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Vulnerability of infra-structural residential frames under extra-ordinary loads

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Abstract. *Residential segment of infra-structural systems in India occupies a significant portion and many cities and towns are witnessing an unusual rise in construction of low-level-up to four or five floors-buildings in reinforced concrete. Present codal provisions and design practices cover wind and seismic loads reasonably well. But unusual -but occurring every year in many parts of India- environmental loads like flood and fire are not considered in many of the designs and the reason for this is the complexity in computational aspects of studying response under such loads and their effects on design in a complex material like reinforced concrete, which is the predominantly used material in India. The present study gives details of computational aspects in the analysis of such frames bot in modeling and response evaluation using finite elements. Two cases of loading are studied on under fire and another under flood. For the study on fire, the modelling and analysis are from a component level like beam, frame and later system. But for flood the analysis id done on the full system considering different cases on functionality of the building like soft-storeyed or structurally in-filled etc. In fire , the studies indicate the performance of concrete as it decays as a material and the consequent effect on components like beams or portions of system like one bay of a frame in response and based on this the temperature vulnerability is evaluated. Similarly for the same frame under flood vulnerability studies are done to evaluate the performance with different base conditions and boundary effects, which might take place due to scouring. Both linear and non-linear design effects are considered by taking into account the cracking in concrete. Similarly dynamic effects of flood are taken in a quasi-static mode as done under seismic loadings. Using these results, it is possible to get an idea of the effects of unusual environmen-*

tal loads like fire and flood, on a fully well-designed building for dead, live, wind and seismic loads both from analysis and design points of view

Keywords: *Concrete, modeling, vulnerability, soft storey, damage*

1. INTRODUCTION

The effect of fire in buildings leads to loss of life, structural damage and impact upon the wider economy and environment. There has been a resurgence of interest in response of building structures to fires over the past several years. This interest was greatly enhanced by the attack on, and subsequent collapse of, the World Trade Center tower. Recent incidents of thermal damage occurring on infra-structural systems like the one in Kolkata, before that in Mumbai and the famous 9/11 twin tower collapse in USA. Floods are one of the most widespread and destructive natural disaster occurring due to various reasons like heavy rainfall, damming of rivers, hurricanes, melting of snow, tsunamis etc. Flood claim over 20,000 lives and adversely affect around 75 million people worldwide annually. Floods occurring in densely populated urban areas have the capacity to do maximum damage to life and property. In this paper, an effort has been made to find out the vulnerability of building subjected to fire and flood. The aim of vulnerability studies is to recognize correct actions that can be taken to reduce vulnerability before the possible harm is realized.

1.1 FIRE EFFECTS ON CONCRETE STRUCTURE

Concrete does not burn – it cannot be 'set on fire' like other materials in a building and it does not emit any toxic fumes when affected by fire. It will also not produce smoke or drip molten particles, unlike some plastics and metals, so it does not add to the fire load. For these reasons concrete is said to have a high degree of fire resistance and, in the majority of applications, concrete can be described as virtually 'fireproof'. This excellent performance is due in the main to concrete's constituent materials (i.e. cement and aggregates) which, when chemically combined within concrete, form a material that is essentially inert and, importantly for fire safety design, has a relatively poor thermal conductivity. When the temperature increases material property (Young's modulus) decreases.

