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SEISMIC PERFORMANCE OF R.C. FRAMES WITH VERTICAL STIFFNESS IRREGULARITY FROM PUSHOVER ANALYSIS

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Abstract
Earthquakes are most devastating natural hazards in terms of life and property of any region. The behavior of the structure greatly depends on size, shape and geometry of that structure in addition to how the earthquake forces are carried to the supporting ground. Irregularity in building attracts forces which lead to stress concentration at the point of irregularity; subsequently it leads to localized failure of that structure. The present study focuses on seismic performance of irregular RC frames in elevation. For this purpose ETABS a finite element software has been used. Here 2-D RC frames with four bays are considered. The irregularity is gradually increased from regular frame to highly irregular frame. Roof displacement; Base shear carried; performance points; number of hinges formed are the parameters used to quantify the performance of the structure.
Keywords: *Irregular frames, Pushover analysis, Performance point, Plastic Hinges.*

1. Introduction

Earthquake is a natural phenomenon associated with violent shaking of the ground. Large strain energy released during an earthquake travels as seismic waves in all directions through the Earth's layers, reflecting and refracting at each interface. The damage to structures due to earthquake depends on the material that the structure is made out of, the type of earthquake wave (motion) that is affecting the structure, and the ground on which the structure is built. Thus the dynamic loading on the structure during an earthquake is not external loading, but inertial effect due to motion of support. Thge various factors of the structure contributing to damage during earthquake are vertical irregularities, irregularity in strength and stiffness, mass irregularity, torsional irregularity etc.

In multi-storied framed buildings, damage from earthquake ground motion generally initiates at locations of structural weaknesses present in buildings. In some cases, these weaknesses may be created by discontinuities in stiffness, strength or mass between adjacent stories. Such discontinuities between stories are often associated with sudden variations in the frame geometry along the height [1]. There are many instances of failure of buildings in past earthquakes due to such vertical discontinuities [2]. Irregular configuration either in plan or in elevation was often recognized as one of the main cause of failure of buildings during past earthquakes. Fig 1.a shows a typical irregular building in New Delhi, India and Fig 1.b shows failure of irregular building in Islamabad collapsed in earthquake in the year 2005. Hence it is imperative to study the structural behavior of the buildings with irregularities. The present study discusses the importance of performance based approach in the seismic design of elevation asymmetric reinforced concrete frames using pushover analysis.

a) Typical Elevation Asymmetric Building, New Delhi [1]

b) Failure of irregular building in Islamabad [8]

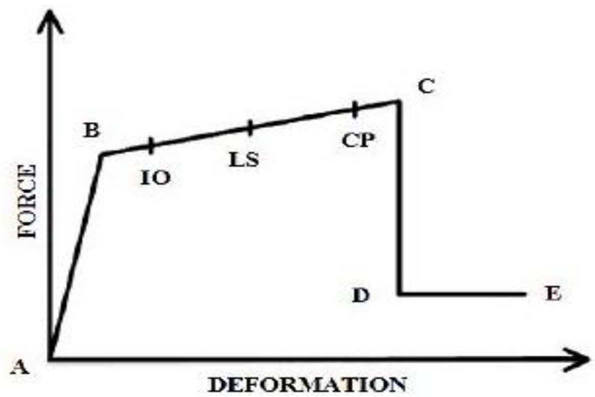
Fig.1: Elevation asymmetric R.C structures

2. Pushover Analysis

In earthquake resistant design, structures are generally designed for a lower level of seismic forces and allowed to undergo non-linear response due to severe ground motion. Hence, the non-linear static (pushover) analysis has become popular in recent years, which is used to determine the parameters such as initial stiffness, yield load, yield displacement, maximum base shear and maximum displacement. The performance of a building is measured by the state of damage under a certain level of earthquake. The state of damage is expressed as a 'performance level'. For the building as a whole, the performance level is quantified by the inelastic drift of the roof. For a member, the performance level is quantified by its deformation.

