Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

DOI: 10.34910/MCE.108.7

Effect of irregularity on seismic design parameters of RC-infilled structures

M. Shendkar*[a], H. Beiraghi[b], S. Mandal[a]

[a]Department of Civil Engineering, Indian Institute of Technology (BHU), India

[b]Department of Civil Engineering, Mahdishahr Branch, Islamic Azad University, Mahdishahr, Iran

**E-mail: mangesh.shendkar94@gmail.com*

Keywords: masonry walls, adaptive pushover analysis, response reduction factor, ductility, irregularity, seismic performance

Abstract. A four-storey reinforced concrete (RC) building is seismically evaluated with the incorporation of different irregularities. Three model systems have been considered, i.e., model I: (RC-infilled regular frame in X and Y direction), model II: (RC-infilled plan irregular frame in X and Y direction), and model III: (RC infilled vertical + plan irregular frame in X and Y direction). Adaptive pushover analyses have been carried out to evaluate the seismic performance of the structure by using seismostruct software incorporating inelastic material behaviour for concrete, steel, and infill walls. Infill walls have been modelled as “double strut nonlinear cyclic models”. The most up-to-date seismic design includes the nonlinearity in the structure through a response reduction factor (R). The ductility reduction factor and overstrength factor are the main components of the response reduction factor. These seismic design parameters were computed from the adaptive pushover analysis, and finally, the response reduction factor has been calculated for all models and compared with the value recommended by IS 1893 part-1 (2016). The result shows that the evaluated R-factors are higher than the value recommended by the BIS code. However, it is observed that R-values are higher than the corresponding values recommended in the BIS code when the irregularity present in the structures.

1. Introduction

Buildings with masonry infill wall RC frames are the most common type of structures used for multistory constructions all over the world. The presence of the infill walls increases the lateral stiffness considerably. Due to the change in stiffness and mass of the structural system, the dynamic characteristics change as well. In several moderate earthquakes, such buildings have shown excellent performance during an earthquake. In the recent era, the earthquake loads imposed in the structure are typically greater than the loads considered in the design. Most of the seismic design codes include the nonlinear response of a structure through a response reduction factor/behavior factor (R). The majority of the structures are designed using the equivalent static method, which is based on the use of the response reduction factor. Different codes and guidelines specify the ‘*R*’ value for different types of moment-resisting frame structures. However, IS 1893 Part-1: (2016) code does not give any specific explanation on different issues namely, irregularities, structural & geometrical configuration, etc. Thus, the primary focus of the present study is to investigate the actual response reduction factor of regular and irregular structures.

Alguhane et al. [1] presented a study about an existing RC building in Madinah that is seismically evaluated with and without an infill wall. Four model systems have been considered i.e. model- I (no infill), model- IIA (strut infill-update from field test), model- IIB (strut infill- ASCE/SEI 41), and model- IIC (strut infill-Soft storey- ASCE/SEI 41). The response modification factor (R) for the 5 story RC building was evaluated from capacity and demand spectra (ATC-40) for the studied models. From this study, the

Shendkar, M., Beiraghi, H., Mandal, S. Effect of irregularity on seismic design parameters of RC-infilled structures. Magazine of Civil Engineering. 2021. 108(8). Article No. 10807. DOI: 10.34910/MCE.108.7

authors concluded that the R factor increase due to the presence of infill and it satisfy the requirement of the code (SBC 301) but in the case of the bare frame, does not satisfy the requirement of the response modification factor. Chaulagain H. et al. [2] studied the response reduction factor of existing reinforced concrete buildings in Kathmandu valley. They concluded that the calculated R values of the buildings are less than the values given by the BIS code. From the extracted results, the R-value is highly dependent on the "column to beam capacity ratio". Motiani R. et al. [3] worked on the calculation of the response modification factor for realistic RC moment frame buildings by using pushover analysis. In this research study, they modeled 4, 8 & 12 storey reinforced concrete buildings as per guidelines provided by IS 456:(2000). The static pushover analysis has been used in SAP2000 software. From the detailed study, the authors concluded that ultimately response reduction factor decreases with increases in the height of the structure. The value of R is given by IS 1893 (2002) is improperly estimated. The actual value of R is lesser than the values given by BIS code because, irregularity in structure, torsional effect, poor workmanship, etc.

Brahmavrathan D. and Arunkumar C. [4] worked on the evaluation of the response reduction factor of irregular i.e., stepped reinforced concrete frames. The stepped building form means the incorporation of vertical irregularity. In this paper, three types of reinforced concrete three-dimensional framed structures having an equal number of bays, but a different number of stories are considered. They modeled 3, 6, and 9 stories for both OMRF and SMRF cases. The non-linear static pushover analysis of the three stepped RC building models was carried out by using SAP 2000 software for both cases. The authors concluded that the actual values of response reduction factor of stepped RC buildings are lesser than the values recommended by the BIS code, the values of R decreases as the storey number increases. Due to vertical irregularity R values decreases significantly so there is a need to consider the irregularity in IS 1893 code and ductility factor depends on the optimum percentage of steel reinforcement beyond its limit range of R values in decreasing trend.

Smyrou et al. [5] described the implementation of the "inelastic infill panel element" for masonry infill panels within a fiber-element-based SeismoStruct program. They assessed analytical results compared with experimentally obtained from the pseudo-dynamic test and also defined characteristic values for material and geometrical properties of infill. Mohamed S. Issa and Heba M. Issa [6] worked on the evaluation behavior factor of reinforced concrete moment resisting frame by using pushover analysis. According to the researcher's statement, nonlinear dynamic analysis consumes more time and it's a complex process but pushover analysis is the more popular and simple method to calculate the behavior factor. In this research three different RC frames were studied i.e., 3 storey, 5 storey and 7 storey RC frame with each of four different bays like 2 bays, 3bays, 4 bays, and 5 bays, and static pushover analysis have been performed in the SesimoStruct program. From the effective study, the authors concluded that Static pushover analysis is an efficient and practical method to study the nonlinear behavior of RC structures as compared to other methods. As the height of the structure increases the behavior factor decreases. The most suitable method to calculate the behavior factor is Uang 1991.

Many researchers did work on this important response reduction factor of the different RC frames. From the analytical study, the value of R is more when the infill is considered in the frame so the R-value is sensitive to the material & geometrical configuration of the structure. Also, the evaluated values of R for the bare frames are lesser than the recommended value by the BIS code. The R-factor significantly decreases by considering the opening in masonry infills, the height of the structure increases, and as the seismic zone increases. The evaluated R-factor based on the "Miranda & Bertero relationship (1994) is the most realistic as compared to other methods [7–18]. In strong earthquakes, the structures experience nonlinear behavior [19, 20].

In this study, the following principal objectives are adopted.

