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Ductility, Rμ, and Overstrength Factors for V Braced Reinforced Concrete Buildings

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***Abstract*—**Steel bracings are used to improve the seismic behaviors of the structures. In this study, 8, 12 and 16 story reinforced concrete (RC) buildings with steel bracings are used in three base shear contributions (25%, 50% and 75%) in the columns. With the help of pushover analysis and capacity curves, the overstrength factors, ductility factors and ductility reduction factors are investigated for braced RC buildings. It is observed that when the base shear contribution in the columns increases the ductility reduction factor also increases. The results show that when the time period of the structures increases, the ductility reduction factors of the structures decrease.

***Keywords*—**Steel bracing, overstrength factor, ductility, ductility reduction factors, base shear contributions.

I. Introductions

DIFFERENT types of steel bracings are used in buildings to resist the lateral earthquake force. Inverted V bracings, diagonal bracings, X bracing, multi X bracings, V shape bracings and Y shape bracings are generally used in the structures. The steel bracings are normally used in steel structures as a retrofitting. Steel bracings are used in RC buildings to improve seismic performances. It reduces the maximum displacements and drift of the structures and increases the stiffness and strength of the structures [1], [2]. The steel bracings are used for retrofitting purposes for existing buildings and also used in new constructions. Many experimental [3]-[5] and analytical [6]-[8] studies have found that steel bracings improve the seismic parameter in the RC buildings. Studies also focused on the seismic behavior and response modifications factors for X, inverted V bracing and knee bracings to investigate the performance and ductility of the steel braced RC buildings [9]-[12]. Also, [9]-[12] focused on the X and inverted V bracings and their base shear contributions in the RC buildings. The researchers studied the relationship between the slenderness ratio and overstrength factors, ductility reduction factors of the structures [9], [12]. Bohara et al. [13] studied the four-story RC building with steel bracing where steel bracings were considered with different thicknesses. In this study, it was observed that the thickness of the bracings can change the strength contribution of bracing in global structures. Bohara et al. [14] performed the seismic analysis in the L shape irregular building with steel bracing to observe the seismic parameter such as top story displacement, inter-story drift, base shear, fundamental time period, torsional irregularity ratio, columns forces. They show that the position of bracings in the L shape of buildings can affect the seismic property of buildings. Even it is more venerable if the position of steel bracings is placed unsymmetrically.

The ductility reduction factors (Rμ) and overstrength factors (Rs) of the structures are important parameters for understanding the performances of the structures and are also used to calculate the response modification factors (R). The response modification factors are used in the code to design the economic buildings. Uang [15] formulated the seismic behavior factors in their study, where μ has defined the ratio of maximum drift and yield displacements (μ=Δ_m/Δ_y). The Rμ is defined as the ratio of base shear at elastic design level and yield strength level. The overstrength factor is the ratio of base shear at yield level and base shear at first significant yield level ($R_s = V_y/V_d$) as shown in Fig. 1. For the calculation of Rμ, the Newmark and Hall (1982) equations are used. Newmark and Hall (1982) purposed the equations between the fundamental time period and ductility of the structures [16].

In this study, the pushover analysis and capacity curves are used to calculate the seismic behavior factors. And the paper discussed about overstrength factor, ductility, and ductility reduction factors for 8, 12 and 16 story buildings with three base shear contributions (25%, 50% and 75%) in columns.

