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Performance Assessment of Different Retrofitting Techniques for Steel-Framed Buildings

A. Tunvar[1], V. Bhaiya[2],R.Chaudhary[3, *],K.M.Gondaliya[4] and P.Gajbhiye[5]

[1] Department of Civil Engineering, M.Tech. Student, Sardar Vallabhbhai National Institute Technology, Surat, 395 007, India
[2]Department of Civil Engineering, Assistant Professor, Sardar Vallabhbhai National Institute Technology, Surat, 395 007, India
[3,4,5]Department of Civil Engineering, Ph.D. Student, Sardar Vallabhbhai National Institute Technology, Surat, 395 007, India,

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Abstract

The requirement for cost-effective critical infrastructure has made employing nonlinear analysis techniques an appealing choice. Estimating seismic loads on structures necessitates explicit consideration of inelastic structural behavior. Hence, nonlinear approaches such as pushover analyses have become more popular. In this study, the performance of a ten-story steel moment-resisting frame retrofitted with various bracings like diagonal-bracing, chevron bracing, x-bracing and k-bracing is evaluated using linear and nonlinear analysis. The responses, such as base shear, lateral load distribution, displacement, drift, and lateral stiffness, are determined using the ETABS-18 building analysis and design program. The results of the study show that the steel-braced frame systems have substantially greater strength and ductility capabilities than their unbraced or alternate steel-braced moment-resistant steel frame. Further, the unbraced steel frame has a low R-factor as compared to the bracing system due to the increased stiffness at the story level.

Keywords: Bracing; Buckling restrained braces; Steel frames; Concentrically braced frames; Moment resisting frames; Ductility; Seismic retrofitting; Performance assessment; Push over analyses

1. Introduction

Previous earthquakes in India have demonstrated that most constructions must be designed to withstand seismic loading. Steel bracings in the structural system can increase structural strength and stiffness in steel moment-resistant frames. Bracing can also be used in two ways: concentric or eccentric bracing. Steel bracings can be arranged in various ways, including cross-bracing 'X,' diagonal bracing, 'K' type bracing, and inverted 'V' type bracing. Steel moment-resistant frames withstand lateral forces by frame action, which includes flexure and shear in beams and columns. Columns and bracings are placed to form a vertical truss in braced structure beams, and lateral loading is resisted by truss action. Ductile failure at columns and beam connections is common in severe earthquake loading.

Narayan et al. 2018, determinedthe susceptibility of damaged building frames to sway collapse during earthquake stimulation. The investigation relied heavily on determining the substantially damaged condition that causes partial or complete sway collapses. It has been accomplished through simulations aided by the genetic algorithm, plastic analysis, and frame pushover analysis.**Dalal etal. (2012)**compared performance of a steel moment-resisting frame designed by the performance-based plastic design method and conventional elastic design under different ground motions using the SAP2000 software. **Lignos et al. (2009)**conducted research on theinvestigation of a unique module and various infill systems made of ductile, high-performance fiber reinforced concrete (HPFRC) with a focus on preserving such critical facilities.**Olariu et al.(2022)**used the seismic isolation approach to retrofit various significant structures by incorporating layers of isolators at appropriate locations.Seismic base isolation reduces seismic forces in superstructures by a factor ranging from 0.3 to 0.8, and it regulates the distribution of these lowered lateral forces among substructures and foundations to increase the overall economy and efficacy of retrofit designs.

Krawinkler et al.(2011)discussed the benefits and drawbacks of structural forecasting behavior and key Engineering demand parameters (EDPs) using nonlinear static pushover (NSP) analysis and nonlinear response history analysis (NRHA) with simple hysteretic models.It is demonstrated that NSP analysis is precious in understanding critical behavior features that are seldom investigated in an NRHA, where engineers frequently focus on-demand/capacity evaluation rather than reaction visualization.The primary objective of this paper is to model various retrofit approaches in ETAB software, obtain the response of the building after introducing retrofitting for different earthquakes and determine optimum location of bracings.Further, a comparison of the different response parameters obtained fromvarious

*Corresponding author. Tel: +918955930089; E-mail address: rahulchaudhary.ced@gmail.com

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analytical procedures like pushover analysis, evaluation of response reduction and ductility factors for various steel moment resisting frames is also done in the present study.

