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Progressive Collapse Study On Irregular Steel Framed Structure By Non-Linear Static Analysis

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***Abstract*— The present study describes the comparison between the irregular steel space frameworks with and without having considerable progressive collapse cases using nonlinear static analysis. Modal pushover analysis and pushover analyses with various invariant lateral load patterns were performed on steel moment resisting frames. The results revealed that the steel space frameworks with progressive collapse cases showed a large decrement in the maximum base share and maximum displacement capacity compared to their irregular steel space frameworks without progressive collapse cases. The results of the pushover analysis also confirmed that the irregular steel space frames works with progressive collapse cases have significantly improved stability in seismic zones over their counterparts without progressive collapse cases.**

Keywords—Progressive collapse study; pushover analysis; non-linear static analysis; irregular steel structure

I. INTRODUCTION

In the construction industry, steel structure plays a vital role. Hence, it is important to design a structure that is stable even under abnormal conditions like earthquakes. Under earthquake conditions, the steel structure experiences high-frequency movements that cause inertial forces on the building components. These internal forces may collapse the structure. Hence it is important to design the pre-analyzed steel structure to predict accurately about the seismic response levels. A simple computer-based push-over analysis is a technique for performance-based design of building frameworks. During the last few years, considerable attention from the civil engineers has been paid on the push-over analysis owing its simplicity and the effectiveness of the results.

Vijay *et al.* (2013)[1] studied about computer based push-over analysis techniquefor performance-based design of steel building frame works subjected to earthquake loading. Through the use of a plasticity-factor that measures the degree of plasticization, the standard elastic and geometric stiffness matrices for frame elements (beams, columns, etc.) are progressively modified to study the non-linear elastic–plastic behaviour under incrementally increasing lateral loads and constant gravity loads. The analysis is performed for two steel frameworks of solid and hollow members. This investigation aims to analyze the difference in structural behavior between hollow and solid frames. The technique adopted in this research is based on the conventional displacement method of elastic analysis.

Ashutosh Bagchi *et al.* (2009)[2] studied about the performance of a 20- story moment resisting steel frame building, designed for western part of Canada. The actual and simulated ground motion records are utilized to evaluate the dynamic response.

Hejazi *et al.* (2011)[3] described about softening at the lower level of high-rise buildings under earthquake conditions. They have also tried to investigate the effect of addition of bracings in various arrangements of the structure to minimize soft story effect. This study leads to understand the vulnerability level of the multi-storied buildings to retrofit to have the minimum requirements.

Gaurav Joshi *et al.* (2013)[4] studied about the seismic analysis of soft storey building frames using 3 building plans, 15 soft storeys cases and 20 load combinations. Floor heights have been varied and infill efficiency has been ignored to create soft storeys. 45 frames have been analyzed. using STAAD.PRO software. The effects of various parameters have been analyzed in terms of max. Moment, max. Shear force, max. Axial force max. Storey displacements and max. Drift.

Nelson Lam *et al.* (2013)[5] investigated the seismic performance of "soft-storey‟ buildings to develop a realistic seismic risk model to understand the priority of the retrofitting work on existing building stock. Bracings have been used as retrofit as well. A typical six-story steel frame building has been designed for various types of eccentric bracings using different types of eccentric bracings (D, K, and V) as per the IS 800-2007. Using nonlinear static analysis, performance of each frame has been studied.

Blonde *et al.* (2012)[6] studied about soft first storied multi-storey building located in seismic zone IV to describe the performance characteristics such as stiffness, bending moment, shear force and drift. The study has been carried out using various different mathematical models adopting various methods to improve the seismic performance of the building. The study also described about the analytical models that represent all the existing components that influence the mass, strength, stiffness and deformability of the structure. The equivalent static and multimodal dynamic analysis have been carried out on the entire mathematical 3D model using the software SAP2000 and the comparisons of these models are reported. The performance of all the building models is also observed in high seismic zone V.