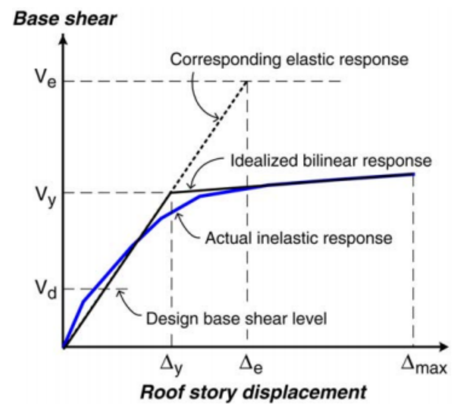

Fig. 1 Capacity curves between base shear and displacements

II. Methodology

The ETABs 2018 software is used to analyze the RC braced buildings. The response spectrum method is used to fix the beam, columns, and bracings sizes. In this study, the bracings are designed first at required base shear contributions in the dual system. Indian standard 1896 (part1) clauses 7.2.7 suggested

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the dual system where the columns are designed to resist at least 25% design base shear. In this paper, three different base shear contribution cases are used. In the first case, 75% base shear is provided in the steel bracing and 25% base shear in the columns. In the second case, nearly 50% base shear is resisted by the columns. And in the last case, 75% base shear is provided in columns. After the design, the bracings, beam and columns cross-sections are fixed. The Indian standard codes [17] are used to design the 8, 12 and 16 story buildings with steel bracings. The capacity design methodology [9] is used for this study. The response reduction factor is considered as 4.5 with a 5% damping coefficient as the Indian standard. The corresponding design spectra are given in Fig. 2, which is corresponding to a 5% damping ratio. Other factors such as zone factor is considered as 0.36, importance factor is considered as 1. For the design, the live load is considered as 5 kN/m^2, for top floor slab load is taken as 2 kN/m^2 and the finishing dead load is assumed as 2.5 kN/m^2. The material property and design cross-section of beam, columns and bracings are considered from [18]. The designed column beam and bracing section in the braced RC frames are changed along the height to decrease the stiffness and strength irregularities as possible. The cross-sections of the columns are reduced every four-story in 8, 12 and 16-story buildings. The bracings are taken as hollow box cross section to reduce the local buckling in bracing during compression force. To optimize the design of bracings, every four story, the thickness of bracings is changed without affecting the base shear contribution in bracing. Fig. 3 shows the plan view and spacing of column to columns distance which are 7 m and Figs. 4 and 5 show the elevation along X and Y direction respectively with height of 3.2 m for each story. Fig. 6 shows the elevation along the Y-axis and also Fig. 7 shows the 3D views of steel braced 16, 12 and 8 story buildings.

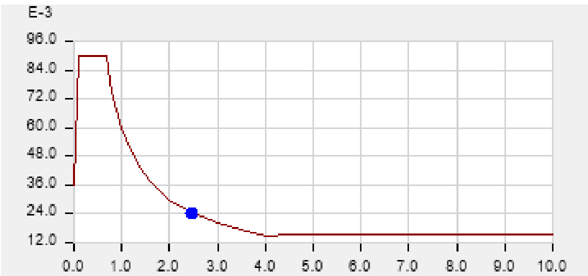


Fig. 2 Response spectrum function for soil type III and 5% damping

To understand each model, the models are named as pDn form, where the p represents the base shear contributions in columns (25%, 50% and 75%), D represents the direction (x and y-axis) and n represents the story buildings (8, 12 and 16).

III. Result and Discussion

The 8, 12 and 16 story buildings are properly designed in the finite element software known as ETABs. At first equivalent, static and response spectrum methods are used to design the models and fix the dimension of columns, beams and bracings by using the software. In the modeling, slabs are considered rigid and the base of the structures are restricted in all x, y and z directions. Finally, the nonlinear pushover analysis is applied in all models. The capacity curves represent the curves between the base shear and displacements of the structures. The study considered the capacity curves from [18]. The design base shear, maximum base shear, maximum displacement and displacement at drift level are calculated from the capacity curves. By using these parameters, the ductility, ductility reductions factor and overstrength factors are calculated and represented in Tables I-III. The tables show the seismic behavior factors with different base shear contributions (25X, 50X and 75X and similar to the y axis).