2. Methodology

To determine the behavior of the steel structure different responses like displacement, base shear, story shear, and drift have been determined using the ETABS. For the analysis purpose of equivalent static analysis, response spectrum analysis, and nonlinear static analysis (pushover analysis) are adopted.

2.1Lateral force calculation in the current codemethod

The lateral seismic loads are calculated based on the elastic design spectra prescribed in I.S. 1893:2016, which gives the design spectral acceleration, "Sa" of the structure having time period "Tn" due to elastic response ($\mu = 1$).

The inelastic activity is accounted for in the current method by applying response reduction factors "R" (table 7, IS1893:2002), zone factors "Z" (table 2 clause 6.4.2, IS1893:2002), and importance factors "I" (table 6 clause 6.4.2, IS1893:2002) in the calculation of the total base shear "Vb." The seismic zone factor (Z) used to determine the value of design forces has been proposed after the seismic zone of our country and based on the earthquake data available. The importance factor (I) depends on the practical use of the structure. From the above information, it is very well observed that the design forces derived from the current code are quite assumptive as the factors governing the design of forces are mainly based on engineering judgments. Because of these reasons, the structures undergo large inelastic deformations during significant earthquakes. Mathematically, the total design base shear Vb is calculated as

$$V_b = A_h W \tag{1}$$

where, W is the total weight of the structure, and Ah is the horizontal acceleration coefficient. Horizontal acceleration coefficient,

$$A_h = \{(Z/2)*(S_a/g)\}/(R/I) \tag{2}$$

This base shear is distributed among the floors, known as the lateral force distribution at each floor level, "Qi" according to clause 7.7.1, IS1893:2002.

$$Q_i = V_b * \left[W_i h_i^2 / \sum W_i h_i^2 \right] \tag{3}$$

2.2 Nonlinear static analysis (push over-analysis)

The static pushover analysis is becoming a popular tool for seismic performance evaluation of existing and new structures. The pushover analysis will provide adequate information on seismic demands imposed by the design ground motion on the structural system and its components. Pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral forces, representing the inertial forces that would be experienced by the structure when subjected to ground shaking. Under incrementally increasing loads, various structural elementsyield sequentially. Consequently, at each event, the structure undergoes a loss in stiffness. Using a pushover analysis, a characteristic nonlinear force-displacement relationship can be determined. Typically, the first pushover load case is used to apply gravity load, and subsequent lateral pushover load cases are specified to start from the final conditions of the gravity.

2.3Evaluation of Response Reduction Factor

The response reduction factor is the factor by which the actual base shear force should be reduced to obtain the lateral design force during basic design earthquake (DBE) shaking. The response reduction factor (R) basically depends on Over strength (Rs), Ductility (Rμ), and Redundancy (Rr). So, there is a need to come up with realistic R factors for different structural systems used in various countries. In the present study, efforts are made to evaluate the response reduction factor, and ductility of Steel braced frames using nonlinear static pushover analysis. The types of the frame considered in this study are Steel frames with Normal bare frame, diagonal bracing, inverted v bracing, X bracing, and K bracing at the center bay. The result of this study shows that the R factor and lateral strength of Steel frames are considerably affected by the types and arrangement of the bracing system.

3. Numerical Study

The study in this section is based on a nonlinear analysis of a steel moment-resisting frame with an eccentrically braced frame. Different configuration of frames is selected, such as normal frame, x-bracing, diagonal bracing, inverted v-bracing, k bracing, and bracings on alternate floors. This chapter presents a summary of various parameters defining the computational models. The performance of the eight models is then evaluated and compared. The plan, elevation, and side view of frames are shown in figure 1 and figure 2.