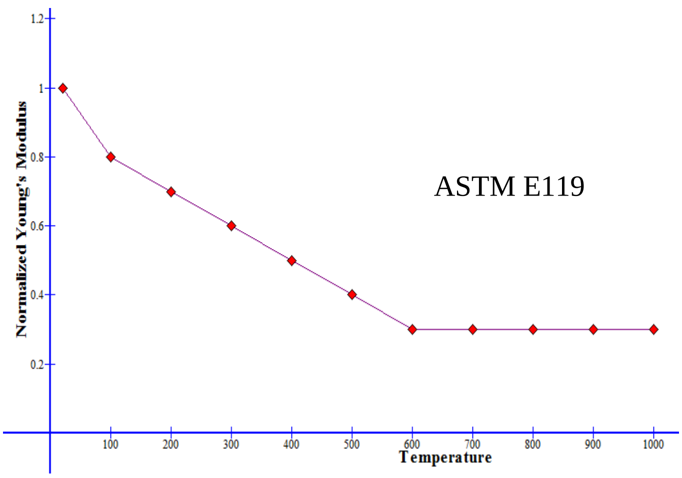

Fig. 1 Normalized young's modulus vs. temperature

1.2 FLOOD EFFECTS ON CONCRETE STRUCTURES

Whether the flooding at a building results from storm surge, riverine flooding, or urban flooding, the physical forces of the floodwaters which act on the structure are generally divided into three load cases. They are hydrostatic loads (lateral), buoyant loads, and impact loads. These load cases can often be exacerbated by the effects of water scouring soil from around and below the foundation. Sufficient hydrostatic loads may cause permanent deflections and damage to structural elements within the building. Buoyancy force is having a significant effect only if the building is surrounded by water or in submerged condition. In addition to these hydrostatic loads, the water flowing around the building during a flood event creates frontal impact loads on the structure and its magnitude is dependent upon the velocity of the floodwaters.

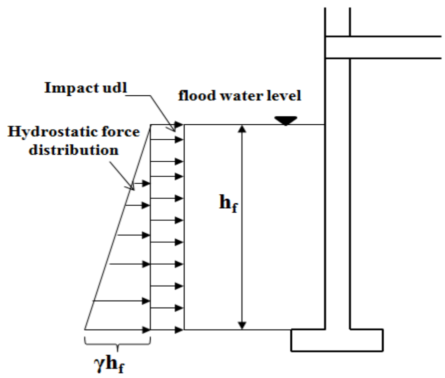

Fig. 2 Hydrostatic and hydrodynamic effects

Fig.2 shows the hydrostatic and hydrodynamic forces acting on a vertical wall. For the present study, the flood is considered as slow moving, not stagnant condition; hence the effect of buoyancy is neglected. Only hydrostatic loads and impact loads were considered for the analysis. Since no codal provisions are available for choosing the flood velocity, the magnitude of impact loads are arbitrarily taken as $0.1\gamma hf$ and $0.2\gamma hf$ acting laterally as udl over the surface.

2. FINITE ELEMENT MODELLING

For the present study "PLANE 55" was used and it is a 2D thermal solid element. The element has four nodes with a single degree of freedom (Temperature) at each node. The input of one analysis depends on the results from another analysis, the analyses are coupled".

Span of beam	3 m
Height of column	4m
Load	15 KN/m
Beam section	250×300
Column section	300×300
Moment of Resistance	72 KNm
Ultimate load	1250 KN
Concrete grade	M25
Steel grade	Fe 415
Thermal conductivity	2 W/m/K
Thermal expansion	10e-6/°C
Specific heat	1255 J*kg/K

- Thermal Analysis

ANSYS gives option to select the various types (steady state, transient state and sub structuring) of analysis. For the present study, steady state analysis is used to find the temperature distribution of the structural member.

- Structural Analysis

ANSYS gives option to select the various types of analysis depending on the requirement of the problem. The various options available are static, harmonic, spectrum, model and sub structuring. For the present study static analysis is used. Here structural analysis depends on the results of thermal analysis

2.2 MODELING IN SAP

A single storied single bay reinforced concrete building is considered for the present study. Height of column is 4m and span of beam is 3m. Sizes of all columns are 300mmx300mm and beam is 250mmx300mm. Masonry walls are having 230mm thickness and slab thickness is 120mm. The material properties considered are: Unit weight of the concrete 25 kN/m3, Unit weight of masonry 20 kN/m3, Elastic modulus of steel 2×108 kN/m2, Young's modulus of concrete 25×106 kN/m2, Young's modulus of masonry 13.8×106 kN/m2, Poisson ratio of concrete 0.2, Poisson ratio of masonry 0.25, Characteristic compressive strength of concrete 25 N/mm2 and Yield strength of steel 415 N/mm2.