Rahiman G. Khan *et al.* (2013)[7] carried out a study to find the best place for soft stories in a high rise buildings using performance based seismic engineering (PBSE), where inelastic structural analysis has been combined with seismic hazard assessment to estimate expected seismic performance. Utilizing the advantage of this tool, structural engineers can

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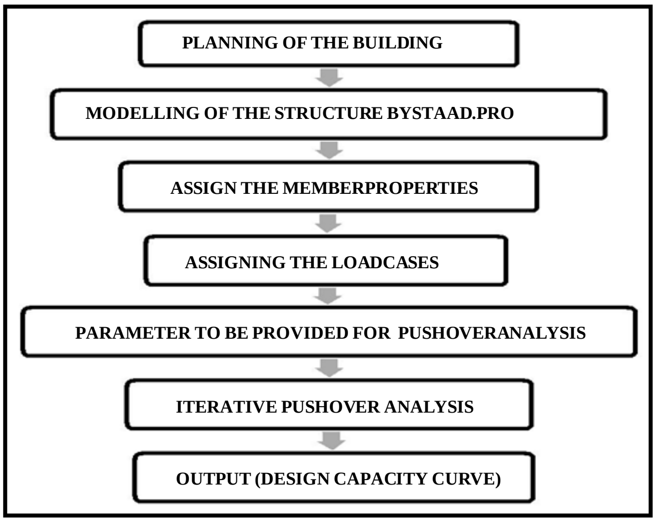

Fig. 1: *Pushover analysis methodology*

observe the expected performance of any structure under large forces and can modify design accordingly on a computer. PBSE generally involves nonlinear static analysis, which is also known as pushover analysis.

Rakshith Gowda K.R *et al*. (2014)[8] investigated the behavior of RC frames under the static and dynamic earthquake loading conditions. The results obtained on bare frame, frame with infill and different location of soft storey provided have been compared and conclusions are made in view of IS code. This study described that, providing infill can improve the earthquake resistant behavior of the structure compared to the building provided with soft story.

The present study describes a push-over analysis on a steel frame structure designed according to IS-800 (2007) and illustrates the progressive collapse conditions of the steel structure under different seismic zones.

II. METHODOLOGY

To study the progressive collapse conditions of a stell structure under different seismic zones, we have modelled an irregular structure using STAAD programme, assigned member properties and load cases to the structure and subjected to progressive collapse study using push-over analysis under different seismic zone conditions. The results obtained were compared with the results of normal irregular structure under similar conditions. The pictorial representation of the adopted methodology is shown in **Fig. 1**.

Building the structure:

The details of considered steel space frame are shown in the corresponding results section and the isometric view of the irregular steel frame structure is provided in **Fig. 2**. The building is assumed to be unsymmetrical in plan. Plan dimensions of the considered steel space frame are 18m x 16m. **Case I:** Irregular G+5 framed structure shown in **Fig. 2** (Regular space frame (IRF)); **Case II:** IrregularG+5 framed structure by considering 1st corner column (C1) removed in X