Pushover analysis is an approximate analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached [3]. In this method of analysis a model of the building is subjected to a lateral load and intensity of the lateral load is slowly increased. The process is continued until a control displacement at the top of building reaches a certain level of deformation or structure becomes unstable. Pushover curve is a plot drawn between base shear along vertical axis and roof displacement along horizontal axis. Performance point of the structure in various stages can be obtained from pushover curve. The various performance levels for a building are expressed in terms of a base shear carried versus roof displacement curve as shown in Fig. 2. The range AB is elastic range, B to IO is the range of immediate occupancy IO to LS is the range of life safety and LS to CP is the range of collapse prevention. When a hinge reaches point C on its force-displacement curve that hinge must begin to drop load [4]. If all the hinges are within the CP limit then the structure is still said to be safe. On the contrary, if the hinges formed are beyond CP limit then it is said that the structure collapses.

A pushover analysis consists of two components, namely, capacity curve and demand spectrum. The capacity curve is a plot between spectral acceleration (base shear) and corresponding spectral displacement (roof displacement) for the structure in question. With increase in lateral load, spectral acceleration increases and displacement also increases. Initially, the curve will be linear. It becomes non-linear and later exhibits very low modulus towards failure. Further, after collapse, strain softening tendency is observed. The demand spectrum depends on the design earthquake load at a location. For this purpose, seismic zone of the location and type of the ground on which the structure is built are the necessary data. The point of intersection of these two curves is called performance point. The location (co-ordinates) of this point suggests the performance level of the structure under a design earthquake load. It indicates the maximum base shear carried by the structure and its ductility characteristics.



Where,
IO - Immediate occupancy
LS- Life Safety
CP- Collapse Prevention

Fig 2: Typical Pushover Curve with Acceptance Criteria

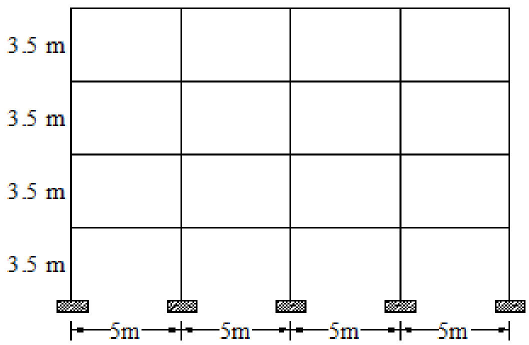
3. Present study

In the present work, six Models of 4-Bay, 4-storey 2-D RC frames have been considered as shown in Fig. 3. Model 1 is treated as a benchmark frame as there is no vertical irregularity in it. The degree of vertical irregularity is increased from Model 2 to Model 6.

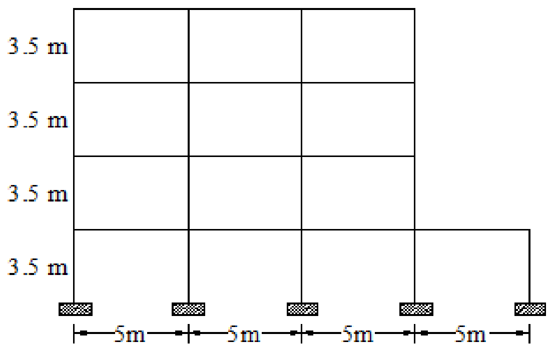
The frames are designed according to the Indian Standard Code IS-456: 2000 and IS 1893 2002 [5]. An imposed load of 20kN/m is assumed which is exclusive of dead load. The structure is assumed to be located at Zone III for analysis and design for this study. ETABS facilitates the plastic hinge properties described in ATC-40 [6,7]. Auto hinge properties such as PMM hinges are assigned at the column ends and M3 hinges are assigned at the beam ends. Pushover analysis is carried out considering displacement controlled analysis. The details of the building data are shown in TABLE 1.