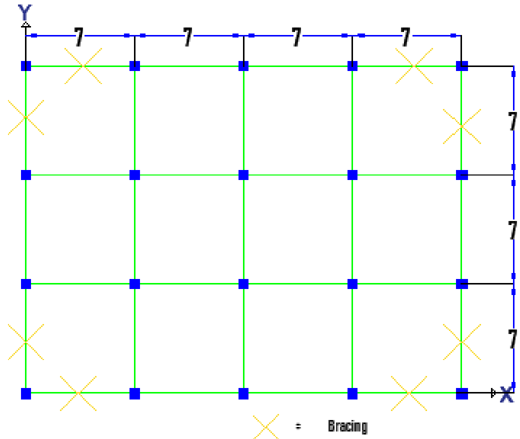


Fig. 3 Plan view

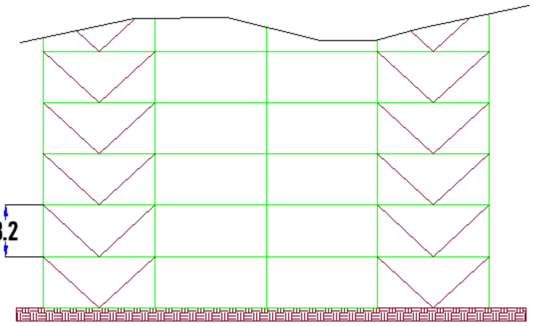


Fig. 4 Frame elevation in X direction

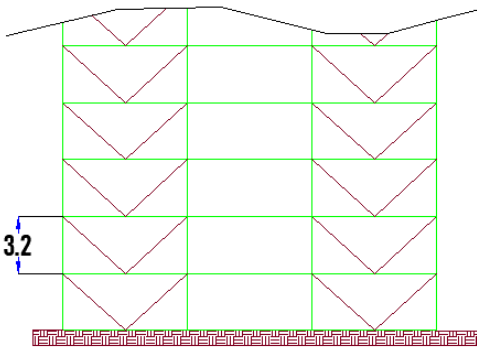
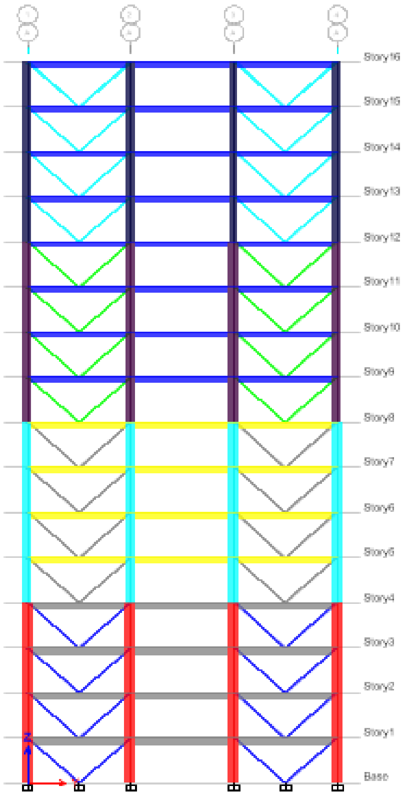
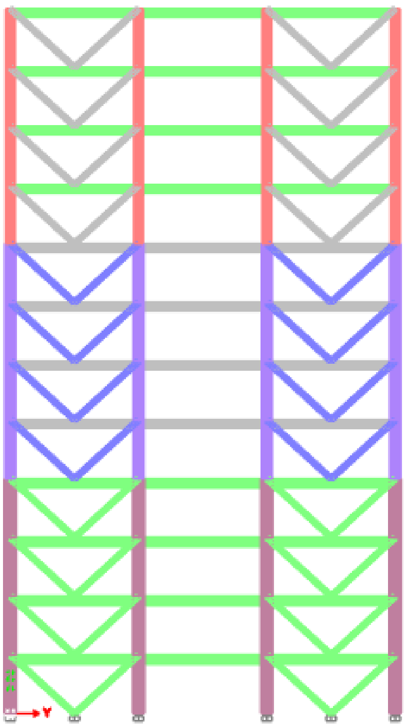