Three frame models were studied; (i) bare frame model (ii) frame model with light weight partition wall and (iii) frame model with structural infill walls. For the frame with structural infill, the infill walls were modeled as a diagonal strut having width 230mm, very less moment of inertia, modulus of elasticity 13800N/mm2 and Poisson ratio 0.25.

3. ANALYSIS

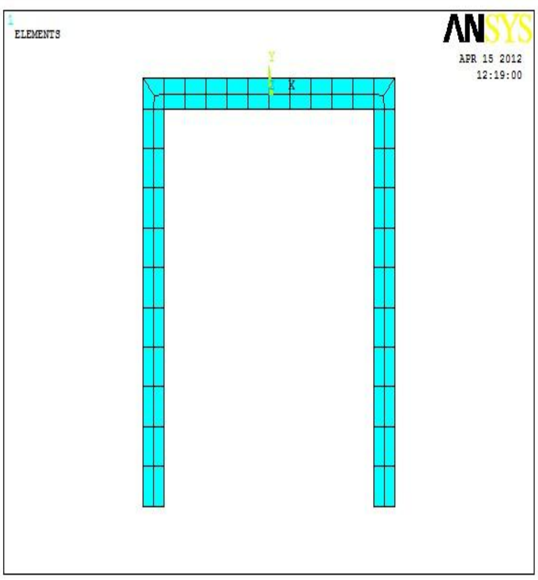

Fig.3 Modelling of frame

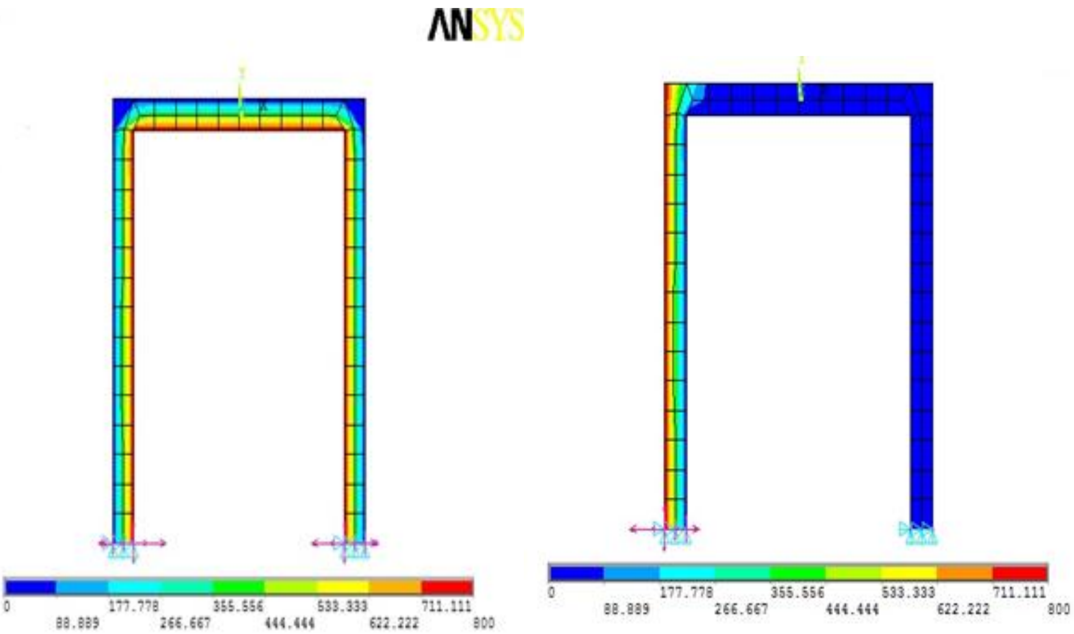

Fig 4 Temperature distribution in 2D thermal analysis

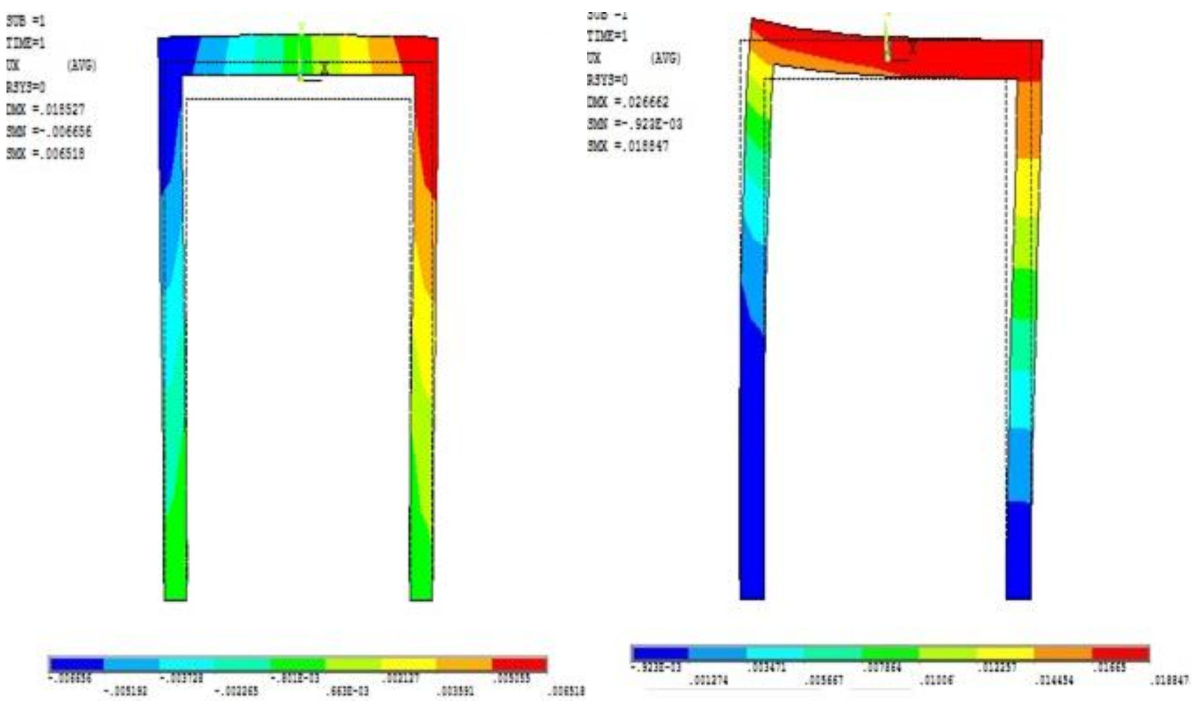

Fig 5 X-Direction Displacement

For the Temperature Analysis, two cases of frame has considered. First is frame with inside temperature and next case is frame with outside temperature. Thermo mechanical analysis is carried out and checks the frame for serviceability and strength aspects. The serviceability check is based on the allowable deflection (span/360). Generally the beam will fail, when the external moments (Me) exceeds the resisting moment (MR). Due to thermal load when the temperature increases moment gets increasing. The frame is designed based on limit state method. The beam is safe up to resisting moment (MR). After that it weakens and damage takes place and collapse of the structure may happen.

Linear static analysis is done in SAP 2000 for the present study. The earthquake load calculations were made for all the zones and all the three models analyzed and designed as per IS 456:2000 for each zone. Here, the earthquake zones are considered to demonstrate the different structural variations; but not the multi-hazard conditions. Maximum design moments obtained in each zone for the fixed support condition are shown in Table 1.

In order to find out the moment due to flood, analyses were carried out by assuming flood is acting upto a height of 2m, 3m and 4m from ground level. The maximum moments obtained in each case due to hydrostatic effects of flood are shown in Fig. 2 and the maximum moments obtained due to the combined effect of hydrostatic and impact forces (for fixed support condition) are shown in Table 2.