Table 1**:** Building parameters considered for the study

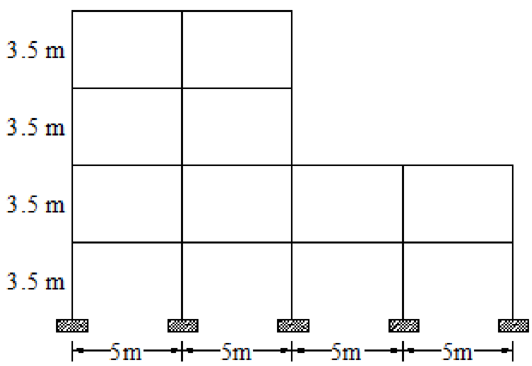
PARAMETER	**TYPE / VALUE**
Structure type	Special Moment Resisting Frame (S.M.R.F.)
Number of stories	Four
Typical storey height	3.5m
Beam size	0.2 m x 0.6 m
Column size	0.2 m x 0.45 m
Imposed Load	20kN/m
Seismic zone	III
Importance factor "I"	1.0
Soil type	Medium stiff (Type II)

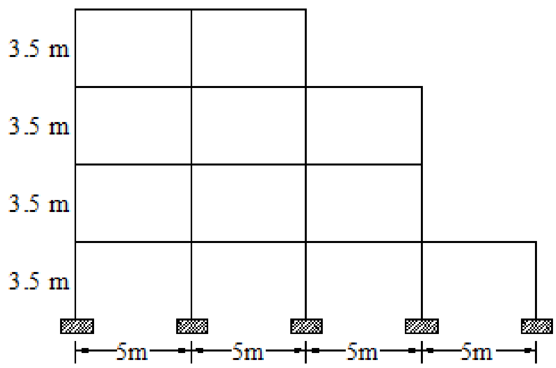


Model 1

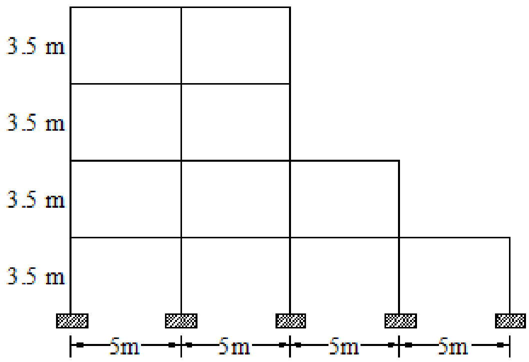


Model 1

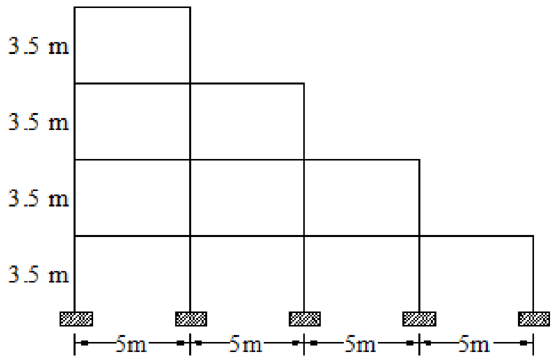




Model 3 Model 4



Model 5



Model 6

Fig 3**:** Typical elevation of the models considered for the study.

4. Results and Discussion

Fig. 4 shows capacity curves of various models considered in the present study. These pushover curves are plotted between base shear carried and roof displacement undergone by the structure. It is seen that as the irregularity in the structure increases the lateral load carrying capacity of the structure decreases. Thus the structure is vulnerable to seismic force as the vertical geometric irregularity in the structure is increased.