Fig. 5 Elevation in Y direction (dimension in meter)





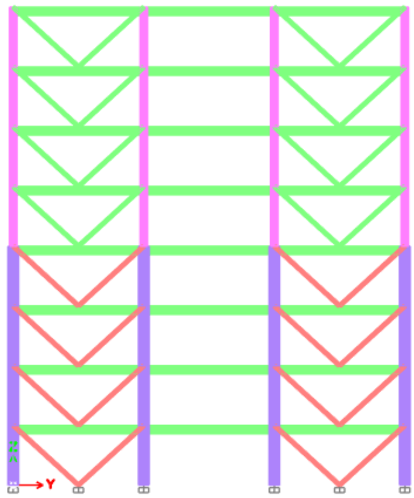


Fig. 6 Elevation of 16, 12 and 8 story buildings with steel V bracings

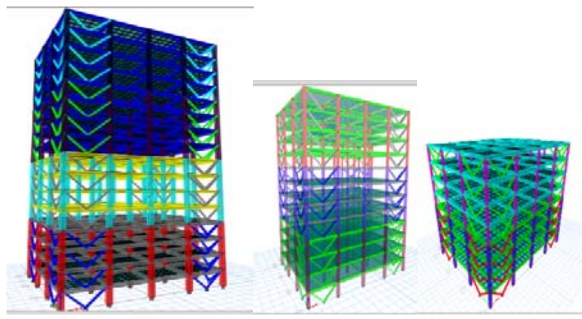


Fig. 7 Elevation of 16, 12 and 8 story buildings with steel V bracings

The curve between the base shear and displacement are obtained by using the nonlinear pushover method. The curve is also known as the capacity curve which shows the capacity of the structure when the lateral force is applied. Ductility reduction factors and ductility capacity are calculated by using the performance point in the capacity curve. Structure shows the different performance levels according to their structural and nonstructural component. The capacity curves are used to understand the performance level of the structures and their performance level under the loadings. After the calculation of performance level, other parameters like ductility, ductility reduction factor, overstrength factor and response reduction factors are calculated. The ductility reduction factor (R_μ) mainly depends upon the fundamental time period and damping. In Tables I-III, T is the natural time period of the buildings. V_0 and V_d are the maximum base shear and design base shear respectively. Δ_m is the maximum displacement and Δ_y is the first yield displacement calculated by using pushover curves. μ, R_μ, and R_s, are the ductility ratio, ductility reduction factors and overstrength factors respectively.

In Tables I-III, it is observed that only structures having 50% and 75% base shear contributed models show a good ductility behavior. Only greater than 50% base shear models have above 3.3 ductility factors. It means that, when the base shear contribution in the columns increases, the ductility factors of the buildings increase. However, when the building height (8 to

16 story) and fundamental time period of the structures increases, the ductility factors of the structures decrease as shown in Figs. 8 and 9. It is also noticed that increasing the base shear contribution of the columns also increases the ductility factors with fundamental time period (see Figs. 8 and 9). A similar result is obtained for X and inverted V braced RC buildings in previous results [9], [12]. Higher the ductility reduction factor is found when the base shear contribution in columns increases. When the time period of the structures increases, the ductility reduction factors of the structures decrease which are opposite to the previous study for inverted V bracings [9]. It is also noticed that when the base shear contributions in the columns increase, the overstrength factors decrease. The result is similar to the previous result for inverted V bracings [9] and the opposite for X bracings [12]. When the story number or fundamental time period of the structures increases, the overstrength factors of the structures decreases. Figs. 10 and 11 show the relation between the overstrength factor and ductility reduction factors with 8, 12 and 16 story buildings having 25%, 50% and 75% base shear contribution. It is observed that the overstrength and ductility reduction factors have reciprocal relationship. When the ductility reduction factors are high then overstrength factor for that particular building decreases and vice versa (see Figs. 10 and 11). To get the strong and durable structures, it is important to design ductile structures. The results show that introducing the steel bracings in the RC buildings affect the ductility behaviors of the structures. Hence the result shows that, to get the ductility behaviors in structure, the structures should be designed for the minimum base shear contribution as 50% in columns. It is also noticed that when the columns are considered as the main line of defense, the structures show low overstrength factors and higher ductility factors. While designing the steel braced RC structures, it is important to observe the ductility of the structures. The base shear contributions in the columns and bracings should be checked properly while designing the braced frame structures.