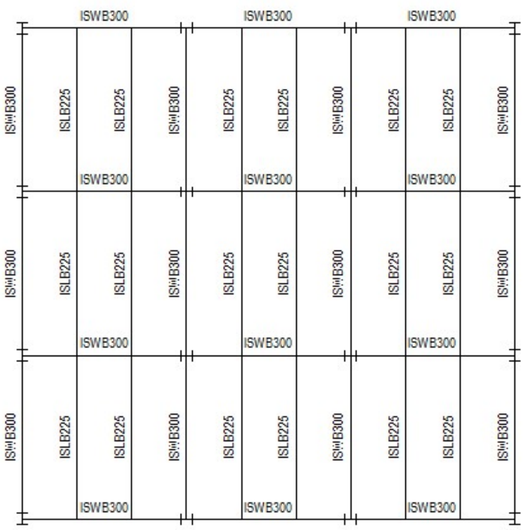

Figure 1Geometry plan of G+10

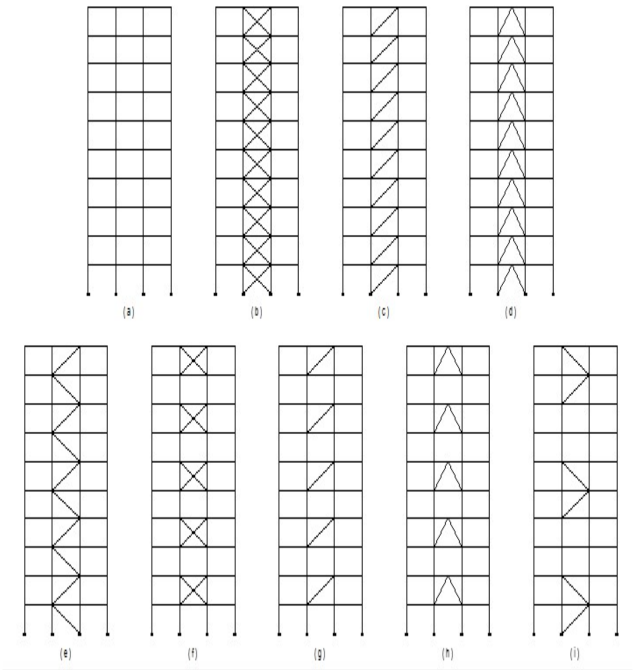

Figure 2Elevation of G+ 10 story's

(a) Normal bare frame (b) frame with X-bracings (c) Frame with diagonal bracings (d) frame with inverted V- bracings (e) frame with K-bracings (f) X-bracing on alternate floors (g) diagonal bracing on alternate floors (h) inverted V-bracing on alternate floors (I) K-bracing on alternate floors

3.1 problem statement and design parameters

The buildings are assumed to be symmetric in the plan, and hence a single plane frame may be considered to be representative of the building in one direction. A Configuration of the building in this study is given in table 1.

Table 1 Problem statement and Design parameters of the ten storied moment resisting frame

Type of design	Limit state design data
Numbers of stories	10
Bays in X-direction	3 bays at 5 m
Bays in Y-direction	3 bays at 5m
Floor height	3 m for all floors
Building height	30 m
Materials	Structural steel f_y = 415 N/mm^2
Spectra used	Elastic design spectrum of IS:1893-2016
Soil profile type	Type 2 medium
T_n (sec)	1.089 sec
Seismic zone factor, Z	0.36
Importance factor, I	1
Response reduction factor, R	5
Sa/g	1.248

The final sections for further analysis after the design of the frames in Etabsare shown in Table 2.

Table 2Sections details

Sections	Steel frame
Columns	WPB 300x300
Primary beams	ISWB 300
Secondary beams	ISLB 225
Deck slab	1mm thick membrane filledwithM30, slab depth of 110mm andrib depth 75mm
Shear studs	6 nos @ each secondary beamwith height 150mm and 19mmdiameter
Bracing	ISMC 150

The load combinations considered for design are given in Table 3.