1. To evaluate the actual response reduction factor of RC-infilled regular and irregular frames.

2. To compare the response reduction factor of different RC-infilled frames with the values recommended by the BIS code.

List of abbreviations:

R is the response reduction factor;

R_d is the ductility reduction factor;

R_o is the Overstrength factor;

R_R is the redundancy factor;

V_d is the design base shear;

V_y is the ideal yield base shear;

$\Delta_{\max}$ is maximum displacement;

Δ_y is the yield displacement;

μ is the ductility;

$X_{oi}$is the horizontal offsets;

Y_{oi} is the vertical offsets;

d_m is the diagonal strut length;

λ_h is the dimensionless parameter;

h_z is the equivalent contact length.

2. Methodology

2.1. Adaptive pushover analysis

This is the advanced version of pushover analysis in which the applied load is updated at every single step of analysis. Researchers (Kalkan & Kunnath [21] and Gupta & Kunnath [22]) proposed to consider higher mode effects in the seismic analysis. So this adaptive pushover analysis considers the variation of dynamic properties & the applied load is updated with respect to input ground motion. In this advanced pushover method, the spectral amplification part is used for updating the load vectors. In the present study, the accelerogram time-history of the IS 1893 response spectrum & Chi-Chi earthquake have been considered for spectral amplification as shown in Fig. 1 and Fig. 2 respectively. Source: Pacific Earthquake Engineering Research Center (PEER) Strong Motion Database.

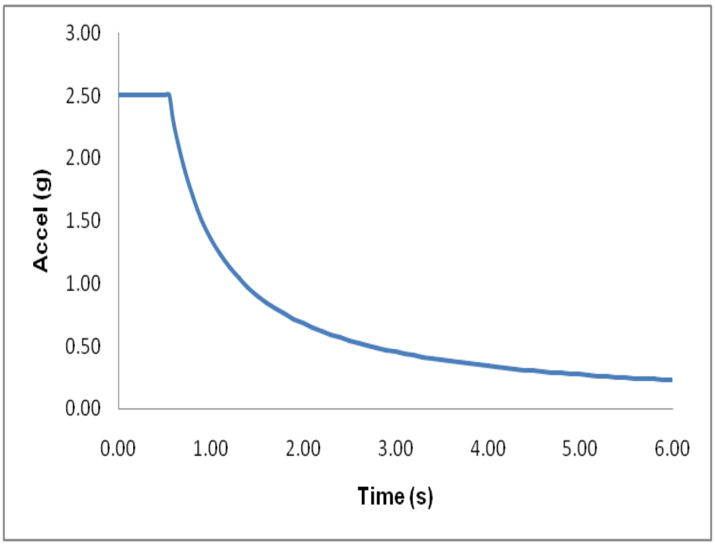


Figure 1. IS: 1893 Response Spectrum Curve.

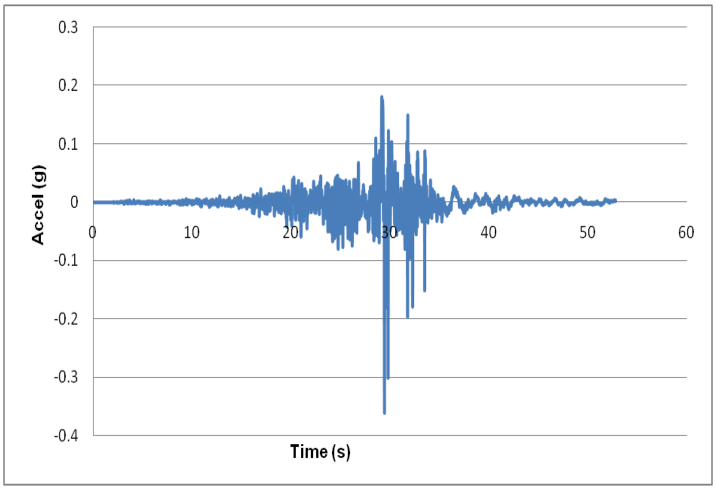


Figure 2. Chi-Chi Earthquake (date: 20 September 1999).

2.2. Response reduction factor

The response reduction factor is defined as the ratio of elastic strength to inelastic design strength. In other word, R-factor is the seismic design tool which shows the level of non-linearity in the structure. The recommended values of response reduction factor by IS: 1893 (Part-1) – 2016 as shown in Table 1. According to ATC-19 [23] the parameters related to the R factor can be mathematically expressed as:

$$R = R_d \times R_o \times R_R, \quad (1)$$

where, R is the Response reduction factor, R_d is the ductility reduction factor, R_o is the overstrength factor and R_R is redundancy. But according to Indian seismic code provision, the response reduction factor can be presented as shown in Fig. 3 and mathematically expressed in equation- 2 [2,9,14].

$$2R = R_d \times R_o. \quad (2)$$

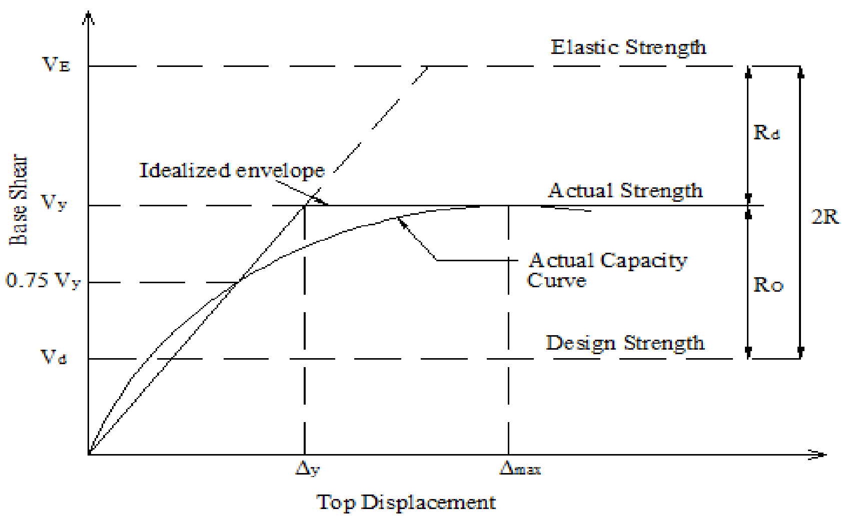


Figure 3.Relationship between Response reduction factor(R), over-strength factor (R_o), and ductility reduction factor (R_d).

Here the ductility is the ratio of maximum displacement (Δ_{max}) to the yield displacement (Δ_y) and it has been calculated based on the reduced stiffness method [24, 25].The ductility reduction factor has been calculated based on the expressions of Newmark and Hall (1982) [26]. The overstrength factor is the ratio of the ideal yield base shear (V_y) to design base shear (V_d). In this study, redundancy is incorporated into the overstrength factor.

Table 1. Recommended values of Response reduction factor by IS: 1893 (Part-1) – 2016 [27].