TABLE I
CALCULATION OF THE OVERSTRENGTH FACTOR AND DUCTILITY FACTOR FOR 8 STORY BUILDINGS

Models	T	V_0 (KN)	V_d	Δ_y (mm)	Δ_m (mm)	μ	R_μ	R_s
25X8	0.75	19760	4115	70	150	2.1	2.0	4.8
25Y8	0.75	19665	4124	77	155	2.0	1.9	4.8
50X8	0.90	10245	3591	45	187	4.2	3.9	2.9
50Y8	0.91	9982	3569	45	188	4.2	3.9	2.8
75X8	1.03	6976	3232	30	202	6.7	6.7	2.2
75Y8	1.04	6758	3195	32	204	6.4	6.4	2.1

TABLE II
CALCULATION OF THE OVERSTRENGTH FACTOR AND DUCTILITY FACTOR FOR 12 STORY BUILDINGS

Models	T	V_0 (KN)	V_d	Δ_y (mm)	Δ_m (mm)	μ	R_μ	R_s
25X12	0.754	17491	4115	93	220	2.4	2.2	4.3
25Y12	0.752	16701	4124	87	221	2.5	2.3	4.0
50X12	0.908	12073	3591	76	252	3.3	3.1	3.4
50Y12	0.914	11874	3569	77	253	3.3	3.1	3.3
75X12	1.035	6273	3232	46	271	5.9	5.9	1.9
75Y12	1.047	6053	3195	46	274	6.0	6.0	1.9

TABLE III
CALCULATION OF THE OVERSTRENGTH FACTOR AND DUCTILITY FACTOR FOR 16 STORY BUILDINGS

Models	T	V_0 (KN)	V_d	Δ_y (mm)	Δ_m (mm)	μ	R_μ	R_s
25X16	1.617	17942	4245	136	313.5	2.3	2.8	4.2
25Y16	1.609	17295	4267	138	317	2.3	2.8	4.1
50X16	1.745	18525	3893	144	395	2.7	3.7	4.8
50Y16	1.75	18327	3882	140	408	2.9	4.0	4.7
75X16	1.991	7863	3618	81	348	4.3	4.3	2.2
75Y16	2.015	7294	3576	93	359	3.9	3.9	2.0

Fig. 8 Relation between fundamental time period and ductility factor for 16, 12 and 8 story buildings with steel V bracings along the X direction

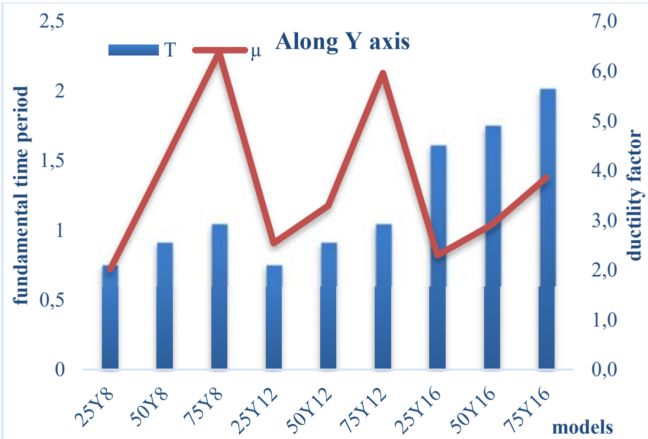


Fig. 9 Relation between fundamental time period and ductility factor for 16, 12 and 8 story buildings with steel V bracings along the Y direction