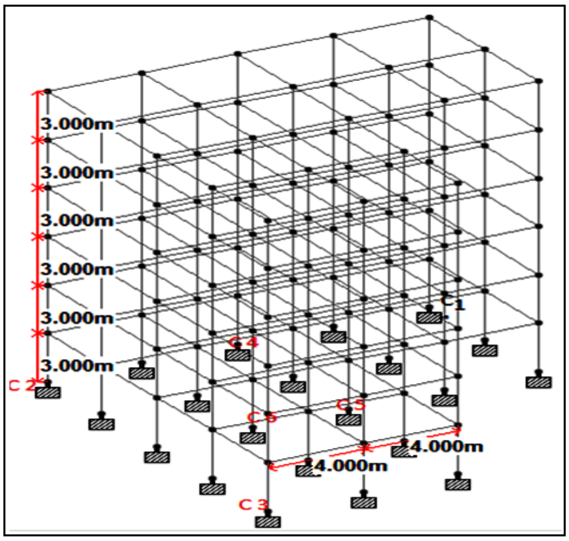

Fig. 2: *Isometric view of the irregular steel frame structure*

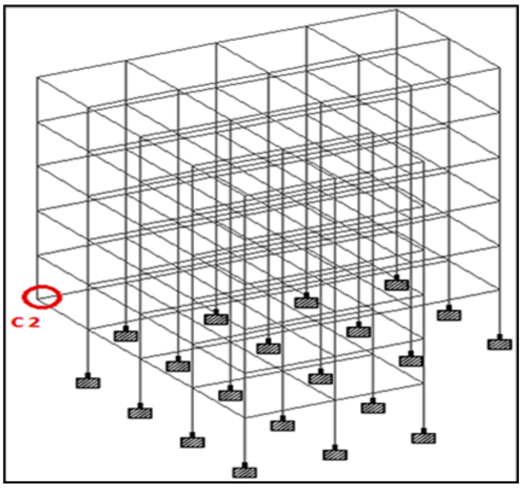

Fig. 3: *Isometric view of IRFC-1 model in STAAD-Pro*

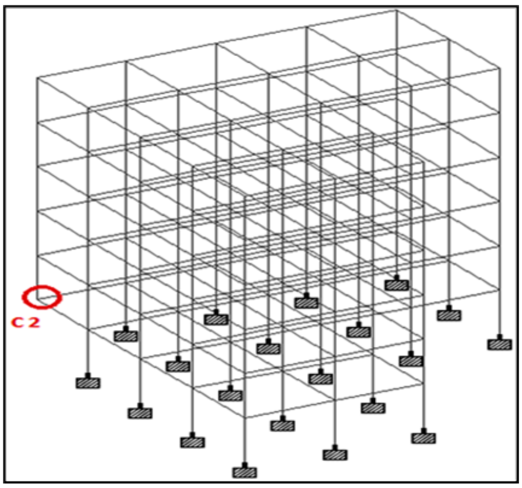

Fig. 4: *Isometric view of IRFC-2 model in STAAD-Pro.*

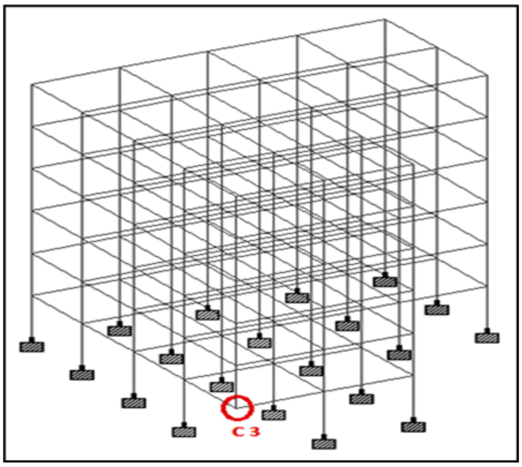

Fig. 5: *Isometric view of IRFC-3 model in STAAD-Pro.*

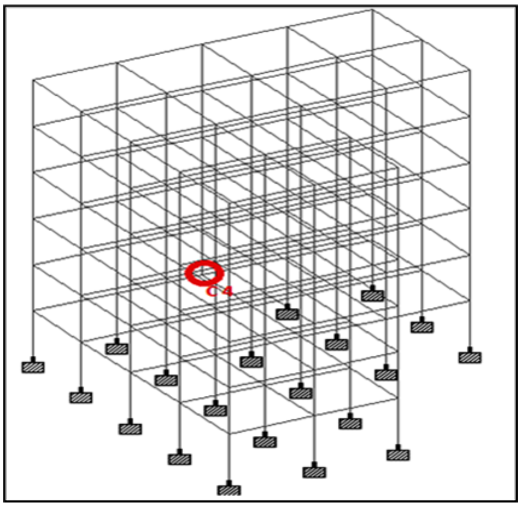

Fig. 6: *Isometric view of IRFC-4 model in STAAD-Pro.*

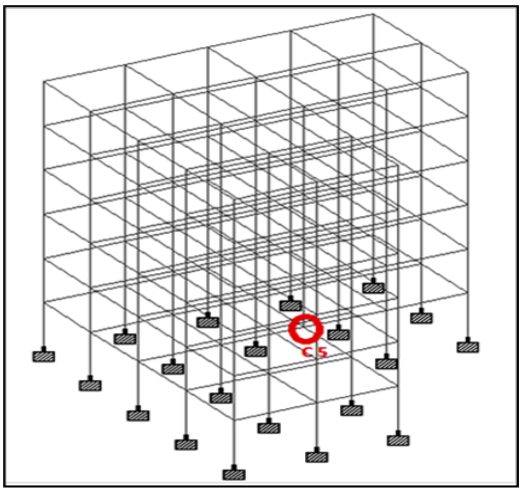

Fig. 7: *Isometric view of IRFC-5 model in STAAD-Pro.*

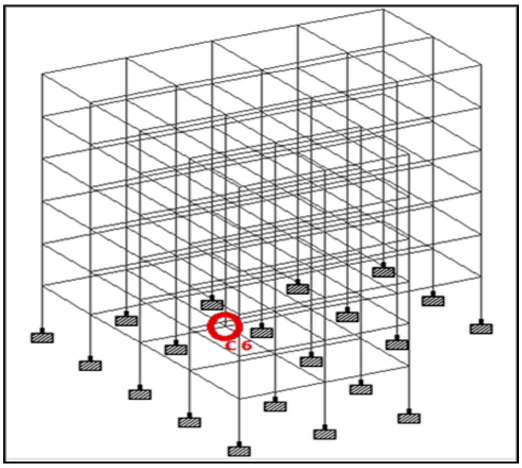

Fig. 8: *Isometric view of IRFC-6 model in STAAD-Pro.*

direction shown in **Fig. 3**. (IRFC-1); **Case III:** Irregular G+5 framed structure by considering 2nd corner column (C2) removed in X-direction shown in **Fig. 4**. (IRFC-2); **Case IV:** IrregularG+5 framed structure by considering 3rd corner column (C3) removed in Z-direction shown in **Fig. 5** (IRFC-3); **Case V:** Irregular G+5 framed structure by considering 4th edge column (C4) removed shown in **Fig. 6** (IRFC-4); **Case VI:** IrregularG+5 framed structure by considering 5th middle column (C5) removed shown in **Fig. 7** (IRFC-5); **Case VII:** IrregularG+5 framed structure by considering 6th middle column (C6) removed shown in **Fig. 8** (IRFC-6).

III. RESULTS AND DISCUSSION

Comparison of base shears and displacements for steel space framed structure with different progressive collapse conditions:

Table 1: *Comparison of Base Shear at all seismic zones for various progressive Collapse cases*

SEISMIC ZONE	BASE SHEAR (KN)						
	(IRF)	(IRFC-1)	(IRFC-2)	(IRFC-3)	(IRFC-4)	(IRFC-5)	(IRFC-6)
Seismic zone II	2134.086	155.300	127.213	207.324	144.369	170.827	177.498
Seismic zone III	2141.703	248.472	210.068	213.587	238.107	259.435	246.817
Seismic zone IV	2346.673	248.612	306.721	213.60	238.208	259.485	246.824
Seismic zone V	2346.782	248.663	310.068	311.663	238.480	260.10	258.10

Table 2: *Comparison of Displacements at all seismic zones for various progressive Collapse cases*

SEISMIC ZONE	DISPALCEMENT (mm)						