Table 3 Load combination as per IS-1893-2016

1.5(DL+SIDL)	1.2(DL+SIDL+LL-ELY)
1.5(DL+SIDL+LL)	1.2(DL+SIDL+LL+ELY)
1.5(DL+SIDL+EQX)	1.2(DL+SIDL+LL-ELY)
1.5(DL+SIDL-EQX)	0.9(DL+SIDL) +1.5ELX
1.5(DL+SIDL+ELY)	0.9(DL+SIDL) +1.5ELY
1.5(DL+SIDL-EQY)	0.9(DL+SIDL)-1.5ELY
1.2(DL+SIDL+LL+ELX)	0.9(DL+SIDL)-1.5ELX

Table 4 Nomenclature of different models used for analysis

Sr.No.	No. of Floor	Model Types	ModelID
1	10- Story	Normal bare frame	1-NB
2	10- Story	Inverted V-bracing	2-IVB
3	10- Story	Diagonal bracing	3-DB
4	10- Story	X-bracing	4-XB
5	10- Story	K-bracing	5-KB
6	10- Story	Alternate floor InvertedV-bracing	6-AIVB
7	10- Story	Alternate floor Diagonal bracing	7-ADB
8	10- Story	Alternate floor X-bracing	8-AXB
9	10- Story	Alternate floor K-bracing	9-AKB

4. Comparisonsof Results

The following are the variations in lateral load distribution for different types of bracings using ETABS software shown in Table 5.

Table 5 Lateral load distributions

Story No.	Lateral load distribution (kN)								
	1-NB	2-IVB	3-DB	4-XB	5-KB	6-AIVB	7-ADB	8-AXB	9-AKB
Story-10	111.38	190.55	167.50	193.38	163.49	157.68	144.16	161.28	141.00
Story-9	94.91	162.5	142.85	165.05	139.42	134.35	122.84	137.42	120.24
Story-8	74.99	128.4	112.87	130.41	110.16	106.16	97.05	108.58	94.93
Story-7	57.41	98.33	86.41	99.84	84.34	81.27	74.31	83.13	72.62
Story-6	42.18	72.24	63.48	73.35	61.96	59.71	54.59	61.07	53.39
Story-5	29.29	50.16	44.08	50.94	43.03	41.46	37.91	42.41	37.11
Story-4	18.74	32.10	28.21	32.60	27.54	26.54	24.26	27.14	23.73
Story-3	10.54	18.06	15.87	18.33	15.49	14.92	13.64	15.26	13.33
Story-2	4.68	8.02	7.05	8.15	6.88	6.63	6.06	6.78	5.93
Story-1	1.17	2.00	1.76	2.03	1.71	1.65	1.51	1.69	1.48
∑ Total	445.34	762.47	670.13	774.12	654.06	630.42	576.37	644.8	563.80

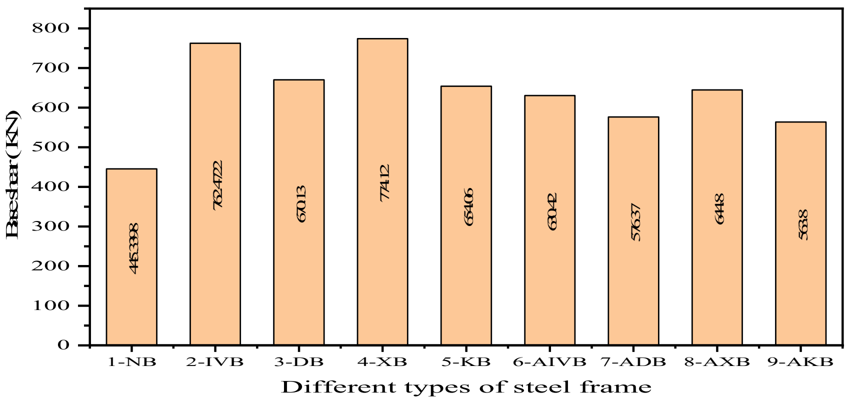

Figure 3 Base shears for different types of frames

Table 6 Comparisons of maximum responses in X- direction

Response	RSx							
	1-NB	2-IVB	3-DB	4-XB	5-KB	6-AIVB	7-ADB	8-AXB
Maximum story displacement (mm)	39.08	23.82	26.71	23.68	27.27	31.39	34.09	30.85
Maximum story drift	0.0019	0.00098	0.00119	0.00095	0.00123	0.00168	0.0018	0.0016
Story overturning moment (KN- m)	7376.31	12509.6	11068	12642.54	10944	11702	10698	11938
Story shear (KN)	399.96	662.08	592.08	671.3	588	629.94	576.66	644
Storystiffness (KN/mm)	142.72	357.84	271.45	374.75	200.47	217.87	195.55	225.05