Table 2 Maximum design moments in kN-m

Zone	Design Moment [kN-m]
II	8.26
III	9.03
IV	10.06
V	11.60

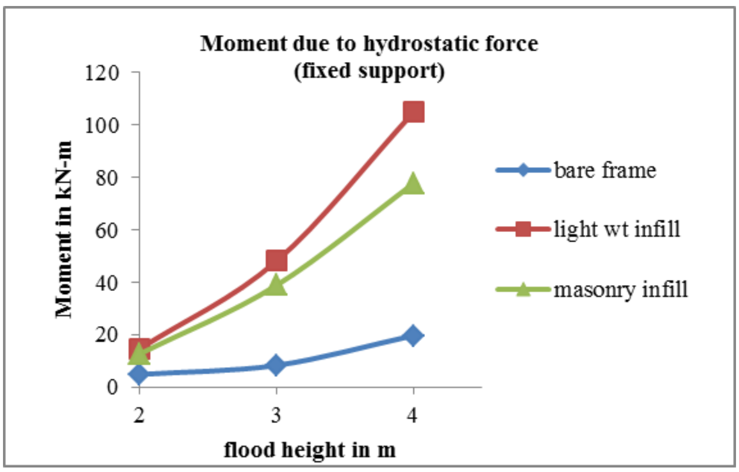

Fig.6 Moment due to hydrostatic force in kN-m for fixed support condition

It can be found that for all three frame models, the moments are found to be linearly increasing as impact load increases. Similarly, the maximum moments obtained for hinged support condition are shown in Fig3 and Table 3.

Water height (m)	bare frame		Light wt. infill		Masonry infill	
	.1ϒh	.2ϒh	.1ϒh	.2ϒh	.1ϒh	.2ϒh
2	.9	.9	8.6	2.6	5.6	8.7
3	0.5	2.7	9.2	0.3	5.7	2.6
4	4.0	8.3	26.5	48.1	8.1	8.5

Table 3 Moment due to hydrostatic and impact forces in kN-m for fixed support condition

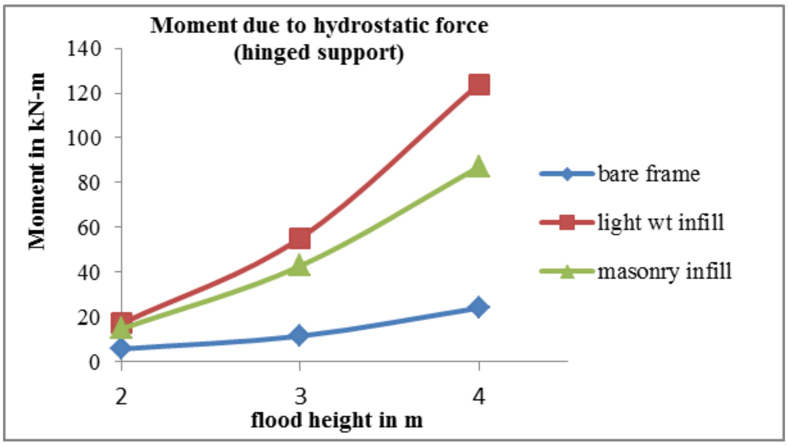

Fig.7 Moment due to hydrostatic force in kN-m for hinged support condition

The flood moments are found to be parabolically increasing as flood water height increases. The flood moment is very less for bare frame model compared to other two frame models.

