Effect of Hybrid System in Stepped Building Frame

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***Abstract*— High rise structures have fascinated mankind from the beginning of the civilization itself. In the last few decades the rate of growth in vertical structures has increased drastically. Seismic performance of a building is an important criteria to be considered in the design phase. Many building nowadays have irregular configuration both in plan and elevation. Usually, irregularities are unavoidable in the construction of buildings. This causes the structure to be more vulnerable to damages during earthquakes. Hence, it is necessary to assess the seismic performance of a structure in the design phase. In this work, a hybrid system which is a combination of conventional lateral load resisting system (bracings and shear wall) and a moment resisting is used, to improve the seismic performance of vertical irregular structures such as stepped building. Different types of concentric bracing systems have been used. The regularity index provides a basis for assessing the degree of irregularities in a stepped building frame. The performance of the structure is assessed by means of modal analysis and nonlinear static analysis in SAP 2000.**

Keywords— Stepped building frame, Hybrid system, Regularity index, Modal analysis, Pushover analysis

I. INTRODUCTION

A. General

Urbanization caused housing problems which have led to the rise of many multistoried buildings. The modern trends is towards architecturally innovative designs which incorporating irregularities in the buildings. Irregularities in buildings will cause damage when subjected to lateral forces such as seismic force. In multistoried buildings, damage from earthquake ground motion generally initiates at the locations where the structure is weak [6]. Structural weaknesses may be caused by the discontinuities in stiffness, strength and mass difference between adjacent storeys. Irregularity may be in the form of vertical and horizontal irregularity [20].

A common form of vertical discontinuity arises from reduction of the lateral dimension of the building along its height commonly known as stepped building. Stepped buildings with vertical discontinuity construction have increased now-a-days because of its functional and aesthetic architecture. Stepped form provides adequate daylight and ventilation in an urban locality with closely spaced tall buildings[3]. They are characterized by staggered abrupt reductions in floor area along the height of the building.

A building is said to be torsionally irregular when the maximum horizontal displacement of any floor in the direction of the lateral force at one end of the floor is more than 1.5 times its minimum horizontal displacement at the far end of the same floor in that direction and the natural period corresponding to the fundamental torsional mode of oscillation is more than those of the first two translational modes of oscillation along each principle and directions[15].

When a building is subjected to seismic excitation, horizontal inertia forces are generated in the building. The resultant of these forces acts through a point, known as center of mass of the structure. The vertical members in the structure resist the lateral forces and the total resultant of systems of forces acting through a point is known as center of stiffness. When the center of mass and center of stiffness does not coincide eccentricities are developed in the buildings thereby generating torsion. Due to the presence of irregularity, the lateral resistance to the ground motion is torsionally unbalanced creating large displacement amplifications and high force concentrations within the resisting elements causing damages and often collapse of the structure. Eccentric arrangement of non-structural components, asymmetric yielding, presence of rotational component in ground motions and the variations in input energy imparted by the ground motions also contributes to the torsion buildings.

B. Stepped BuildingFrame

Stepped buildings are characterized by abrupt reductions in floor area along the height of the building. Height-wise changes in stiffness and mass, imparts render the dynamic characteristics to a stepped building. Stepped buildings are a typical form of vertical geometric irregularity that required special design consideration due to transverse and torsional responses and higher mode effects. As per IS 1893:2016, stepped building forms are to be treated as vertically irregular when the lateral dimension of the maximum offset (A) at the roof level exceeds 25% of the lateral dimension of the building at the base (L) as shown in Fig.1.

Fig.1. Stepped building frame

There are generally two ways of providing steps in buildings (assumed square in plan); the first type has steps in one direction alone whereas in the second type, steps are provided in the two orthogonal directions. As per IS 1893(1):2016, vertical geometric irregularity exists, when A/L > 0.25.[20]
In this study, steps were provided along the x-direction.
Research works on stepped buildings are gaining importance now-a-days due to the difficulty in predicting the response of such buildings under seismic excitation.
The design codes such as IS 1893 (part 1):2016 and ASCE 7:2005 consider the ratio of geometric lateral dimension of one storey of a building to the other storey as a parameter to define vertical geometric irregularity as shown in Fig.2.