4.1 Comparison of maximum responses of the frames

The maximum responses of all moment-resisting frames after response spectrum analysis aregiven in Table 6 & Table 7. Figures for maximum response of all moment resisting frames are given in figure 4, figure 5, figure 6 &figure 7.

Table 7 Comparisons of maximum responses in Y- direction

Response	RSy							
	1-NB	2-IVB	3-DB	4-XB	5-KB	6-AIVB	7-ADB	8-AXB
Maximum story displacement (mm)	39.56	23.93	26.87	23.78	30.48	31.58	34.36	31.04
Maximum story drift	0.0019	0.00099	0.00119	0.00095	0.00138	0.00169	0.00181	0.0016
Story overturning moment(KN- m)	7271.79	12462	11010	12598.69	12093	11622.49	10611	11865
Story shear(KN)	393.34	660.02	589.56	669.44	650.68	626	572	641.11
Story stiffness(KN/mm)	140.25	356.1	269.56	373.08	198.83	216.31	193.74	223.6

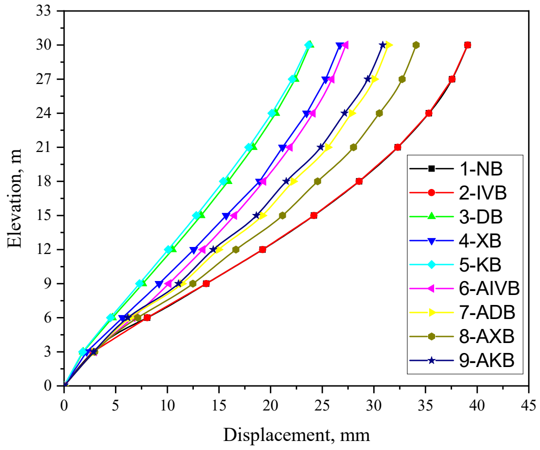

Figure 4 Maximum story displacements along the x-axis

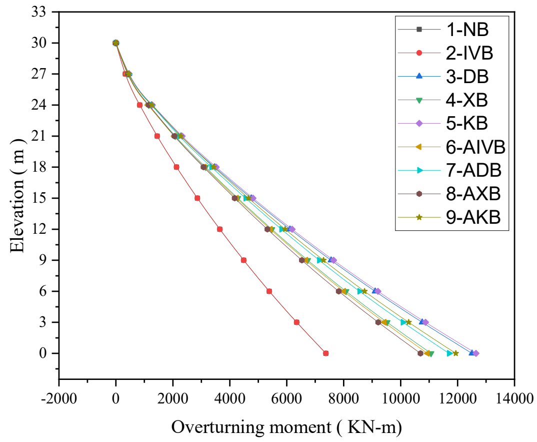

Figure 6 Story overturning moment along the y-axis

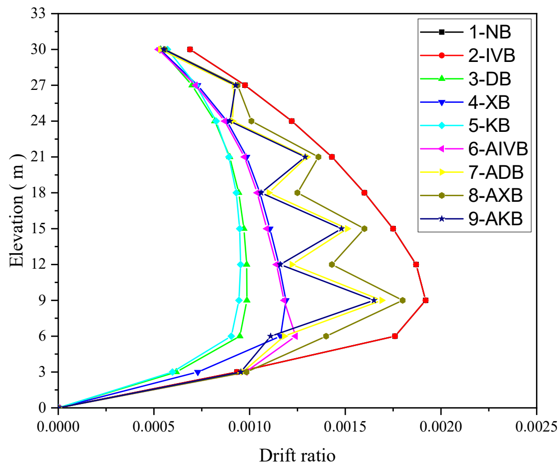

Figure 5 Maximum story drift along the x-axis

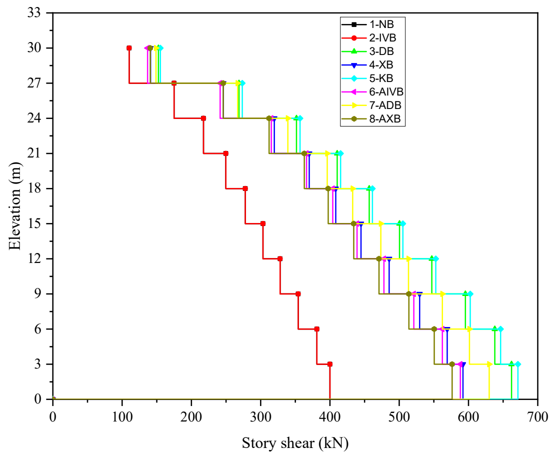

Figure 7 Story shear along the y-axis

Table 8Comparison of performance points

