γhf
2	4.4756	4.475	35.762	42.43	31.26	36.98
3	9.65	11.30	102.20	118.60	87.763	100.69
4	19.70	22.60	202.60	231.16	164.90	182.98

Table 20 Moment due to hydrostatic and impact forces in kN-m

Frame type	R=1	R=1.413	R=1.732	R=2
Bare frame	0.0402	0.0602	0.0802	0.1204
Frame with masonary infill	0.0096	0.0416	0.0195	0.0295

Table 21 Duration of flood (t_d) in sec

zone	Bare frame				Frame with partitions			
	R=1	R=1.413	R=1.732	R=2	R=1	R=1.413	R=732	R=2
II	16.14	22.80	27.96	32.30	33.77	48.05	58.32	68.33
III	25.44	35.83	43.99	50.77	49.40	69.73	85.40	98.90
IV	30.55	43.38	53.22	61.33	69.32	98.35	120.55	139.23
V	42.61	60.30	73.82	85.30	100.82	142.65	174.68	201.32

Table 22 Flood moment due to dynamic flood forces in kN-m

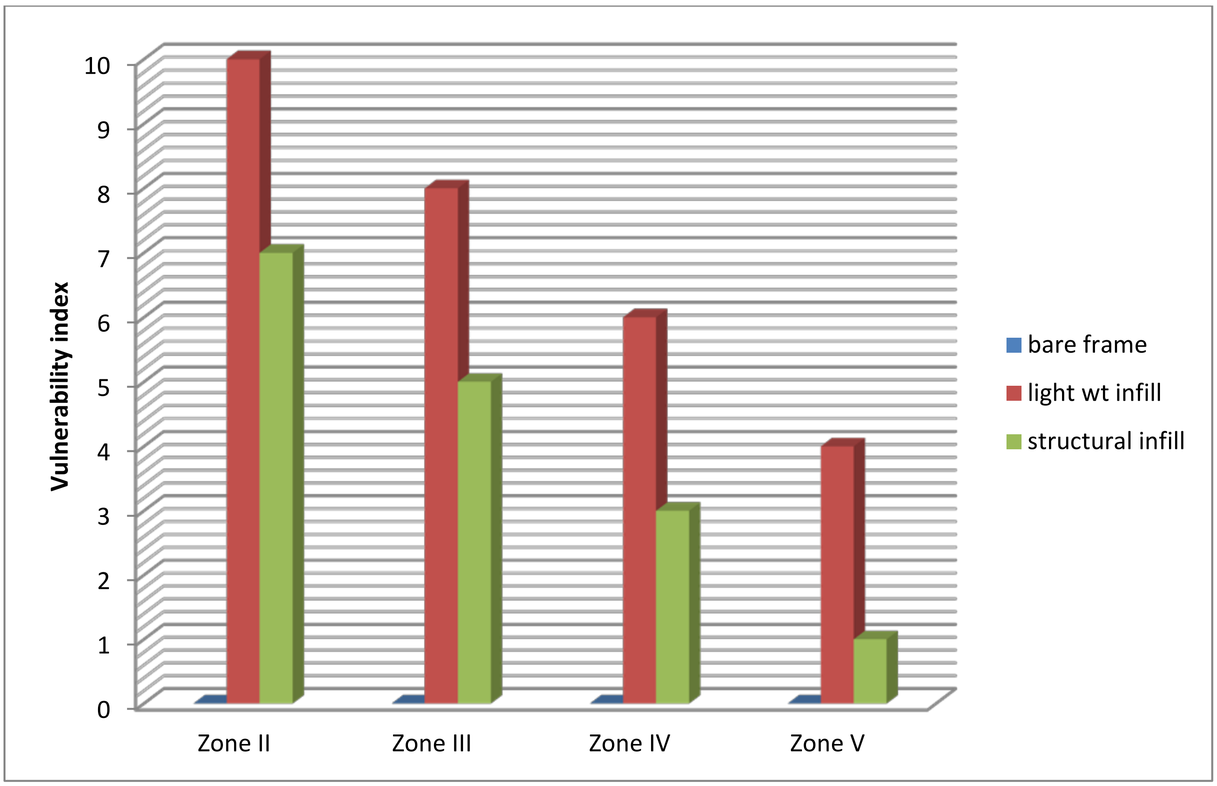


Figure 22 Variation of vulnerability in various zones

zone	Bare Frame		Light weight infill		Structural infill	
	0.1γh_f	**0.2γh_f**	**0.1γh_f**	**0.2γh_f**	**0.1γh_f**	**0.2γh_f**
II	0	0	0.635	0.660	0.425	0.525
III	0	0	0.566	0.595	0.407	0.432
IV	0	0	0.532	0.565	0.307	0.345
V	0	0	0.462	0.502	0.192	0.234