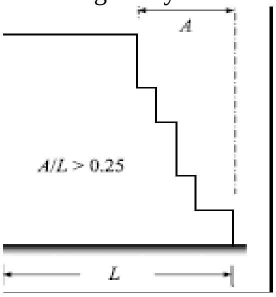


Fig.2. Vertical geometry according to IS 1893 (1) : 2016

C. Structural systems

A structural system consists of elements which are used to resist the various combination of vertical and horizontal loads. The selection of one structural system depends on various factors such as location, height and architectural requirements of the building[6].
One of the major consideration in the modern office building is the requirement of large working spaces.Therefore all the load carrying members especially the lateral load resisting members are placed over the exterior periphery and at the core of the structures. Currently there are different forms of structural systems, out of which moment resisting frame, braced frame and shear wall framed system are the conventional types.
Building frame with shear wall and structural system (bracing) combination is called hybrid system. In this study various structural systems are to be used such as;

a. Rigid Frame System

b. Braced Frame system

c. Shear wall frame system

II. OBJECTIVE

The objective of this study is:

- To study the effect of hybrid system in stepped building frame

III. METHODOLOGY

A. Building Idealization

RC framed building of 6 storeys having stepped configuration with different concentric bracing and shear wall structural system combinations were considered. The parameter of the building are tabulated in Table I and material property described in Table II.

TABLE I. PARAMETERS OF BUILDING

Building type	Office building
Zone factor, z	0.16
Importance factor, I	1
Response reduction factor, R	5
Damping (% critical)	5
Soil type	Medium
Plan dimension (m)	24m x 24m
No of bays	4
Bay width in x and y direction(m)	6m
Ground storey height (m)	4.5m
Upper storey height (m)	3.3m
Opening area in shear wall (m)	1m x 2m

TABLE II. STRUCTURAL PARAMETERS

Parameter	Dimensions
Slab thickness	150mm
Wall thickness	230mm
Shear wall thickness	250mm
Structural steel section for bracings	ISMB 300
Beam	300mm x 700mm
Column	600mm x 600mm

B. Finite Element Modelling

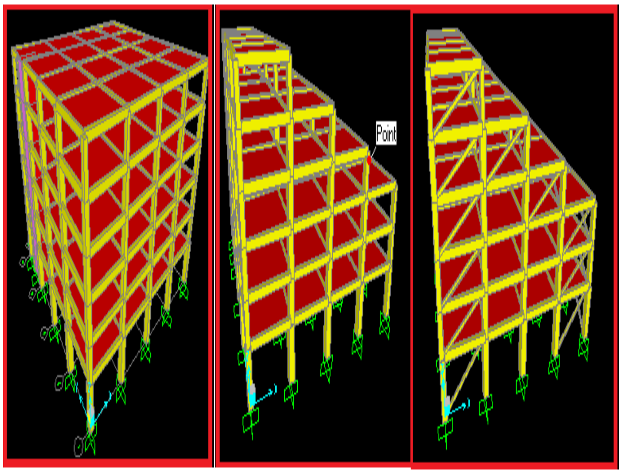
The beams and columns are modelled as frame elements. The slab and shear wall are modelled as thin shell element [2]. The data chosen for the modelling is shown in Table I. The material data chosen for study is shown in Table II. The modelling of the structures is done in SAP 2000.

a. Computational Model

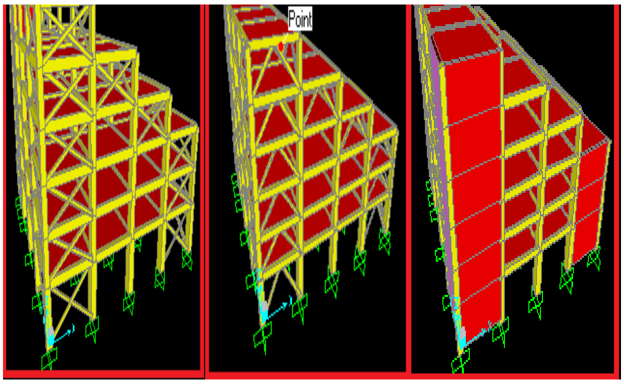
Modelling a building involves modelling and assemblage of its various load-carrying elements. The model must ideally represent the mass distribution, strength, stiffness and deformability. Modelling of the material properties and structural elements used in the present study were discussed below.
Following models are considered for the analysis and are described in Table III. Different structural models were chosen as shown in Fig. 3.