Table 3 Moment due to hydrostatic and impact forces in kN-m for hinged support condition

Water ht(m)	bare frame		Light weight infill		Masonry infill	
	.1ϒh	.2ϒh	.1ϒh	.2ϒh	.1ϒh	.2ϒh
	.4	.1	9.7	2.4	6.5	8.4
	3.7	6.1	3.3	1.4	7.4	2.1
	7.7	3.0	41.3	58.5	4.6	02.3

3.1 FLOOD VULNERABILITY ASSESSMENT

Vulnerability (or vulnerability index) was assessed as a factor of ground floor height. It indicates the extent upto which the design values are exceeded if flood water reaches up to ground floor height. It is calculated using the Eq.1 shown below.

$$\text{Vulnerability index} = \frac{\text{ground floor height} - \text{safe flood height}}{\text{ground floor height}}$$

The safe flood height is found out by plotting a graph between moment due to hydrostatic force and flood height. Height corresponding to the design moment is the safe flood height (hf, safe). For example, consider a frame in Zone II; its design moment from Table 1 is

8.26kN-m. The maximum moment due to hydrostatic loading for bare frame from Fig. 3 is plotted against flood height as shown in Fig. 6. From the graph, the height corresponding to design moment 8.26kN-m is 2.84m. It is the safe flood height. It indicates the flood height upto which the structure is safe. The corresponding vulnerability index is computed by using the above equation.

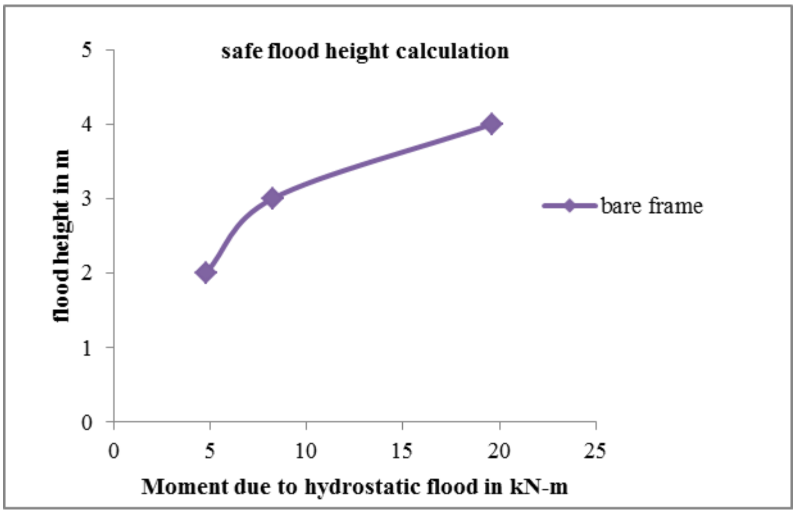

Fig.8 Variation of moment due to hydrostatic force with flood height for bare frame

The vulnerability values obtained in each case is tabulated under the following heading.

4. RESULT AND DISCUSSION

4.1 FIRE ANALYSIS RESULTS

The material property of the structural member decreases at elevated temperature. When the temperature increases, moisture in concrete is evaporated and bond is weakened and hence spalling of concrete is takes place.

When the temperature increases material nonlinear behaviour takes place. The temperature distributions, displacement of the beam are changed. Temperature and displacement variation at midspan of the beam and right quarter span of the beam is shown below.

Serviceability check

For frame with inside temperature

Safe temperature for beam is 365°C

Safe temperature for column is 1350°C

For frame with left side temperature

Safe temperature for beam is 332°C

Safe temperature for column is 475°C

Strength check

For frame with inside temperature

Safe temperature for beam is 541°C

Safe temperature for column is 255°C

For frame with left side temperature

Safe temperature for beam is 165°C

Safe temperature for column is 332°C

4.2 FLOOD VULNERABILITY RESULTS

Fig.9 shows the variation of vulnerability with respect to hydrostatic forces in different zones under fixed support condition and table shows the combined effect of hydrostatic and impact forces on vulnerability.