Table 23 Vulnerability index due to hydrostatic and impact forces

Bare frame				
R	1	1.413	1.732	2
Zone II	0.00	0.299	0.425	0.502
Zone III	0.00	0.175	0.330	0.415
Zone IV	0.00	0.125	0.285	0.382
Zone V	0.00	0.045	0.215	0.320

Frame with light weight infill				
R	**1**	**1.413**	**1.732**	**2**
Zone II	0.602	0.715	0.772	0.801
Zone III	0.525	0.656	0.725	0.765
Zone IV	0.485	0.645	0.705	0.740
Zone V	0.420	0.590	0.662	0.712

Frame with structural infill				
R	**1**	**1.413**	**1.732**	**2**
Zone II	0.444	0.605	0.675	0.720
Zone III	0.350	0.540	0.625	0.675
Zone IV	0.260	0.475	0.574	0.632
Zone V	0.142	0.396	0.505	0.572

Table 24 Vulnerability index due to dynamic flood forces

The storey drift is lower for fixed support condition and the maximum value concerns the frame with light weight partition walls (Fig. 23.). The frame with structural infill wall show the smallest storey drift: this indicates the significance of infill in resisting lateral storey drift. Storey drift reaches the maximum of 20.184 mm for the frame with light weight partition walls, which is less than that specified for seismic resistant building (Table 25). For the frame with structural infill wall, even though the initial relative cost is high, the vulnerability is lower if compared to frame with non-structural partition walls (Table 26).

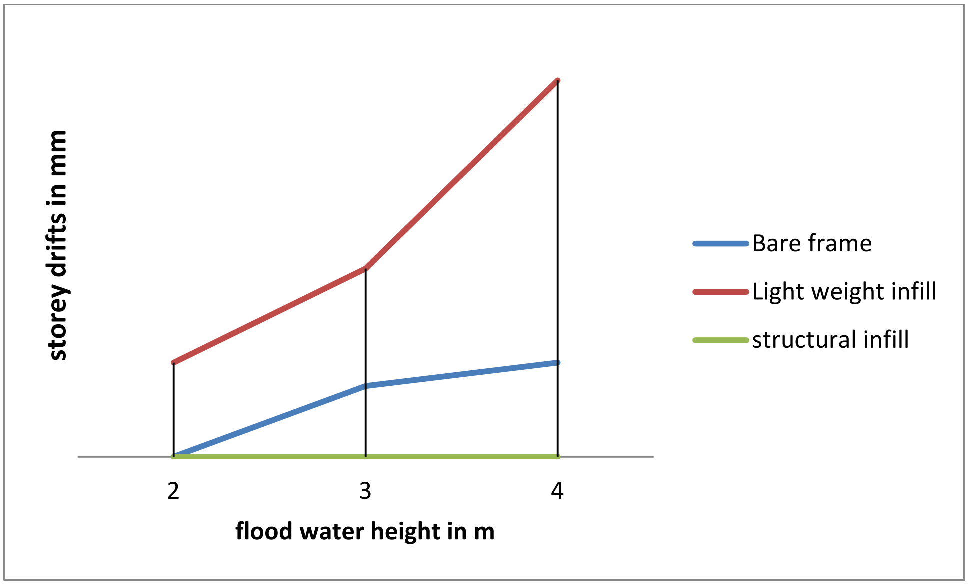


Figure 23 Variation of storey drift with flood water height

h_f (m)	Bare frame		Light weight frame		Structural infill	
	0.1γhf	0.2γhf	0.1γhf	0.2γhf	0.1γhf	0.2γhf
2	0.16	0.20	1.26	1.60	0.07	0.104
3	0.602	0.776	5.495	7.222	0.20	0.272
4	1.614	2.070	15.620	20.184	0.530	0.64