IV. CONCLUSIONS

The static nonlinear analysis is performed and ductility factors, ductility reduction factors and overstrength factors are investigated and the following conclusions are found:

1. When the steel braced RC buildings are designed it is important to consider the base shear contributions in the columns in the dual system. To get suitable ductile structures, the base shear contribution in the columns should be a minimum of 50%.
2. When the base shear contribution in the columns increases,

the ductility factors and ductility reduction factors increase and the overstrength factor decreases.

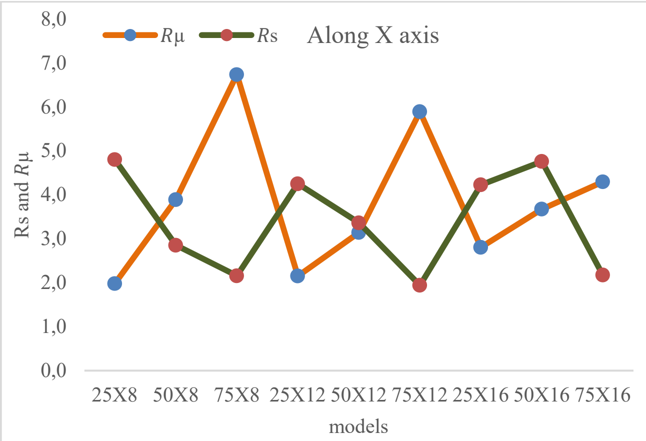


Fig. 10 Relation between Rs and $R\mu$ for 16, 12 and 8 story buildings with steel V bracings along the X direction

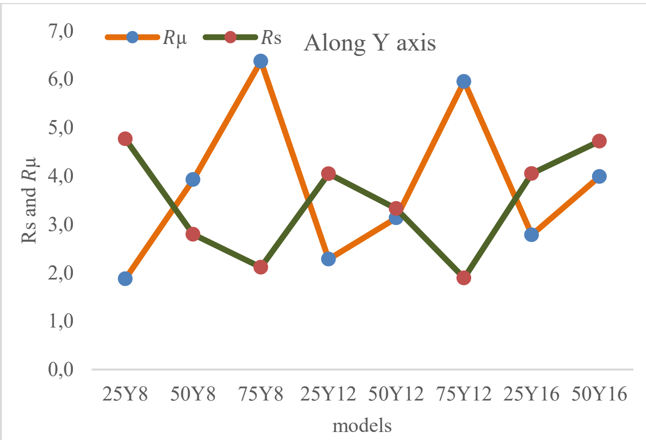


Fig. 11 Relation between Rs and $R\mu$ for 16, 12 and 8 story buildings with steel V bracings along the Y direction

3. As the height of the structures increases, the ductility, ductility reduction factor and overstrength factor of the buildings decrease.
4. When the steel braced RC buildings are designed, the columns must be considered as the main line of defense to get more ductile and suitable structural behavior of the structures. It is obtained when the columns resist at least 50% base shear in the dual system.