Frame System	Response Reduction Factor
Ordinary moment-resisting frame	3
Special moment-resisting frame	5

3. Results and Discussion

3.1. Model Description

In this study, three-dimensional 4-storey building with 3 bay frames in both directions i.e., X and Y direction. Models are studied for regular and irregular structures with considered openings in masonry infill. The buildings are designed for seismic zone 'IV' and it has been modeled in SeismoStruct software as follows:

1. RC-infilled regular frame in X and Y direction;
2. RC-infilled plan irregular frame in X and Y direction;
3. RC infilled vertical + plan irregular frame in X and Y direction.

The plan of the building is shown in Fig. 4 and Fig. 5 shows the models of the building. Material and sectional properties are as shown in Table 2.Column & beam dimensions have shown in Table 3, 4.

These special moment resisting frames are rigidly connected at beam-column junction. Also foundation of the structure assumed as a rigid connection in the present study.

The total seismic weight of the three models has been calculated manually as per the BIS code and the design base shear has also been evaluated according to IS 1893 Part-1:2016 as:

$$V_b = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g} \times W, \quad (3)$$

where V_b is the design base shear, Z is the seismic zone factor, I is the importance factor, $\frac{S_a}{g}$ is the design acceleration coefficient, W is the seismic weight of the structure.

The seismic weight of the RC-infilled regular frame is 9617.77 kN. Similarly, the seismic weight of the RC-infilled plan irregular frame and RC infilled vertical + plan irregular frame is 7898.88 kN & 6041.25 kN respectively.

The time period of building with masonry infill is $\frac{0.09 \times h}{\sqrt{d}}$ as per IS 1893 Part-1:2016 (4)

Where, h is the height of building, and d is the base dimension of the building in the direction earthquake shaking.

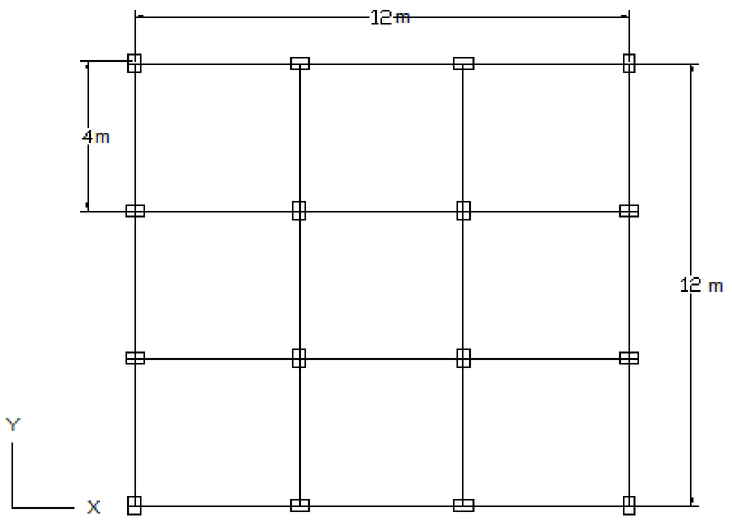


Figure 4. a – Regular Plan of the building.

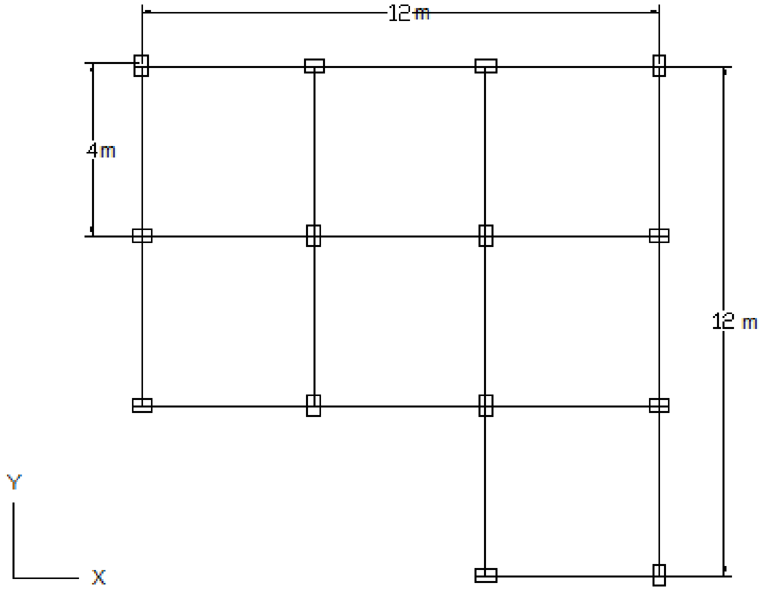


Figure 4.b – Irregular Plan of the building.

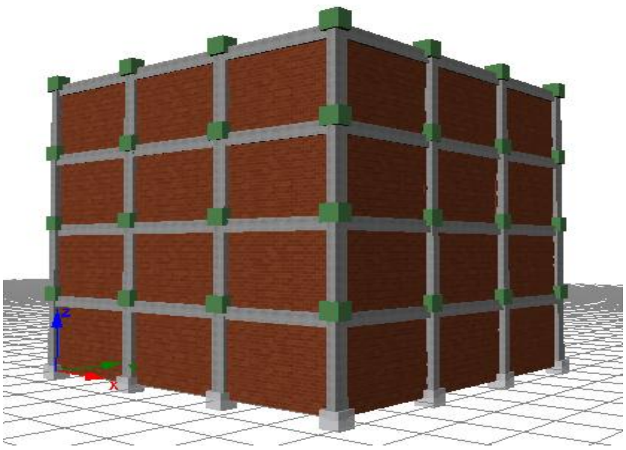


Figure 5.a – RC-infilled regular frame.

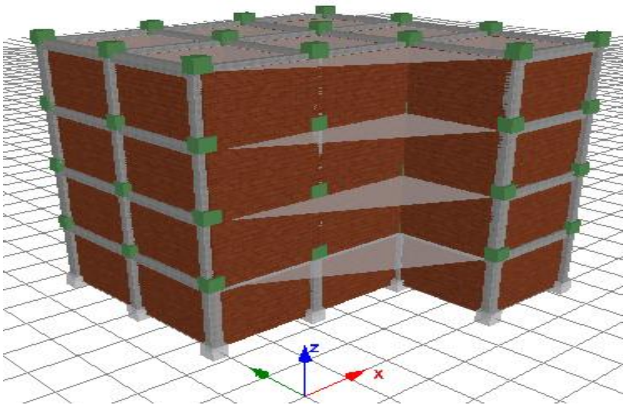


Figure 5.b – RC-infilled plan irregular frame.

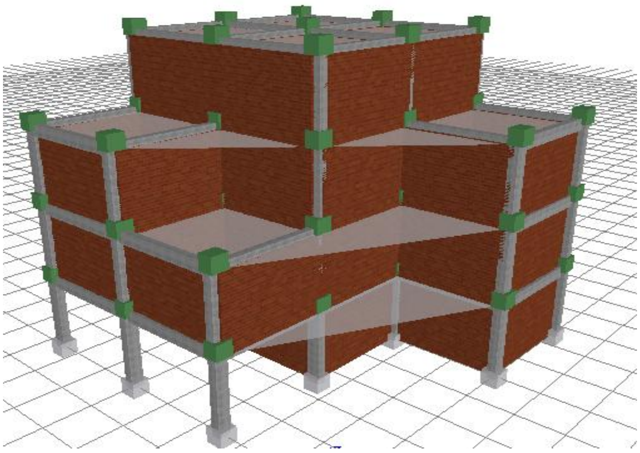


Figure 5.c – RC infilled vertical + plan irregular frame.