Parameters	Performance point as per FEMA 440 EL								
	1-NB	2-IVB	3-DB	4-XB	5-KB	6-AIVB	7-ADB	8-AXB	9-AKB
Shear(KN)	2669.45	6870	6013	7047	5793	5373	4684	5716	2592
Displacement (mm)	320.6	211.75	233	207.55	238	246	266	240	244.39
Sa (g)	0.14	0.37	0.34	0.39	0.30	0.29	0.25	0.31	0.14
Sd (mm)	260.12	211.75	199.25	159.44	184	192.54	180	130	106
T_{eff}(s)	2.50	1.31	1.49	1.27	1.55	1.62	1.81	1.55	1.75

Table 9 Comparison of target displacement

Parameters	Target displacement as per ASCE 41-13 NSP								
	1-NB	2-IVB	3-DB	4-XB	5-KB	6-AIVB	7-ADB	8-AXB	9-AKB
Shear(KN)	2733	6787	5754	6846	5744	5362	4709	5681	2542
Displacement (mm)	343	208	234	204	237	246	268	238	132

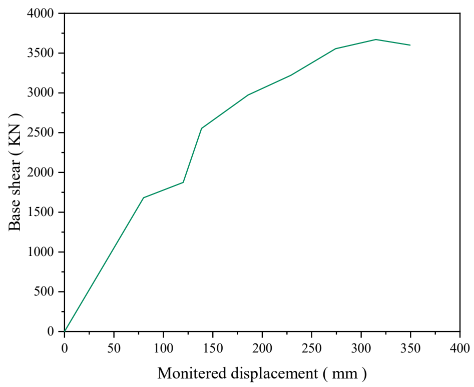

Figure 8 The static pushover curve for 1-NB

4.2 Comparison of performance point and target displacement for frames

The performance point and target displacement values for normal and braced frame structures are compared and shown in Tables 8 and 9.

4.3 Structural characteristics of steel frame with bracings

The static pushover curve of steel frames with different bracings is shown in Fig.8 to Fig.10. The figure shows the lateral resistance vs. deformation of the structures until they reach failure from a Global Standpoint