Table 25 Storey drifts due to hydrostatic and impact forces in mm

zone	Bare Frame		Light weight infill		Structural infill	
	DM	Cost relative	DM	Cost relative	DM	Cost relative
II	16.140	0.00	16.140	0	33.665	1.085
III	25.330	0.575	25.330	0.575	49.305	2.056
IV	30.665	0.906	30.665	0.906	69.500	3.307
V	42.600	1.642	42.600	1.642	100.806	5.254

Table 26 Relative cost as a factor of design moment for three frame models

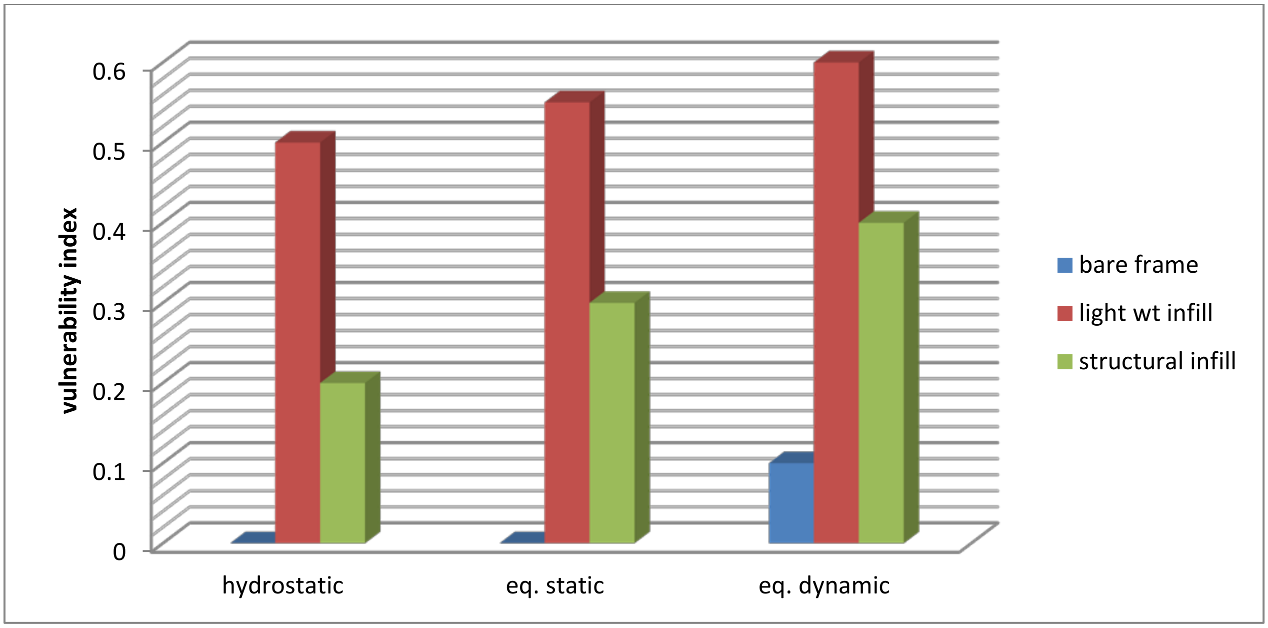


Figure 24 Vulnerability for different frame models under different flood loading conditions in Zone V

The vulnerability results obtained for different flood loadings are compared with respect to partitions (Fig. 24. and 25.). The frame with light weight infill wall is more vulnerable and bare frame is least vulnerable. This is due to the free movement of water in between the columns of the bare frame so that the contact area of flood water is lower if compared to the other frames. For the frame with masonry infill, vulnerability is lower if compared to light weight partition, even though the flood moment is the same for both the cases (Fig. 24.). It is due to the structural action of masonry infill against the lateral flood load.

The vulnerability reduces from zone II to zone V because the design moment in zone V is higher if compared to zone II and hence the building is more resistive to flood. The variation of vulnerability for the frame with light weight infill and with masonry infill under different flood loading conditions in different zones are shown in Fig. 26 and 27, respectively.