	(IRF)	(IRFC-1)	(IRFC-2)	(IRFC-3)	(IRFC-4)	(IRFC-5)	(IRFC-6)
Seismic zone II	50.274	7.028	5.632	7.852	5.871	6.524	6.779
Seismic zone III	54.411	7.560	6.166	5.350	6.158	6.500	6.184
Seismic zone IV	52.468	7.558	6.875	6.90	6.316	6.808	6.526
Seismic zone V	58.795	7.560	6.896	7.806	6.54	6.890	6.782

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Comparison between base shears and displacements from the capacity curves obtained from the pushover analysis at Seismic zone II:

From the **Fig. 9,** it is observed that the base shear capacity of the Space frames IRFC-1, IRFC-2, IRFC-3, IRFC-4, IRFC-5, IRFC-6 is reduced by 92.22%, 92.28, 92.4%, 92.04%, 92.21% and 92 % when compared to Irregular space frame IRF.

From the **Fig. 10**, it is observed that the displacements of the Space frames IRFC-1, IRFC-2, IRFC-3, IRFC-4, IRFC-5, IRFC-6 is reduced by 89.8%, 90.0%, 89.1%, 89.8%, 89.9%, 89.6% when compared to Irregular space frame IRF.

Comparison between base shears and displacements from the capacity curves obtained from the pushover analysis at Seismic zone III:

From the **Fig. 11**, it is observed that the base shear capacity of the Space frames IRFC-1, IRFC-2, IRFC-3, IRFC-4, IRFC-5, IRFC-6 is reduced by 91.9%, 92.2%, 92.2%, 92.3%, 92.2%, 92.2% when compared to Irregular space frame IRF.

From the **Fig. 12**, it is observed that the displacements of the Space frames IRFC-1, IRFC-2, IRFC-3, IRFC-4, IRFC-5, IRFC-6 is reduced by 89.5%, 89.6%, 89.7%, 89.9%, 89.9%, 89.8% when compared to Irregular space frame IRF.

Comparison between base shears and displacements from the capacity curves obtained from the pushover analysis at Seismic zone IV:

From the **Fig. 13**, it is observed that the base shear capacity of the Space frames IRFC-1, IRFC-2, IRFC-3, IRFC-4, IRFC-5, IRFC-6 is reduced by 92.2%, 92.1%, 92.1%, 91.6%, 92.1%, 92.1% when compared to Irregular space frame IRF.

From the **Fig. 14**, it is observed that the displacements of the Space frames IRFC-1, IRFC-2, IRFC-3, IRFC-4, IRFC-5, IRFC-6 is reduced by 89.8%, 88.9%, 89.5%, 89.0%, 89.6%, 89.6% when compared to Irregular space frame IRF.