TABLE III. MODELS AND NOTATIONS

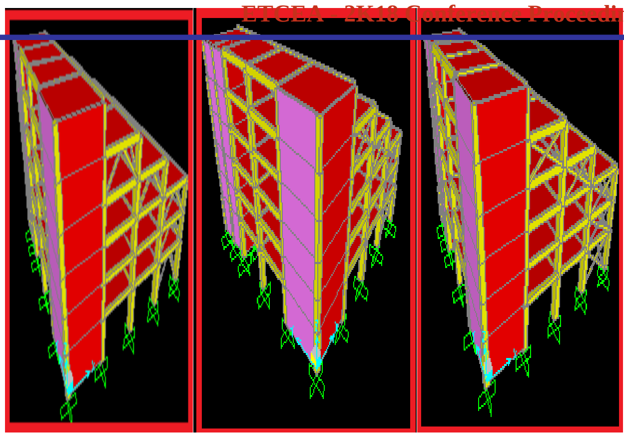
Models	Notations
Bare frame	BF
Irregular frame	S1
X brace	XB
Diagonal brace	DB
Chevron brace	CB
Shear wall	SW
Shear wall with X brace	SW-XB
Shear wall with diagonal brace	SW-DB
Shear wall with inverted brace	SW-CB



a)BF b) IR c)S1CB



d)S1XB e) S1CB f)S1SW



g)S1SWCB h) S1SWDB i)S1SWXB

Fig.3. Structural modals

IV. RESULTS AND DISCUSSIONS

All the selected building models with different stepped irregularities are analyzed by nonlinear static analysis in SAP2000 (v12).

A. Modal Analysis

The information obtained from modal analysis is used to classify the buildings as torsionally stiff or flexible. The period of vibration as shown in Fig.4.The storey stiffness of different models were shown in Fig.5.

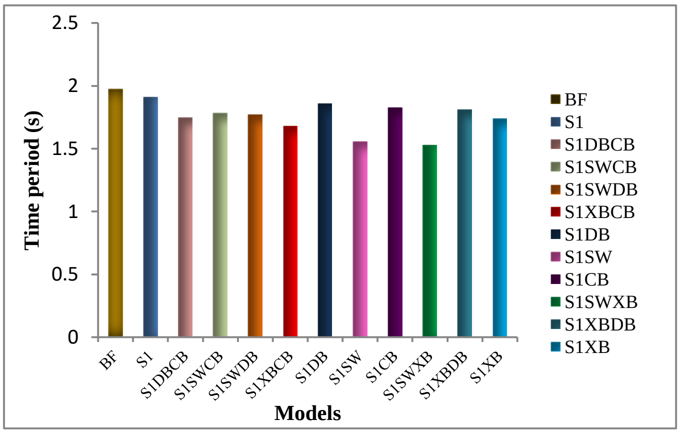


Fig.4. Fundamental time period of different models

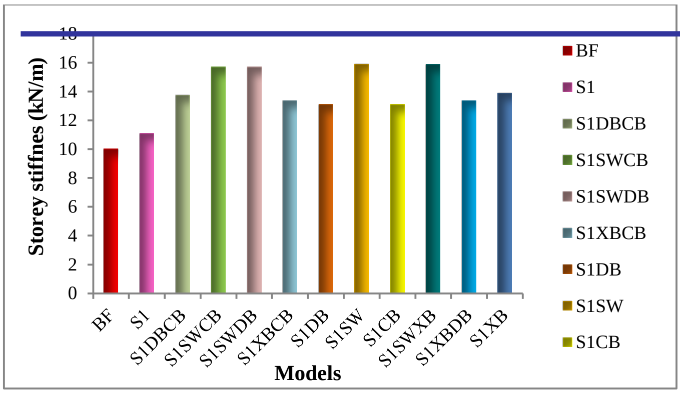


Fig.5. Storey stiffness of different models

TABLE IV. FUNDAMENTAL TIME PERIOD OF BUILDING

Percentage increase in fundamental time period with respect to IR	
Models	**Fundamental time period (s)**
BF	1.973
S1	1.91
S1DBCB	1.75
S1SWCB	1.785
S1SWDB	1.77
S1XBCB	1.68
S1DB	1.86
S1SW	1.56
S1CB	1.83
S1SWXB	1.532
S1XBDB	1.81
S1XB	1.74

From Table IV it is to be noted that fundamental time period of stepped building decreased due to increasing irregularity. Another important observation regarding stepped building is that the building become stiffer as the number of steps is increased. Implementation of hybrid system in stepped building improves the dynamic property of building.