For the frame with light weight infill, vulnerability is higher in Zone II (71.91%) and it reduced as zone increases (Fig. 26.). For frame with masonry infill, vulnerability is higher in Zone II (60.82%) and it decreases as zone increases (Fig. 27.). This is because the design moment of building in zone V is higher if compared to zone II and hence the building in zone V will be more resistant to flood. The vulnerability results obtained for different flood loadings are compared with respect to seismic zones (Fig. 28. and 29.). As the duration of flood increases, vulnerability increases (Fig.28.); vulnerability is lower for bare frame than for frame with partitions. A building in zone V

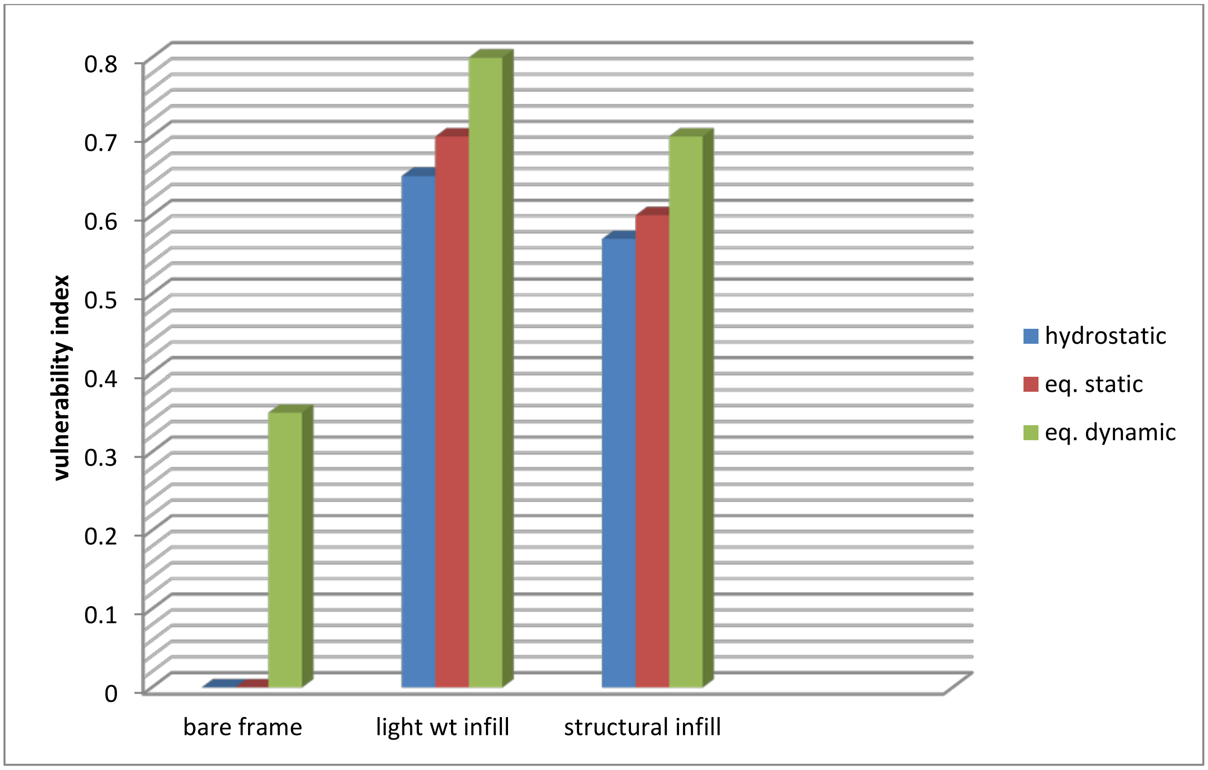


Figure 25 Vulnerability for different frame models under different flood loading conditions in Zone II