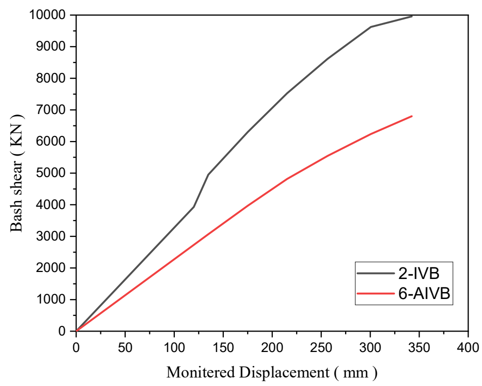

Figure 9 The static pushover curve for 2-IVB vs. 6-AIVB

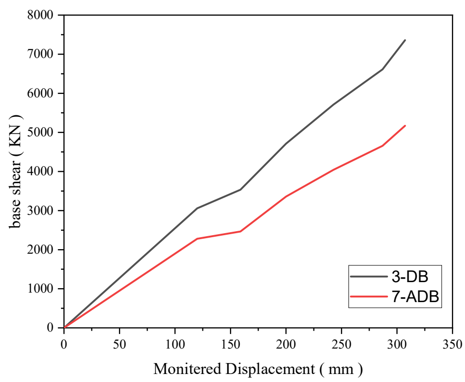

Figure 10 The static pushover curve for 3-DB vs. 7-ADB frame

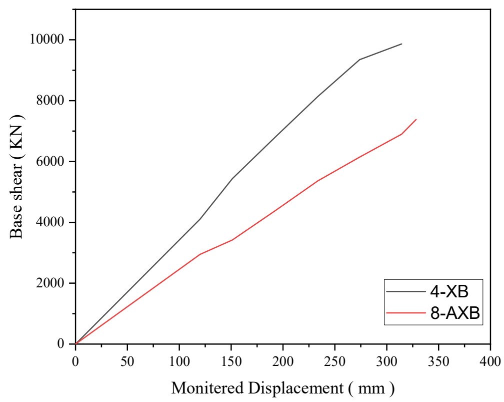

Figure 11 The static pushover curve for 4-XB vs. 8-AXB frame

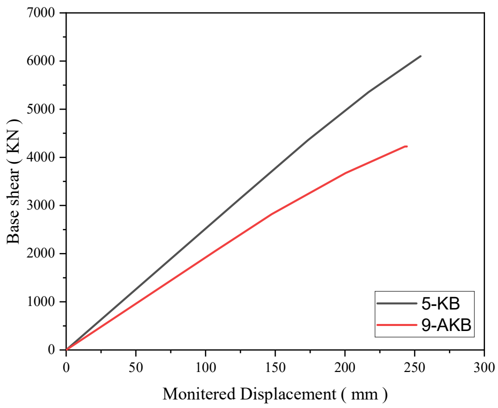

Figure 12 Static pushover curve for 5-KB vs. 9-AKB frame

4.4Response modification factor and ductility

The response modification factor (R) is utilized in force-based seismic design processes to convert linear elastic response spectra to inelastic ones. In other words, the strength ratio needed to maintain structural flexibility is the response modification factor. the response modification factor (ATC19) is determined as follows:

$$R = R\mu * R_S * R_\xi \quad (4)$$

where $R\mu$ is a reduction factor due to ductility, R_S is the over-strength factor, and R_ξ is the damping factor set equal to 1.0.

Table 10 shows the value of the R-factor and its vital component of the considered Steel moment-resisting frame in this study.

Table 10 Response reduction factor and its vital component of Steel frame

Frametype	R_S	$R\mu$	R_ξ	R	μ
1-NB	7.64	3.75	1.0	28.69	3.72
2-IVB	13.06	2.46	1.0	32.12	2.17
3-DB	11.83	2.76	1.0	32.65	2.52
4-XB	12.74	2.16	1.0	27.51	1.93
5-KB	9.32	3.48	1.0	32.4	3.17
6-AIVB	10.78	2.76	1.0	29.75	2.55
7-ADB	9.98	2.93	1.0	29.24	2.78
8-AXB	11.44	2.64	1.0	30.20	2.43
9-AKB	7.49	3.219	1.0	24.11	3.05

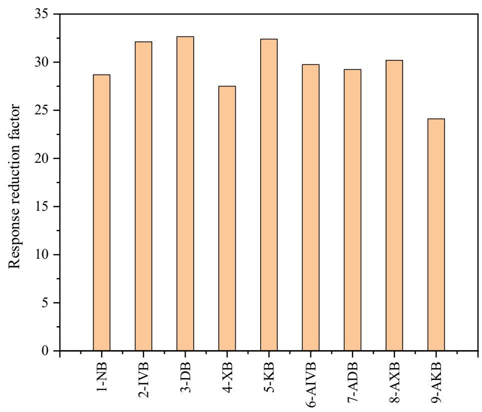

Figure 13 Comparative values of the response reduction factor

5. Conclusions

The linear static, linear dynamic and nonlinear static analysis of a ten story moment resisting steel building is performed using ETABS software. The response data like maximum story displacement, story drift, story shear, and the overturning moment is carried out when adding different bracing to the steel frame. Stiffness parameters obtained by linear static and linear dynamic analysis are compared with moment-resisting structures.