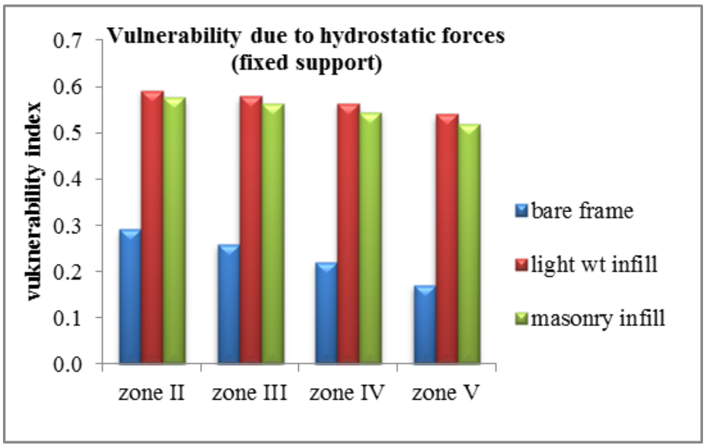

Fig.9 Variation of vulnerability due to hydrostatic forces in various zones for fixed support

Table 4 Vulnerability index due to hydrostatic and impact forces in various zones for fixed support

one	bare frame		light wt infill		masonry infill	
	.1ϒh	.2ϒh	.1ϒh	.2ϒh	.1ϒh	.2ϒh
I	.330	.377	.628	.656	.615	.646
II	.303	.355	.616	.645	.601	.632
V	.269	.327	.601	.630	.583	.615
	.224	.288	.579	.610	.559	.592

Similarly the vulnerability results for hinged support condition are shown in Fig.6 and Table 5.

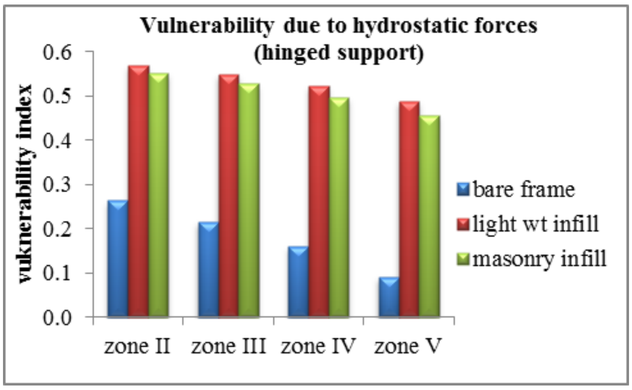

Fig.10 Variation of vulnerability due to hydrostatic forces in various zones for hinged support

The vulnerability of frame with light weight partition wall is found to be very high (57%) compared to the bare frame. For frame with structural infill it is reaching a maximum of 55% and it is only 26% for bare frame model.

Vulnerability index obtained due to hydrostatic and impact forces in various zones are shown in Table 4. It is found to be very high for frame with light weight partition wall.

Table 5 Vulnerability index due to hydrostatic and impact forces in various zones for hinged support

one	bare frame		light wt infill		masonry infill	
	.1ϒh	.2ϒh	.1ϒh	.2ϒh	.1ϒh	.2ϒh
I	.315	.360	.592	.611	.575	.594
II	.268	.315	.572	.591	.550	.570
V	.213	.263	.547	.567	.521	.542
	.145	.198	.514	.535	.481	.503

4.3 STOREY DRIFT DUE TO FLOOD

The storey drifts are evaluated from the lateral joint displacements and the results got are shown in Fig.10 and Table 9.

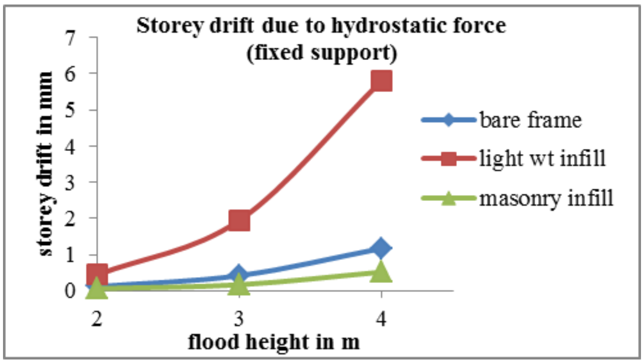

Fig.11 Variation of storey drift due to hydrostatic forces in various zones for fixed support

The storey drift is found to be less for fixed support condition. Maximum value is only 10.64mm for the frame with light weight partition walls. It is found from graph that frame with structural infill wall is having least storey drift compared to other two frames. It indicates the significance of infill in resisting lateral storey drift.