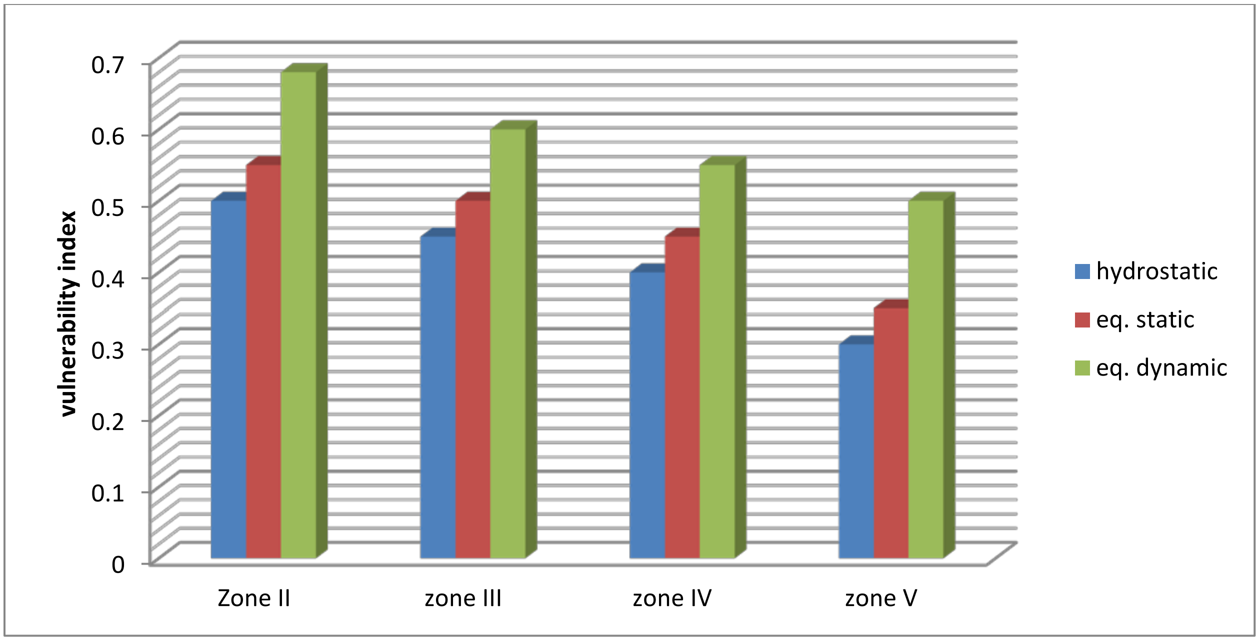


Figure 26 Vulnerability for the frame with light weight infill under different flood loading conditions in different zones