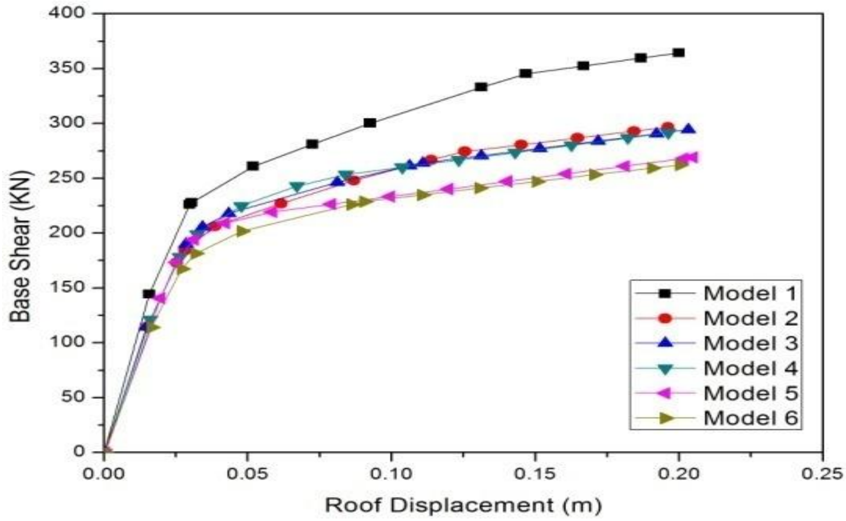


Fig 4**:** Pushover curves for the six frame models

Fig. 5 shows plot between spectral acceleration, spectral displacement and demand. Here the capacity curve is plotted in Acceleration Displacement response Spectra (ADRS) format in which base shear carried and roof displacement undergone are represented by spectral acceleration and spectral displacement respectively. The point of intersection of Capacity curve and Demand curve gives Performance Point of the structure. In the present study performance point of all the models is checked against Zone III and Zone V. It is observed that the performance point shifts rightwards with Zones there by indicating vulnerability of the structures.