B. Quantifying Building Irregularity

Building frame having different building geometries with different stepped irregularities due to the successive reduction of one bay and one step height of one storey (S1 at the top of the building as shown in Fig.3.

The mass and stiffness distributions in the frame have to be considered in quantifying the irregularity of stepped building frame. Studying the dynamic property of regular building, it is observed that participation of first mode is dominant. When the vertical irregularities (step in the building frame) are introduced, it is observed that as the irregularity increases the first mode participation decreases with increased participation on higher modes. It can be seen that irregularity in the stepped building frame can be captured by relative first mode participation factor [3]. Inorder to access the irregularity of building a factor is to be derived such as regularity index based on Sarkar [3].

$$\eta = \Gamma / \Gamma_{ref} \quad (1)$$

Where, η - Regularity index

Γ - First modal participation factor for irregular building

Γ_{ref} - First modal participation factor for regular building

TABLE V. BUILDING IRREGULARITY

Building Irregularity		
Models	**Proposed irregularity index (η)**	**% irregularity**
BF	1	0
S1	0.65	54
S1EBDB	0.71	41
S1SWCB	0.85	18
S1SWDB	0.82	22
S1XBCB	0.80	25
S1EB	0.69	45
S1SW	**0.89**	**12**
S1CB	0.73	37
S1SWXB	**0.95**	**5**
S1XBDB	0.79	27
S1XB	0.71	41

From Table V it is to be noted that hybrid system in stepped building frame reduces the irregularity of building frame.

C. Pushover Analysis

Pushover is a static-nonlinear analysis method where a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern which continuously increases through elastic and inelastic behavior until an ultimate condition is reached. The arrangement of hinges are plotted in Fig.6. Plastic hinges formation starts at beam ends and base columns of lower storeys, then propagates to upper storeys and continue with yielding of interior intermediate columns in the upper storeys.

Based on pushover analysis roof displacement and base shear of different models are plotted as shown in Fig.7. and Fig.8.

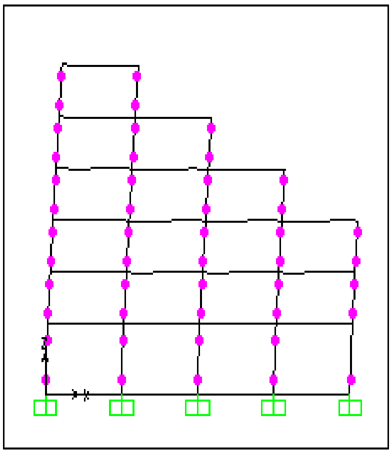


Fig. 6. Hinge pattern 6 story building setback with one storey height

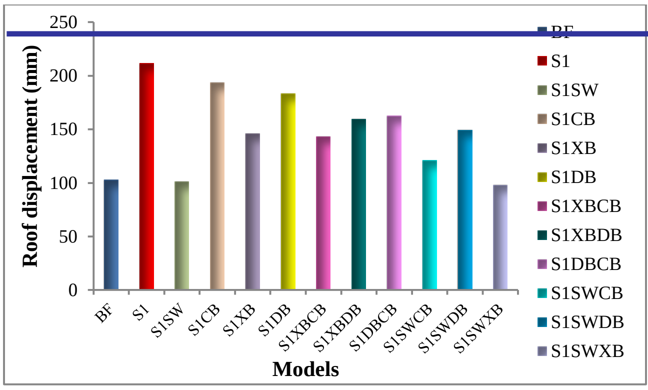


Fig.7. Roof displacement of different models

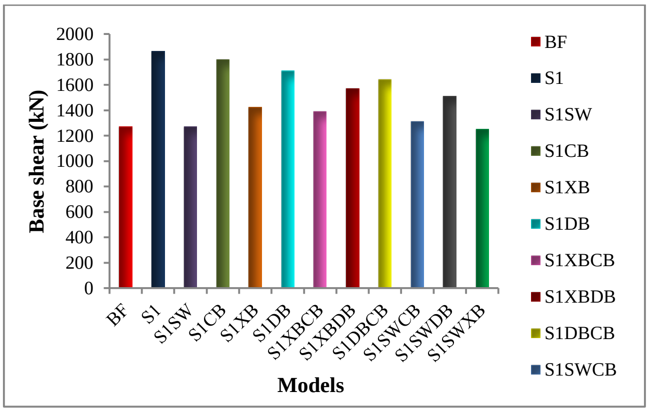


Fig.8. Base shear of different models

V. CONCLUSION

The following are the conclusions obtained from this study,

- The use of hybrid system in stepped building decrease the fundamental time period of stepped building and stepped building become more stiffer.
- Implementation of hybrid system reduces the irregularity of stepped building frame.
- The most effective hybrid system in stepped building is that shear wall dual system and shear wall with x brace structural system combination.