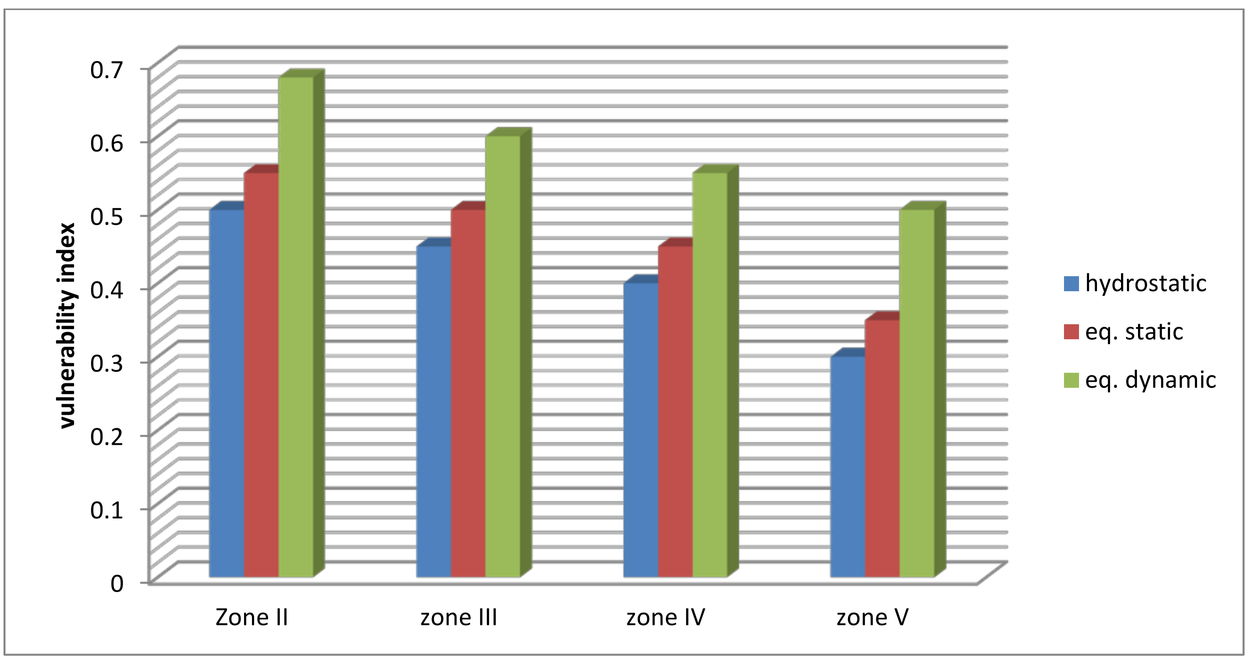


Figure 27 Vulnerability for the frame with masonry infill under different flood loading conditions in different zones

with flood duration Tn/3 is less vulnerable (66.73%) than a building in zone II with flood duration of Tn/2 (71.92%) (Fig. 26.), hence vulnerability is higher for building subjected to longer floods even if it also depends on the seismic zone.

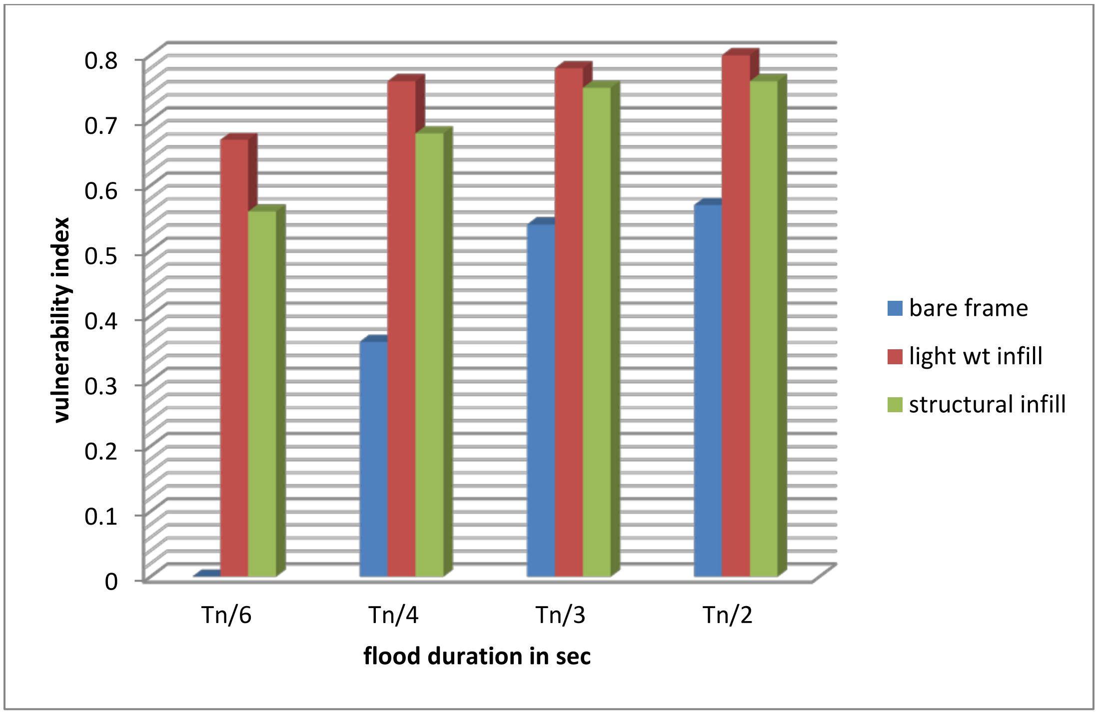


Figure 28 Vulnerability for different frame models under different flood duration in Zone II