Table 2. Structural details of building.

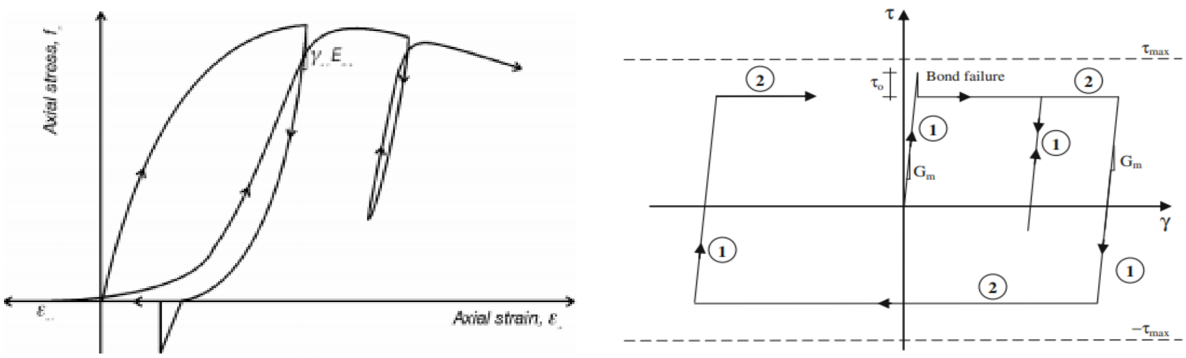
Frame structure	Special moment-resisting frame
Number of storey	4
Seismic zone	IV
Floor Height	3 m
Bay length	4 m in both direction
Infill wall	230 mm
Comp. strength of masonry	3 MPa
Modulus of Elasticity of masonry	1650 MPa
Width of a strut with the opening in infill	262 mm
Area of strut	60,260 sq. mm
Equivalent contact length (h_Z)	20.37 %
Horizontal offset (X_o)	5.62 %
Vertical offset (Y_o)	7.5 %
Type of soil	Medium stiff soil
Column size (mm)	300 X 450
Beam size (mm)	250 X 450
Slab Depth (mm)	150
Live load (kN/m^2)	3
Material	M -25 grade concrete and Fe-415 reinforcement
Damping	5 %
Importance factor	1.2

3.2. Inelastic Infill Panel Element (infill)

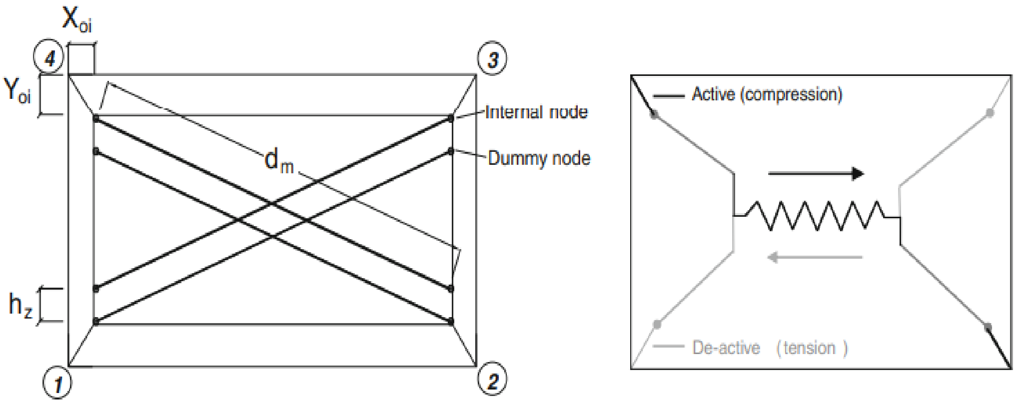
Each infill panel element is represented by four axial struts and two shear springs, as shown in Fig. 6.“Double strut nonlinear cyclic model” was developed by the Crisafulli (1997) [28]. It accounts for separately compressive and shears behavior of masonry and adequately represents the hysteretic response. The presence of an opening in infill will directly affect the seismic performance of the structures; the effect can be incorporated by minimizing the width (diagonal strut).

$$W_{do} = \left(1 - 2.5A_r\right) \cdot X \cdot W_d, \quad (5)$$

Where W_{do} is the width of the diagonal strut with an opening in infill, W_d the width of the diagonal strut, and Ar is the ratio of opening area to face area of infill. The Eq. 5 is valid for openings in walls ranging from 5 % to 40 % [8]. In this paper, the opening size in infill is considered as 2.44 sq. m, this implies that approximately 20 % opening area is considered in the infill.



(a) **(b)**



(c)

Figure 6.(a) Masonry strut hysteresis, (b) Shear cyclic relationship, and (c) Infill panel element configuration [28, 29].

Here, X_{oi} and Y_{oi} represent horizontal and vertical offsets respectively, d_m is the diagonal strut length, and h_z is the equivalent contact length.

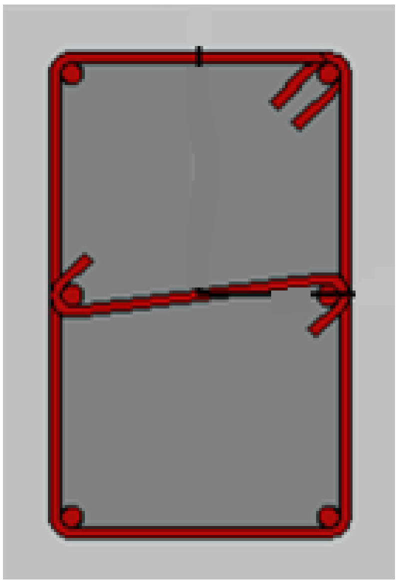


Figure 7.a Column Detailing.

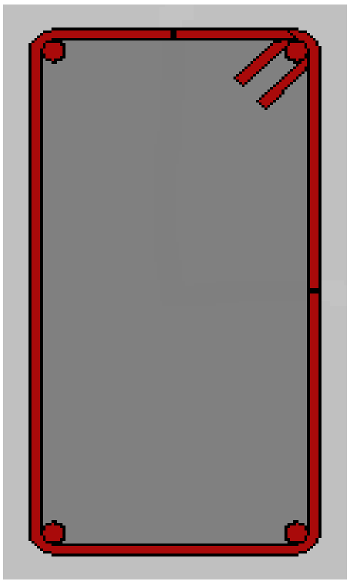


Figure 7.b Beam Detailing.

Table 3. Column dimensions and detailing.