REFERENCES

[1] B. K. Bohara, "Seismic Response of Hill Side Step-back RC Framed Buildings with Shear Wall and Bracing System," *Int. J. Struct. Constr. Eng.*, vol. 15, no. 4, pp. 204–210, 2021.
[2] K. H. Ganaie, B. K. Bohara, and P. Saha, "Effects of Inverted V Bracing in Four-Story Irregular RC," *Int. Res. J. Mod. Eng. Technol. Sci.*, vol. 03, no. 04, pp. 2346–2351, 2021, (Online). Available: www.irjmets.com.
[3] M. R. Maheri and A. Sahebi, "Use of steel bracing in reinforced concrete frames," *Eng. Struct.*, vol. 19, no. 12, pp. 1018–1024, 1997, doi: 10.1016/S0141-0296(97)00041-2.
[4] Y. Yamamoto and H. Umemura, "Analysis of reinforced concrete frames retrofitted with steel brace," in *Earthquake Engineering, teenth World Conference*, 1992, pp. 5187–5192.
[5] B. M. Badoux and J. O. Jirsa, "Steel Bracing of RC Frames for Seismic Retrofitting," *J. Struct. Eng.*, vol. 116, no. 1, pp. 55–74, 1990.
[6] H. Abou-Elfath, M. Ramadan, and F. Omar Alkanai, "Upgrading the seismic capacity of existing RC buildings using buckling restrained braces," *Alexandria Eng. J.*, vol. 56, no. 2, pp. 251–262, 2017, doi: 10.1016/j.aej.2016.11.018.
[7] A. Rahimi and M. R. Maheri, "The effects of retrofitting RC frames by X-bracing on the seismic performance of columns," *Eng. Struct.*, vol. 173, 2018, doi: 10.1016/j.engstruct.2018.07.003.
[8] A. Rahimi and M. R. Maheri, "The effects of steel X-brace retrofitting of RC frames on the seismic performance of frames and their elements," *Eng. Struct.*, vol. 206, no. December 2019, 2020, doi: 10.1016/j.engstruct.2019.110149.
[9] E. A. Godínez-Domínguez and A. Tena-Colunga, "Nonlinear behavior of code-designed reinforced concrete concentric braced frames under lateral loading," *Eng. Struct.*, vol. 32, no. 4, pp. 944–963, 2010, doi: 10.1016/j.engstruct.2009.12.020.
[10] [10] M. R. Maheri, R. Kousari, and M. Razazan, "Pushover tests on steel X-braced and knee-braced RC frames," *Eng. Struct.*, vol. 25, no. 13, pp. 1697–1705, 2003, doi: 10.1016/S0141-0296(03)00150-0.
[11] [11] M. R. Maheri and R. Akbari, "Seismic behaviour factor, R, for steel X-braced and knee-braced RC buildings," *Eng. Struct.*, vol. 25, no. 12, pp. 1505–1513, 2003, doi: 10.1016/S0141-0296(03)00117-2.
[12] E. A. Godínez-Domínguez and A. Tena-Colunga, "Behavior of ductile steel X-braced RC frames in seismic zones," *Earthq. Eng. Eng. Vib.*, vol. 18, no. 4, pp. 845–869, 2019, doi: 10.1007/s11803-019-0539-0.
[13] B. K. Bohara, K. H. Ganaie, and P. Saha, "Seismic Analysis of Retrofitting of RC Regular Frame with V-Braced Frame," *J. Eng. Technol. Plan.*, vol. 2, no. 1, pp. 55–63, 2021, doi: 10.3126/joetp.v2i1.39229.
[14] B. K. Bohara, K. H. Ganaie, and P. Saha, "Effect of position of steel bracing in L-shape reinforced concrete buildings under lateral loading," *Res. Eng. Struct. Mater.*, vol. x, no. xxxx, pp. 1–23, 2021, doi: 10.17515/resm2021.295st0519.
[15] C. Uang, "Establishing R (or Rw) and Cd Factors for Building Seismic Provisions," *J. Struct. Eng.*, vol. 117, no. 1, pp. 19–28, 1991, doi: 10.1061/(asce)0733-9445(1991)117:1(19).
[16] N. M. Newmark and W. J. Hall, *Earthquake spectra and design*. Oakland: Earthquake Engineering Research Institute (EERI), 1982.
[17] I. S. IS, *Part 1(2016)*. General provisions and buildings: Criteria for Earthquak Resistant Design of Structure, 1893.
[18] Birendra Kumar Bohara, "Nonlinear Behavior of Moment Resisting Reinforced Concrete with Steel Braced Frame under Lateral Loading," mtech Thesis in Sharda University, 2021.