The studyalso includes the lateral strength, ductility factor, and response reduction factor (R) of 10-story Steel braced frames evaluated using static pushover analysis. the significant outcomes of the present study are summarized as follows:

- The response spectrum analysis results show that the displacement and drift are more significant in the 1-NB frame, and story responses such as story shear, story stiffness, and overturning moment are more effective in the 4-XB frame.

- Bracing on alternate floors compared with the frame having to brace on all the floor story displacement and story drift of bracing on alternate floor significantly increase up to 7.0 percent.
- Push over analysis result shows that 4-XB performed better in the inelastic region. From the idealized capacity curve, the stiffness of the 4-XB frame is 49 percent more in the elastic area than that of the normal steel frame.
- The lateral strength of the 4-XB frame is 20 percent higher than that of the 8-AXB structure. The ductility ratio of the 4-XB and 1-NB frames is 1.93 and 3.72, respectively. The target displacement as per ASCE 41-13 displacement modification pushover analysis for the 4-XB frame derived 49 percent less than1-NB frame.
- From the bracing on the alternate floor, the target displacement as per ASCE 41-13 displacement modification pushover analysis gets 60% less in the 9-AKB frame than other bracing on the alternate floor.

Disclosures

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6. References

1. Dalal, Sejal P., S.A. Vasanwala, and Atul K. Desai. 2012. "Comparison of Elastic Design and Performance Based Plastic Design Method Based on the Inelastic Response Analysis Using SAP2000."*International Journal of Computer Applications* 45 (9): 975–8887.

2. Krawinkler, Helmut, Dimitrios G Lignos, and Chris Putman. 2011. "Prediction of Nonlinear Response - Pushover Analysis versus Simplified Nonlinear Response History Analysis." In *Structures Congress 2011 - Proceedings of the 2011 Structures Congress*, 2228–39. https://doi.org/10.1061/41171(401)193.

3. Lignos, Dimitrios G, Carlos Molina-Hunt, Andrew D Krebs, and Sarah L Billington. 2009. "Comparison of Retrofitting Techniques for Existing Steel Moment Resisting Frames." In *Improving the Seismic Performance of Existing Buildings and Other Structures - Proc. 2009 ATC and SEI Conference on Improving the Seismic Performance of Existing Buildings and Other Structures*, 988–99. https://doi.org/10.1061/41084(364)90.

4. Narayan, S., M. K. Shrimali, S. D. Bharti, and T. K. Datta. 2018. "Collapse of Damaged Steel Building Frames Because of Earthquakes."*Journal of Performance of Constructed Facilities* 32 (1): 04017128. https://doi.org/10.1061/(asce)cf.1943-5509.0001125.

5. Olariu, Ioan, Felicia Olariu, and Dragos Sarbu. 2022. "Base Isolation for Seismic Retrofitting of Existing Structures." In *Seismic Design Practice into the Next Century*, 417–24. https://doi.org/10.1201/9780203740026-57.

6. ComputercodeETABS18, Computers and Structures, Inc.

7. BIS. IS 1893 (Part 1): 2002, Criteria for Earthquake Resistant Design of Structures: Part 1 General Provisions and Buildings. In: 5th Rev., Bureau of Indian Standards, New Delhi, India; 2002.

8. I.S. 800:2007, General construction steel code of practice.

9. ATC 40. Seismic Evaluation and Retrofit of Concrete Buildings. Applied Technology Council, Volumes 1 and 2, Redwood City, CA, USA; 1996

10. FEMA 440. Improvement of nonlinear static seismic analysis procedures. Applied Technology Council (ATC). Rep. No. FEMA-440, Washington, D.C.; 2005.

11. ASCE. Seismic evaluation and retrofit of existing buildings. ASCE/SEI 41–13, Reston, VA; 2013.