Table 5 Variation of storey drift due to hydrostatic and impact forces in various zones for fixed support

water ht (m)	bare frame		light wt infill		ma-sonry infill	
	.1ϒh	.2ϒh	.1ϒh	0 .2ϒh	.1ϒh	.2ϒh
2	.158	.199	.646	0 .853	.077	.092
3	.598	.779	.857	3 .777	.237	.322
4	.65	.123	.229	1 0.638	.732	.946

Similarly the vulnerability results for hinged support condition are shown in Fig.6 and Table 5.

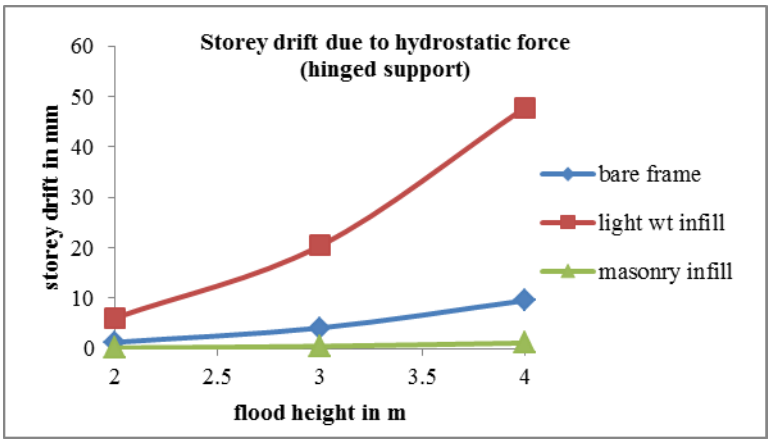

Fig.12 Variation of storey drift due to hydrostatic forces in various zones for hinged support

Table 5 Variation of storey drift due to hydrostatic and impact forces in various zones for hinged support

Water ht(m)	bare frame		light wt infill		masonry infill	
	.1ϒh	.2ϒh	.1ϒh	.2ϒh	.1ϒh	.2ϒh
2	.609	.965	.873	.653	.173	.204
3	.239	.398	6.19	1.98	.594	.732
4	2.110	4.67	0.70	3.57	.416	.713

Storey drift for frame with light weight partition wall is reaching upto 73.57 mm, which is more than that specified for seismic resistant building in IS 1893-2002.

5. LIMITATIONS AND FUTURE WORK

Flood is a time-dependent natural phenomenon. The effects and damages caused by flood can be evaluated accurately only if the flood duration is considered. But in the present study, only static analyses have done without considering the duration of flood. Further study will examines the dynamic effects of flood on the buildings.

7. CONCLUSIONS

Frame with inside fire takes more temperature than frame with left side fire due to unequal expansion in left side.

Temperature distribution along the depth of the beam is reduced

The vulnerability of frame with light weight partition wall in hinged support condition in zone II is very high compared to the other two frames. Also, vulnerability is found to be reducing as the zone increases.

Storey drift for frame with light weight partition wall in hinged support condition is reaching up to 73.57mm, which is very high than that specified for seismic resistant building. While, for other two frames, it is within specified limit.

Storey drift for frame with light weight partition wall in fixed support condition is found to be very less than hinged condition. The maximum value of storey drift for frame with light weight partition wall is only 10.64mm which is within specified limit

The storey drift for the frame with structural infill walls is found to be very less compared to other two frame models. It indicates the significance of infill in resisting lateral storey drift.

Frame with light weight partition wall is found to be most vulnerable and frame without any wall in ground floor is least vulnerable. Hence frame with light weight partitions like plywood are not preferred in flood prone areas. Results also indicate the real need of considering the flood loads in the present design procedure of a reinforced concrete building.

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