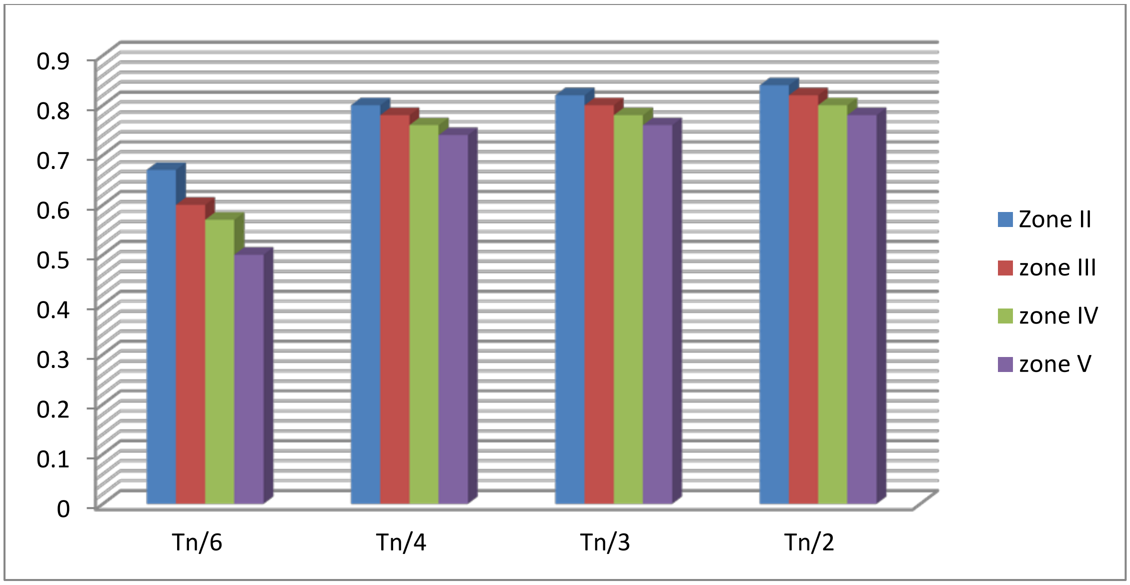


Figure 29 Vulnerability for the frame with light weight infill in different zones

CHAPTER 5

Conclusions

Flood physical vulnerability deals with the level of loss that elements at risk or built environment suffer from the occurrence of flooding. This study aims to calculate the flood vulnerability limit as a factor of ground floor height under flood forces and to quantify flood load.

Three models were designed and the impact of flood forces in each frame were analysed. The significance of infill walls in resisting lateral storey drift during flood is also investigated.

The main conclusions of the analysis are:

- The flood moments parabolically increase as impact load increases and linearly increase as flood water height increases.
- The vulnerability of frame with light weight partition wall, for hinged support condition, reaches 64.24% for dynamic flood forces, which is very high if compared to the other frames.
- For frame with light weight partition wall in hinged support condition, storey drift reaches 71.32 mm, which is more than the value specified for seismic resistant building.
- The vulnerability of frame with light weight partition wall, for fixed support condition, is up to 60% in zone II which is very high if compared to the other frames.
- Storey drift for frame with light weight partition wall in fixed support condition is found to be less than hinged condition. The maximum value of storey drift for frame with light weight partition wall is 20.189mm.
- The initial cost is more for frame with structural partitions; its vulnerability is very low if compared to frame with non-structural partitions.
- Buildings in zone II is most vulnerable and the vulnerability is reducing as zone increases. It reaches zero for frame with structural infill as zone varies from zone II to zone V. This is because the design moment of building in zone V is larger if compared to zone II and hence the building in zone V is more resistive to flood.

Bare frame is less vulnerable and frame with light weight partition wall result as the most vulnerable. Hence frame with non-structural partitions like plywood are not preferred in flood prone areas. The storey drift for the frame with structural infill walls is very low if compared to the other frame models and this indicates the significance of infill in resisting lateral storey drift. Soft storied buildings are less vulnerable compared to ordinary buildings and this depends on the free movement of water in between the columns. Results also indicate the real need of considering the flood loads in the design procedure of reinforced concrete buildings.

5.1 Future research scope:

Despite the contributions of this study, many knowledge gaps remain in this area and plenty of scope exists for reducing uncertainties in the calculations.

More research is needed to incorporate the full range of flood actions into the vulnerability matrices. One approach to solving this problem would be to provide a list of scenarios, such as the presence of different contaminants, wind-generated waves, or scour.

In this study I have analysed the effect of flood on different types of buildings, this work can be further extended for the following:

1. Analyse the frame by jacketing of the column to reduce the effect of contaminants on it.
2. Using steel frame buildings, its behaviour can be analyzed.
3. Research on the same can be done on rural buildings as maximum flood occurs in that area.

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