Comparison between base shears and displacements from the capacity curves obtained from the pushover analysis at Seismic zone V:

From the **Fig. 15**, it is observed that the base shear capacity of the Space frames IRFC-1, IRFC-2, IRFC-3, IRFC-4, IRFC-5, IRFC-6 is reduced by 91.5%, 91.8%, 91.8%, 91.9%, 91.7%, 91.8% when compared to Irregular space frame IRF.

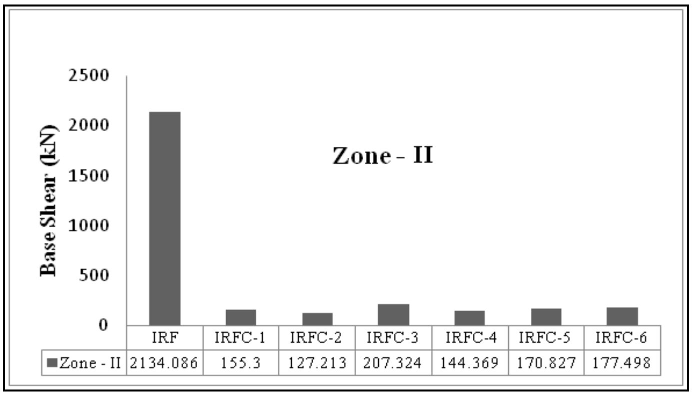

Fig. 9: *Comparison of base shear for seismic zone II*

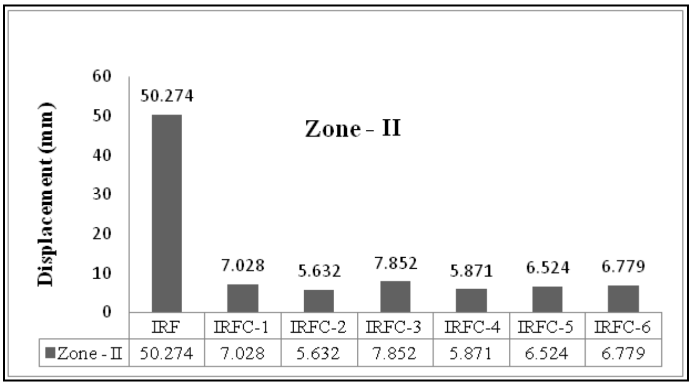

Fig. 10: *Comparison of displacements for seismic zone II*

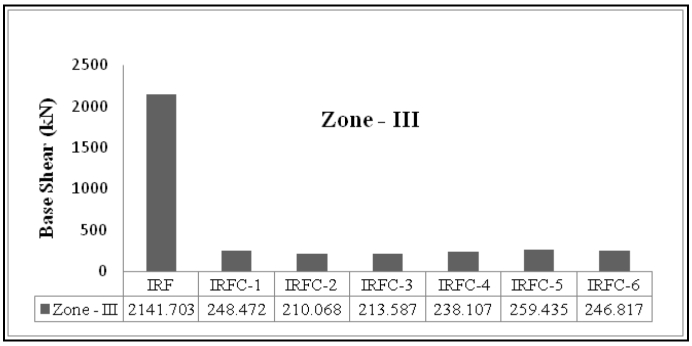

Fig. 11: *Comparison of base shear for seismic zone III*

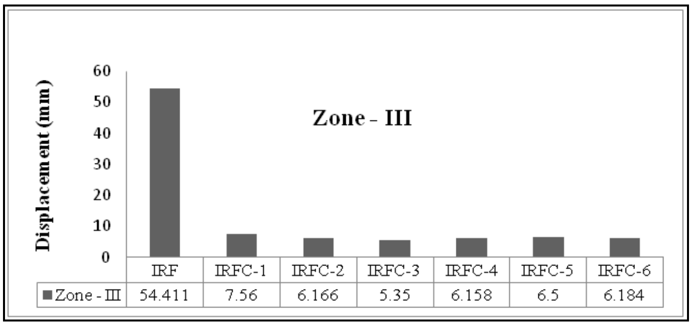

Fig. 12: *Comparison of displacements for seismic zone III*

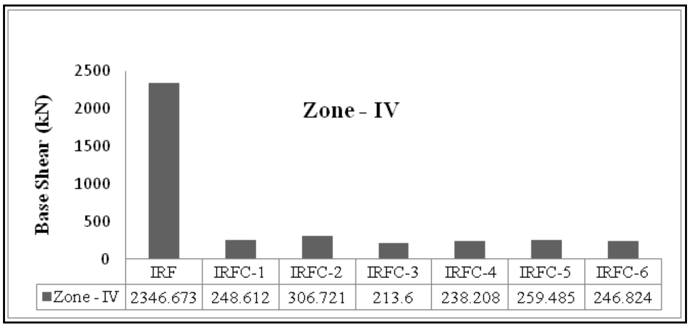

Fig. 13: *Comparison of base shear for seismic zone IV*

From the **Fig. 16**, it is observed that the displacements of the Space frames IRFC-1, IRFC-2, IRFC-3, IRFC-4, IRFC-5, IRFC-6 is reduced by 88.9%, 89.2%, 89.3%, 89.3%, 89.3%, 89.3% when compared to Irregular space frame IRF.

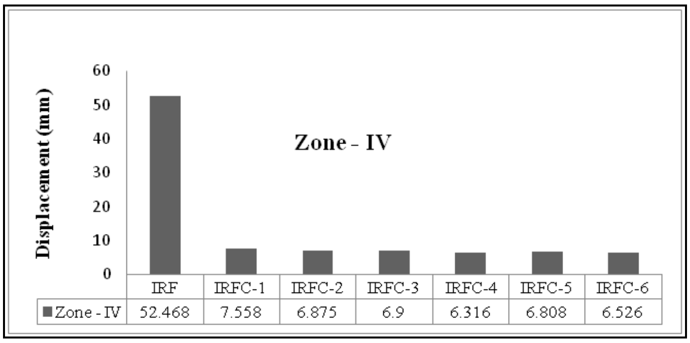

Fig. 14: *Comparison of displacements for seismic zone IV*

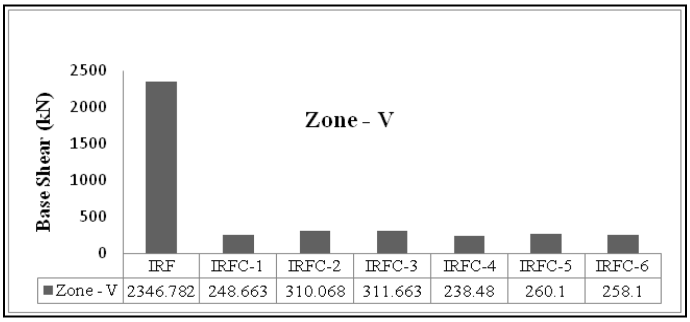

Fig. 15: *Comparison of base shear for seismic zone V*

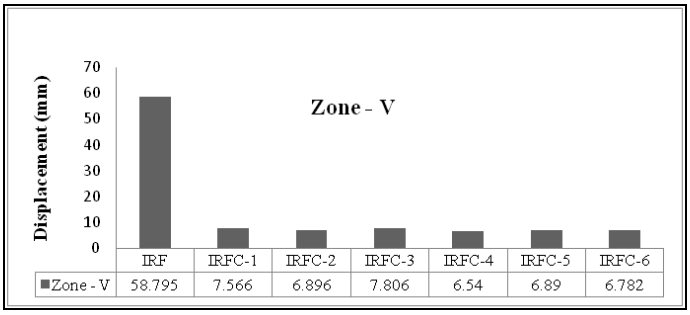

Fig. 16: *Comparison of displacements for seismic zone V*

IV CONCLUSIONS

Performed pushover analysis on braced steel space frames for various progressive collapse cases (i.e., IRF, IRFC-1, IRFC-2, IRFC-3, IRFC-4, IRFC-5 & IRFC-6). Following were the conclusions drawn from the study.

The maximum base shear and maximum displacement capacity of the Space frame with considering progressive collapse case is reduced by92.4% and 90.093% when compared to Irregular space frame in Seismic zone II

The maximum base shear and maximum displacement capacity of the Space frame with considering progressive collapse case is reduced by 92.3% and 89.9% when compared to Irregular space frame in Seismic zone III

The maximum base shear and maximum displacement capacity of the Space frame with considering progressive collapse case is reduced by 92.2% and 89.8% when compared to Irregular space frame in Seismic zone IV

The maximum base shear and maximum displacement capacity of the Space frame with considering progressive collapse case is reduced by 91.9% and 89.27% when compared to Irregular space frame in Seismic zone V

Out of all the seismic zones compared the percentage change in reduction of both base shear and displacements is very minute in all progressive collapse load cases of same zones.

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