Column	Size(mm)	Main Reinforcement	Shear Reinforcement
All columns of the building	300 × 450	4 nos. of 16 mm dia. at the corner and two nos. of 16 mm on the longer side.	8 mm Dia. @ 100 mm c/c

Table 4. Beam dimensions and detailing.

Beam	Size(mm)	Main Reinforcement	Shear Reinforcement
All beams of the building	250 × 450	2 nos. of 16 mm diameter @ top as well as the bottom	8 mmDia.@ 100 mm c/c

3.3. Verification of masonry infill through experimental and analytical by pseudo-dynamic loading

This example describes the modeling of a full-scale, four-storey building, which was designed according to initial versions of Eurocode 8 (CEN, 1995) and Eurocode 2 (CEN, 1991). The structure was tested at the ELSA laboratory under pseudo-dynamic loading using an artificial accelerogram derived from the 1976 Friuli earthquake.

The analytical results, obtained with the FE analysis program SeismoStruct, are compared with the experimental results.

Figure 8. Four-storey 3D infilled frame tested by Negro et al. (1996) [29].

Structural Geometry: The model consists of eight (exterior) RC columns (0.4 × 0.4 m), one (interior) RC column (0.45 × 0.45), T-section RC beams with different dimensions and infill panels.

Material Properties: The Mander et al. concrete model is employed for defining the concrete material used for columns and beams. Menegotto-Pinto steel model is employed for defining the steel material with the following properties: Es = 200000000 kPa; fy = 555000 kPa, μ = 0.02.

3.4. Modeling and Loading

The RC columns and beams are modeled through 3D force-based inelastic frame elements (infrmFB) with 4 integration sections. The number of fibers used in section equilibrium computations is set to 200. The infill panels are modeled through a four-node masonry panel element (inelastic infill panel element).

In order to run a nonlinear static time-history analysis, four time-history curves (one for each floor) are loaded in the time-history curves.

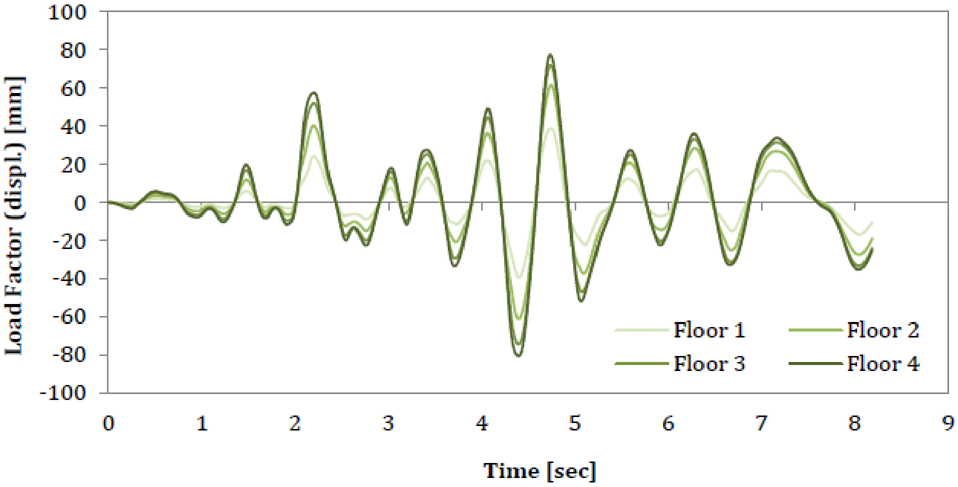


Figure 9. Artificial record generated from Friuli accelerogram – displacement histories.

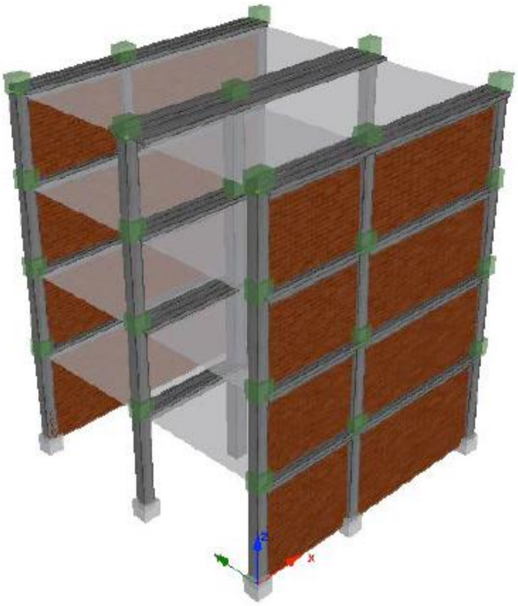


Figure 10. Model of building.

3.5. Results comparison

The comparison between experimental and analytical results is shown Fig. 11.

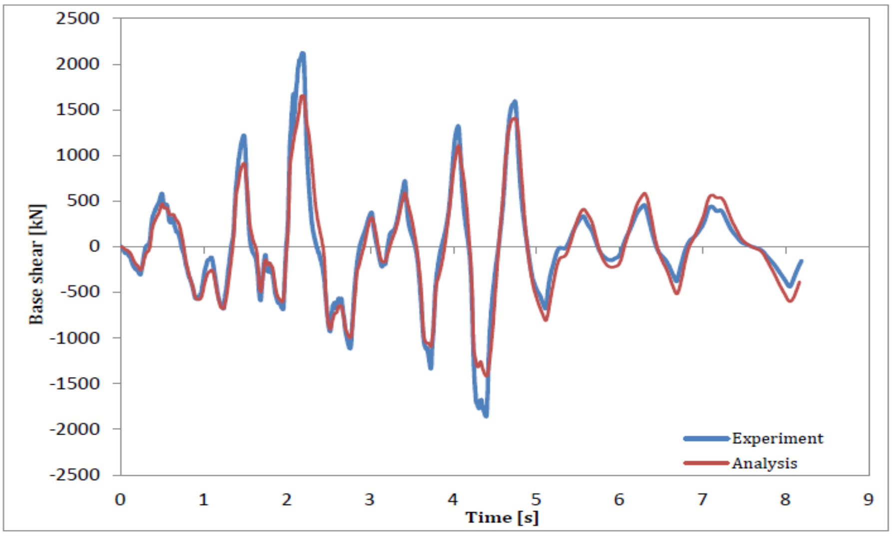


Figure 11. Experimental vs. Analytical results.

3.6. Pushover Curves

The several seismic design parameters namely; strength, ductility, response reduction factor, etc. are evaluated from pushover curves. The significance of masonry infills which play an important role in the RC frame has been quantified. These pushover curves are as shown in Fig.12.