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REFERENCES

[1] **Kiran, S., Ramtekkar, G. D.** and **Titiksh, A.** (2017) “Comparative study for mitigating the soft storey effect in multi storey buildings using different structural arrangements”, *International Journal Of Civil Engineering And Technology*, 8, 520 – 53.

[2] **Drazic, J. and Vatin, N.** (2016) “The influence of configuration on to the seismic resistance of a building”, *Procedia Engineering*, 165, 883 -890.

[3] **Sarkar, P., Prasad, M. A. and Menon, D.** (2015) “Vertical geometric irregularity in stepped building frames”, *Engineering Structures*, 32, 2175 -21

[4] **Namdev, V., Singh, Y.** and **Lang, D. H.** (2012) “A comparative study of design base shear for rc buildings in selected seismic design codes”, *Earthquake spectra*, 28, 1047 – 1070.

[5] **Agarwal, P.** and **Shrikhande, M.** (2011) “Earthquake Resistant Design of structures”, Rajkamal Electric Press, New Delhi.

[6] **Kim, S.** and **Elnashai, A. S.** (2009) “Characterization of shaking intensity distribution and seismic assesment of RC buildings for the Kashmir earthquake”, *Engineering Structures*, 02, 105 -111.

[7] **Karavasilis, T. L., Bazeos, N.** and **Beskos, D. E.** (2008) “Seismic response of plane steel MRF with stepped , estimation of inelastic deformation demands”, *Journal of Constructional Steel Research*, 64, 644 – 654.

[8] **Inel, M., Ozmen, H.** and **Bilgin, H.** (2008) “Re-evaluation of building damage during recent earthquakes in Turkey”, *Engineering Structures*, 30, 286 -292.

[9] **Athanassiadou, C. J.** (2008) “Seismic performance of RC frames irregular in elevation”, *Engineering Structures*, 30, 1250-1261.

[10] **Gunel, M. H.** and **Ilgin, H. E.** (2007) “A proposal for the classification of structural systems of tall buildings”, *Building and Environment*, 42, 2667 – 2675.

[11] IS 800: 2007, Indian Standard General Construction in Steel – Code of Practice, 3rd Revision, Bureau of Indian Standards, New Delhi.

[12] **Magnusson, J.** and **klemencic, R.** (2006) “Case studies of Recent high rise structures”, ASCE Structures Congress 2006.

[13] **Sharon, B. L.,** and **Wood, S. L.** (2005) “Seismic response of RC frames with irregular profiles”, *Engineering Structures ASCE*, 08, 545 – 566.

[14] **Chintanapakdee, C.** and **Chopra, A. K.** (2004) “Seismic performance of irregular frames, response history and modal pushover analysis”, *Engineering Structures*, 130, 1170 – 1185.

[15] **Goel , R, K.** and **Chopra, A. K.** (2003) “Period formula for moment resisting frame buildings”, *Engineering Structures*, 123, 1454 –1461.

[16] IS 875(Part 1): 1987 (Re: 2003) Indian Standard Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures, Part 1 Dead Loads – Unit Weights of Building Materials and Stored Materials, 2nd Revision,8th Ed., Bureau of Indian Standards., New Delhi.

[17] **Smith, B. S.** and **Coull, A.** “Tall Building Structures – Analysis and Design”, United States of America, 1991.

[18] IS 4326: 1993 (Re: 2003) Indian Standard Criteria for Earthquake Resistant Design and Construction of Buildings – Code of Practice, 2nd Revision,3.3rd Ed., Bureau of Indian Standards., New Delhi.

[19] **Maheri, M. R.** and **Sahebi, A.** (1997) “Use of Steel Bracing In Reinforced Concrete Frames”, Engineering structures, 19, 1018-1024.

[20] IS 1893 (Part 1): 2016, Indian Standard Criteria for Earthquake Resistant Design of Structures, Part 1 General Provisions and Buildings, Fifth Revision, Bureau of Indian Standards., New Delhi.