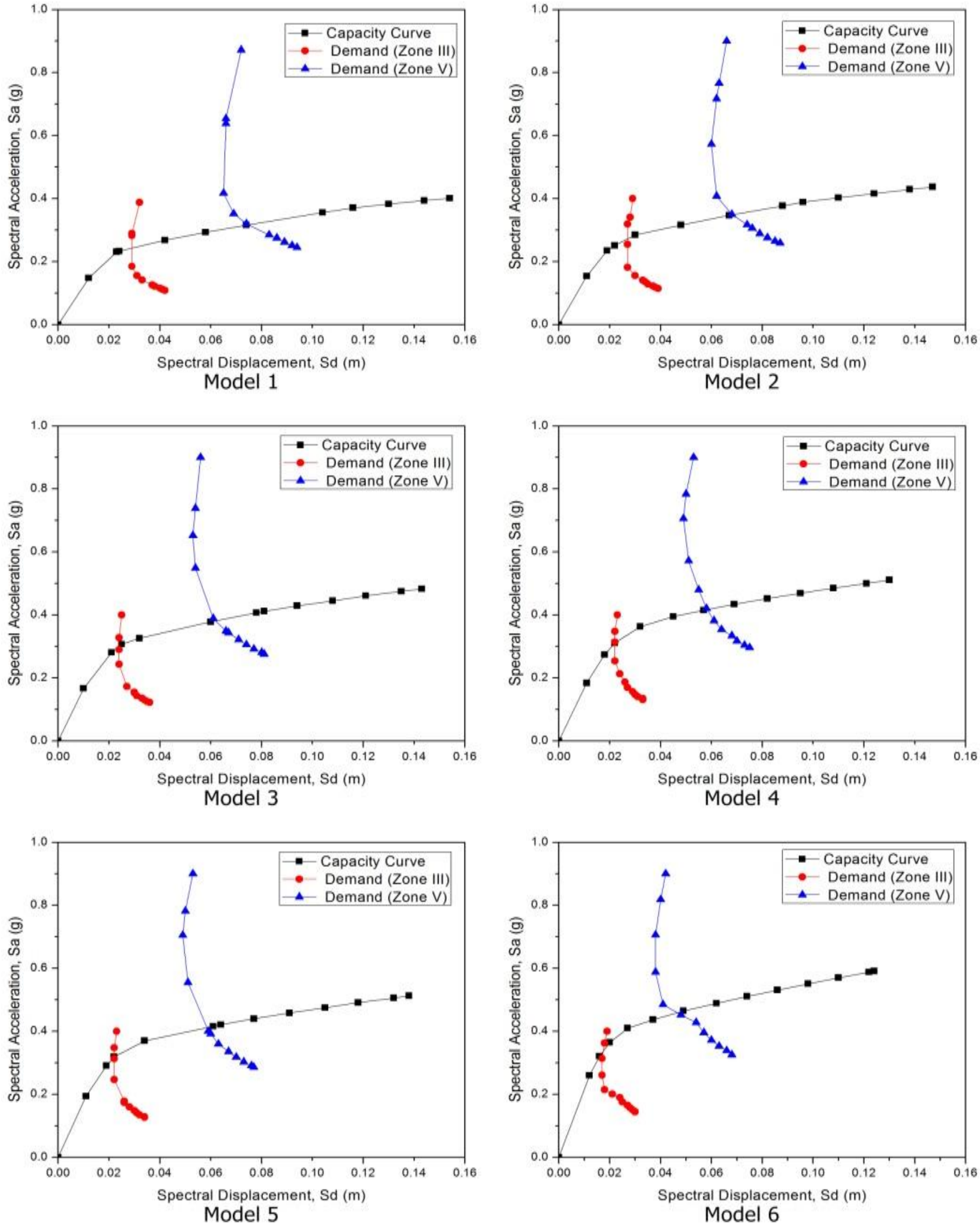


Fig 5: Performance point of the six frame models

TABLE 2 gives the number and status of plastic hinges at different states of six models considered for the present study. When the magnitude of earthquake shaking exceeds the design value, the status is likely to worsen. In the present work, it can be observed that the severity of plastic hinges formed increases from Model 1 to Model 6 wherein the frame becomes more and more asymmetric in elevation. This indicates that the asymmetry in elevation of the building increases the severity of lateral forces on the buildings.

Table 2**:**Number and status of plastic hinges in the models**.**

Type of Models	**No. of Hinges**	**HINGE STATUS**							
		E		**IO**		**LS**		**CP**	
		No.	% Total	No.	% Total	No.	% Total	No.	% Total
Model 1	72	43	59.72	5	6.94	11	15.27	13	18.05
Model 2	60	36	60.0	4	6.67	14	23.33	6	10
Model 3	56	33	58.92	4	7.14	17	30.35	2	3.57
Model 4	54	30	55.55	12	22.22	12	22.22	0	0.00
Model 5	52	30	57.7	12	23.07	10	19.23	0	0.00
Model 6	48	28	58.33	9	18.75	11	22.91	0	0.00

Table 3**:** Base Shear (V) and Roof Displacement (D) at Performance point

Performance Points	**SEISMIC ZONE V**					
Type of Model	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
V	301	248	248	253	223	224
D	0.094	0.088	0.084	0.086	0.082	0.074
Performance level	LS	IO	IO	IO	IO	IO

TABLE 3 shows base shear and roof displacement at performance point which indicates the damage level of the structures considered for the present study. It is observed that the structure lies between elastic state to life safety level.

5. Concluding remarks

Following conclusions are drawn from the analysis:

1. Structure becomes vulnerable with increase in vertical irregularity.

2. With increase in vertical irregularity the percentage of plastic hinges crossing elastic limit increase, rendering the structure more vulnerable.

3. Vulnerability of the structure depends on the Zone in which structure is located. Therefore utmost care should be taken while designing irregular structure in high earthquake prone regions.

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