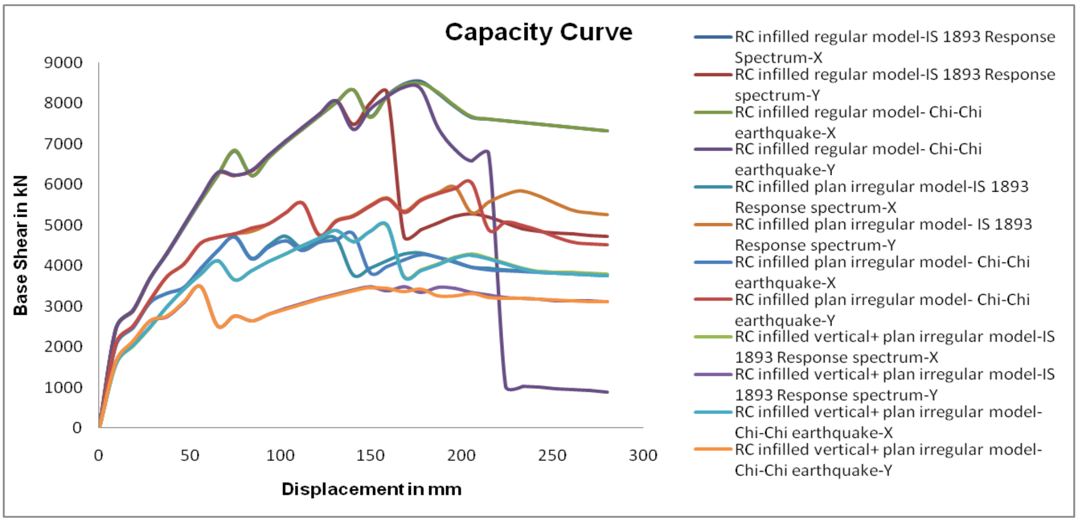


Figure 12. Comparisons of Pushover Curves.

3.7. Base Shear

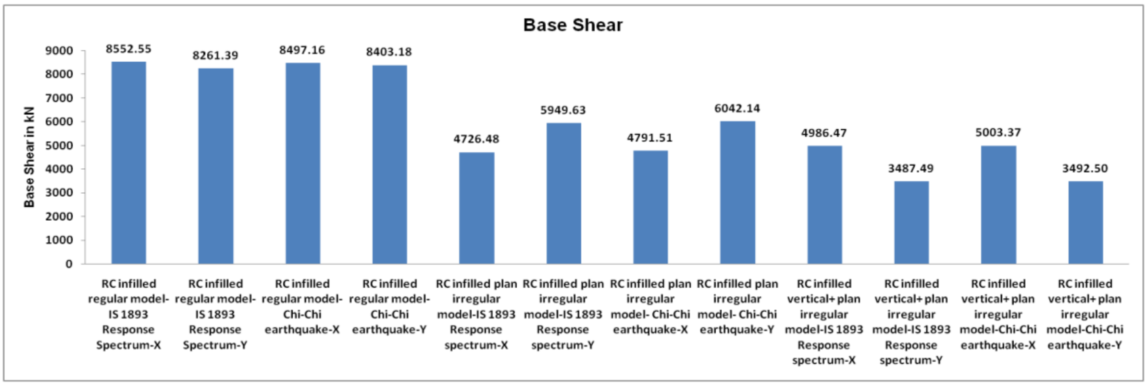


Figure 13. Comparison of Base Shear.

As per the Fig. 13, base shear is lower in RC-infilled vertical +plan irregular frame as compared to other frames. Averagely 25.98 % and 27.51 % base shear increases in RC-infilled plan irregular frame as compared to RC-infilled vertical + plan irregular frame for IS-1893 response spectrum and Chi-Chi earthquake respectively. In the case of RC-infilled regular frame in x and y direction, there is a small variation of base shear due to more symmetry as compared to others. The base shear is more in RC–infilled regular frame as compared to other irregular frames due to the presence of regularity in the structure.

3.8. Ductility

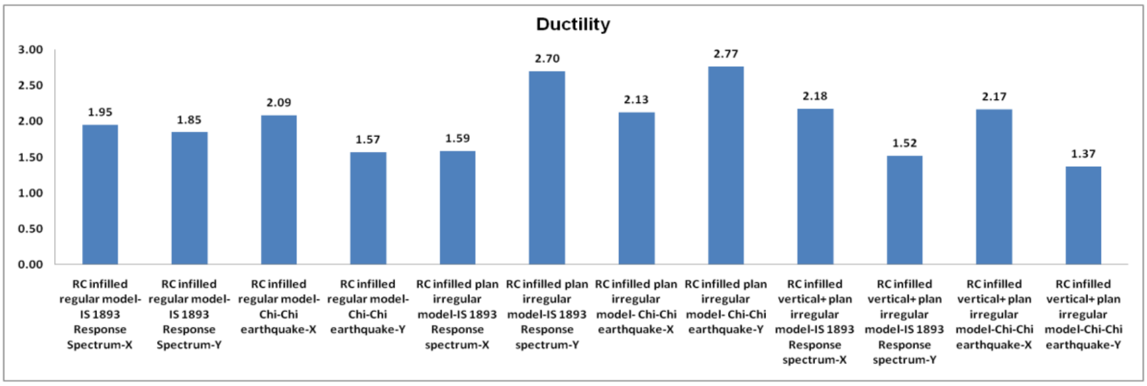


Figure 14.Comparison of Ductility.

As per the Fig. 14, the average ductility obtained is higher in RC-infilled plan irregular frame as compared to other frames. Averagely 12.63 % and 33.87 % ductility increases in RC-infilled plan irregular frame as compared to RC-infilled regular frame for IS-1893 response spectrum and Chi-Chi earthquake respectively. In the case of both irregular frames, there is an average variation of ductility by 15.67 % and 38.41 % for IS-1893 response spectrum and Chi-Chi earthquake respectively.

3.9. Ductility Reduction Factor

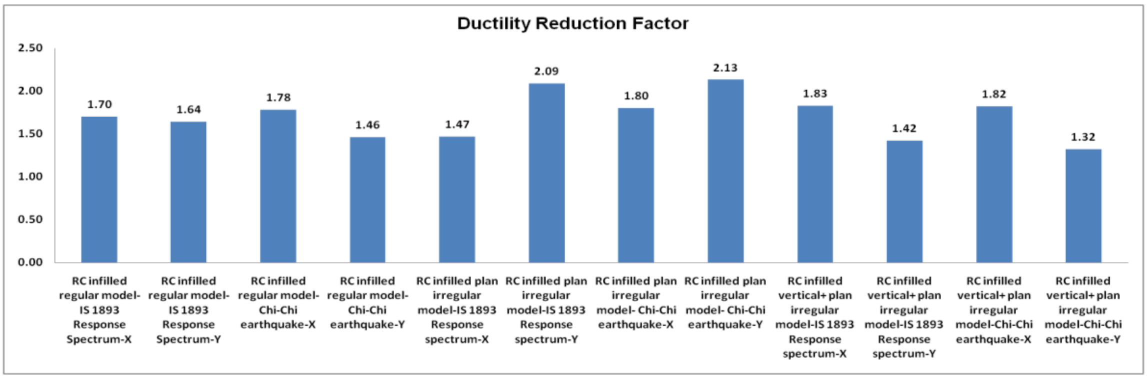


Figure 15.Comparison of Ductility Reduction Factor.

The ductility reduction factor is evaluated based on the “Newmark & Hall” theory. As per the Fig. 15, averagely 6.58 % and 20.98 % ductility reduction factor increases in RC-infilled plan irregular frame as compared to the RC-infilled regular frame for IS-1893 response spectrum and Chi-Chi earthquake respectively. In the case of both irregular frames, there is an average variation of ductility reduction factor by 9.53 % and 24.84 % for IS-1893 response spectrum and Chi-Chi earthquake respectively.

3.10. Overstrength Factor

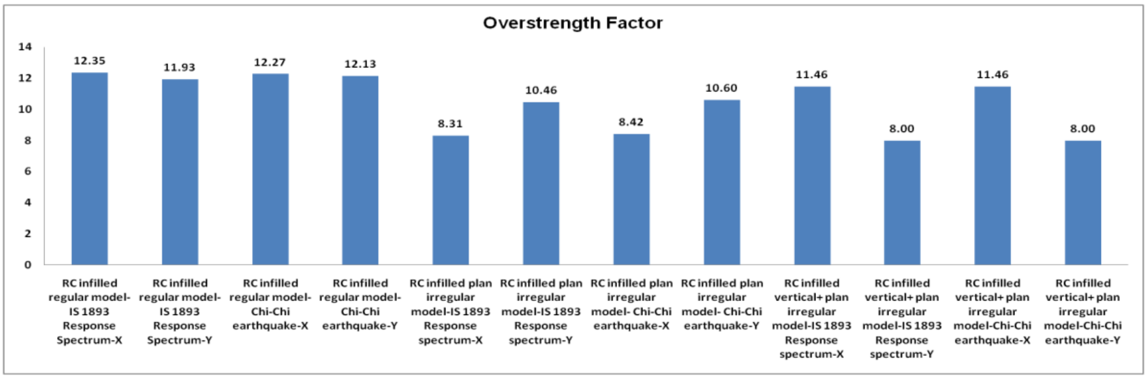


Figure 16.Comparison of Overstrength Factor.

As per the Fig. 16, the overstrength factor is higher in the RC-infilled regular frame as compared to other frames due to less irregularity. Averagely 24.76 % and 25.38 %overstrength factor increases in RC-infilled regular frame as compared to RC-infilled vertical + plan irregular frame for IS-1893 response spectrum and Chi-Chi earthquake respectively. In the case of irregular frames, there is an average variation of overstrength factor by 3.73 % and 2.31 % for IS-1893 response spectrum and Chi-Chi earthquake respectively.

3.11. Response Reduction Factor

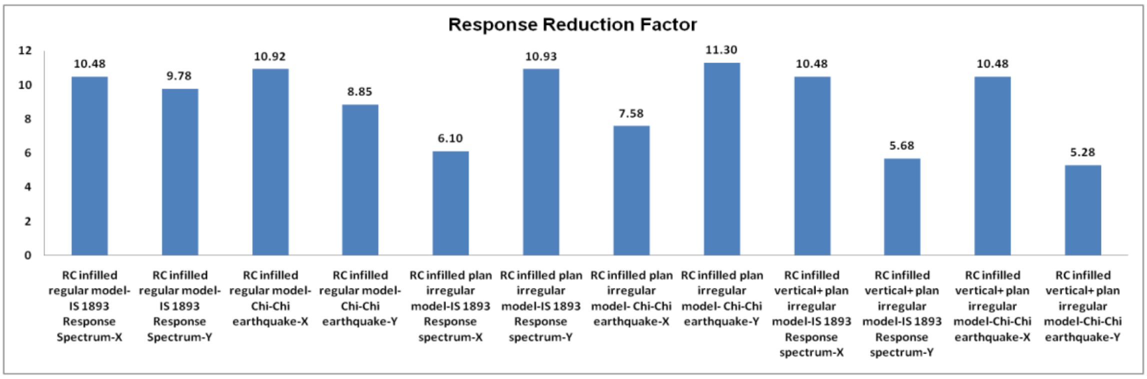


Figure 17.Comparison of Response Reduction Factor.

Using Equation (2) the R factor has been evaluated. As per Fig. 17, the response reduction factor is higher in the RC-infilled regular frame as compared to other frames similar to the overstrength factor. Averagely 25.37 % and 25.38 % R- factor increases in RC-infilled regular frame as compared to RC-infilled vertical + plan irregular frame for IS-1893 response spectrum and Chi-Chi earthquake respectively. In the case of irregular frames, there is an average variation of R-factor by 5.32 % and 19.79 % for IS-1893 response spectrum and Chi-Chi earthquake respectively. Similarly, Alguhane T.M. et al. [1] presented the study about an existing RC building (irregular in plan and elevation) in Madinah city that is seismically evaluated with and without an infill wall. In which the response reduction factor of the bare frame is lesser than the specified code value (R-value- 2.5, Ω factor-3 according to Saudi Building Code SBC 301) by 18.4 %. However, including an infill wall in the frame system, increase the value of the response modification factor (4.55) by 82 % and Over-strength factor (4.55) by 51.66 % as compared to specific code value i.e., satisfying the code requirements.

4. Conclusions

After the interpretation of analytical results and comparison of values, the conclusions drawn from this study are as summarized below:

1. The base shear values are larger in regular RC-infilled frames as compared to other irregular frames.

2. Average ductility and ductility reduction factor are higher in RC-infilled plan irregular frame as compared to other frames because there is no infill and structural members in some part of the frames, so it allows higher drift.

3. The over-strength factor is significantly influenced by the redundancy of the frame. Also, as a result of it, the response reduction factor of the RC-infilled regular frame is higher than the other irregular frames.

4. The computed values of '*R*' for regular and irregular RC-infilled frames evaluated by adaptive pushover analysis are more than the value suggested by the BIS code. To note, after the incorporation of different irregularities in the frames the computed values of 'R' also are more than the values given by BIS code, because, infill plays an important role to maintain the overall structural integrity of the frames.

5. As per the present study, in the case of both irregular frames, the R-factor is more influenced by the ductility reduction factor as compared to the overstrength factor due to maximum variation in the ductility & ductility reduction factor.

6. Generally, the R-factor indirectly depends on the redundancy of structure. In the case of irregular frames, R-factor is less in RC-infilled vertical + plan irregular frame as compared to RC-infilled plan irregular frame due to less redundancy.

7. According to the present study, the evaluated response reduction factor (R) of different RC-infilled frames is more as compared to the value given by BIS code.

8. As per the present study, R-factor is sensitive to material, geometrical & structural configuration of the structure.

References

1. Alguhane, T.M., Ayman H.K., Fayed, M.N., Ismail, A.M. Seismic assessment of old existing RC buildings with masonry infill in Madinah as per ASCE. International Journal of Civil, Environmental, Structural, Construction, and Architectural Engineering. 2015. 9 (1). Pp.52–63.
2. Chaulagain, H., Rodrigues, H., Spacone, E., Guragain,R., Mallik, R., Varum, H. Response reduction factor of irregular RC buildings in Kathmandu valley. Earthquake engineering and engineering vibration. 2014.13. Pp. 455–470. https://doi.org/10.1007/s11803-014-0255-8
3. Motiani, R., Kunal, J.R., Gahrana, S., Nambiar, A., Desai, M. Evaluation of response reduction factor by pushover analysis. Int. J. Structural Engineering. 2018.9(2). Pp. 116–129.
4. Brahmavrathan, D., Arunkumar, C. Evaluation of response reduction factor of irregular reinforced concrete framed structures. Indian Journal of Science and Technology.2016.9(23).DOI: 10.17485/ijst/2016/v9i23/95981
5. Smyrou, E., Blandon, C., Antoniou, S., Pinho, R., Crisafulli, F. Implementation and verification of a masonry panel model for nonlinear dynamic analysis of infilled RC frames. Bulletin of Earthquake Engineering. 2011. 9. Pp. 1519–1534. DOI: https://doi.org/10.1007/s10518-011-9262-6
6. Mohamed, S.I., Heba, M.I. Application of Pushover Analysis for the calculation of Behavior Factor for Reinforced Concrete Moment-Resisting Frames. International Journal of Civil and Structural Engineering. 2015.5(3). Pp.216–226. DOI: 10.6088/ijcser.2014050021
7. Goud, S.S., Pradeep kumar, R. Rationalizing Response Reduction Factor (R) for better Performance of Reinforced Concrete Framed Buildings. National Conference on Recent Research Advances in Civil Engineering, Tamilnadu, India, 2014. https://www.researchgate.net/publication/268805699

8. Shendkar, M., Pradeep Kumar, R. Influence of opening in infill on R factor of RC infilled frame structures. Indian Concrete Institute Journal. 2018.October-December 2018. Pp. 1–6.
9. Shendkar, M.R., Mandal, S., Pradeep Kumar, R. Effect of lintel beam on response reduction factor of RC-infilled frames. Current Science. 2020.118(7). Pp. 1077–1086. DOI:10.18520/cs/v118/i7/1077-1086
10. Mandal, S., Shendkar, M.R. Evaluation of response reduction factor of RC-infilled frames. 17th World Conference on Earthquake Engineering.17WCEE Sendai. Japan, 2020. Pp. 1–12.
11. Shendkar, M., Pradeep Kumar, R. Response Reduction Factor of RC framed structures with Semi-interlocked masonry and Unreinforced masonry infill. Indian Concrete Institute (ICI) Journal. 2018. Jan-Mar 2018.Pp. 24–28.
12. Shendkar, M., Mandal, S., Pradeep Kumar, R., Maiti, P.R. Response Reduction Factor of RC-infilled frames by using different methods. Indian Concrete Institute (ICI) Journal. 2020. April-June 2020.Pp.14–23.
13. Shendkar, M.R., Pradeep Kumar, R., Maiti, P.R. Effect of aspect ratio on response reduction factor of RC framed structures with semi-interlocked masonry and unreinforced masonry infill.The Indian Concrete Journal.2020.94(12). Pp.7–16.
14. Shendkar, M.R., Kontoni, D.-P.N., Mandal, S., Maiti, P.R., Gautam, D. Effect of lintel beam on seismic response of reinforced concrete buildings with semi-Interlocked and unreinforced Brick Masonry Infills. Infrastructures. 2021.6(6). Pp.1–18. https://doi.org/10.3390/infrastructures6010006
15. Nishanth, M., Visuvasam, J., Simon, J., Packiaraj, J.S. Assessment of seismic response reduction factor for moment-resisting RC frames. IOP Conf. Series: Materials Science and Engineering.2017. Pp. 1–11. https://doi:10.1088/1757-899X/263/3/03-2034
16. Mwafy, A.M., Elnashai, A.S.Calibration of Force Reduction Factors of RC buildings. Journal of Earthquake Engineering.2002.6(2). Pp. 239–273. https://doi.org/10.1080/13632460209350416
17. Maheri, M.R., Akbari, R. Seismic behaviour factor, R, for steel X-braced and knee-braced RC buildings. Eng. Struct. 2003.25. Pp.1505–1513.
18. Chaulagain, H., Guragain, R., Mallik, R.K. Assessment of response reduction factor of RC buildings in Kathmandu valley using nonlinear pushover analysis. ME thesis. Purbanchal University. Nepal, 2010.
19. Beiraghi, H. Earthquake effect on the concrete walls with shape memory alloy reinforcement. Smart Structures and Systems. 2019. 24(4). Pp. 491–506.
20. Beiraghi, H. Fragility assessment of shear walls coupled with buckling restrained braces subjected to near-field earthquakes. Steel and Composite Structures. 2019.33(3). Pp. 389–402.
21. Kalkan, E., Kunnath, S.K. Adaptive modal combination procedure for nonlinear static analysis of building structures. Journal of Structural Engineering ASCE.2006.132(11). Pp.1721–1731. https://doi.org/10.1061/(ASCE)0733-9445(2006)132:11(1721)
22. Gupta, B., Kunnath, S.K. Adaptive spectra-based pushover procedure for seismic evaluation of structures. Earthquake Spectra. 2000.16(2). Pp.367–391.https://doi.org/10.1193/1.1586117
23. ATC 19 Seismic response modification factors. Applied Technical Council. California Seismic Safety Commission. Redwood City. California, 1995.
24. Park, R. Ductility evaluation from laboratory and analytical testing. Proceedings of the 9th World Conference on Earthquake Engineering. University of Tokyo. Japan, 1988. Pp.605–616.
25. Pauley, T., Priestley, M.J.N. Seismic design of reinforced concrete masonry buildings. Wiley Interscience. New York. USA, 1992.
26. Uang, C.M. Establishing R and Cd Factors for Building Seismic Provisions. Journal of Structural Engineering ASCE.1991.117(1). Pp. 19–28. DOI: https://doi.org/10.1061/(ASCE)0733-9445(1991)117:1(19)
27. IS 1893 Criteria for Earthquake Resistant Design of Structures-Part-1 General Provisions and Buildings (sixth Revision).Bureau of Indian Standards.New Delhi, 2016.
28. Crisafulli, F.J. Seismic behavior of reinforced concrete structures with masonry infills (Doctoral Thesis) University of Canterbury. New Zealand, 1997.https://ir.canterbury.ac.nz/handle/10092/1221
29. Seismosoft-Seismostruct, A computer program for static and dynamic nonlinear analysis of framed structure,seismostruct user manual.2020.http://www.seismosoft.com: SeismoSoft

Contacts:

Mangeshkumar Shendkar, mangesh.shendkar94@gmail.com
Hamid Beiraghi, h.beiraghi@msh-iau.ac.ir
Sasankasekhar Mandal, smandal.civ@itbhu.ac.in