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Response Reduction Factor for SMRF 3D Frame Buildings on Sloppy Ground

Suman Devkota, Vijay Kumar

Abstract**:** ***Lateral forces are key factors in the design of building structure and in general these forces are evaluated using linear static method with the incorporation of response reduction factor. The actual intensity of lateral force is minimized by response reduction factor. However IS Code 1893:2016 does not give information about the components of response reduction factor. The value mentioned in IS code may be based on expert engineering judgment without any scientific basis. The Present research work focus on the estimation of response reduction factor (R) of SMRF frames considering slope terrain without any impairment in slope in Zone V. Fifteen frame models are prepared according to the guideline of IS Code 456:2000 and lateral load on frame was assigned as per IS 1893:2016 (Part-1) for the research purposes. Evaluation of response Reduction Factor according to Applied Technical Council (ATC-19) is carried out which stated that response reduction factor is the product of Strength factor, Redundancy factor and Ductility factor. Pushover analysis also termed as nonlinear static analysis under displacement control method is performed on the analytical models by an integrated finite element software for structural analysis and design called ETABS 2017. P-delta governs the geometrical non-linearity of structure. It has been observed over strength of regular structure is more as compared to irregular geometrical model whereas the ductility reduction factor does not show any significant trend. Moreover, all the models are limited in 6 story only with same structural property additional research is needed considering wider set of parameters framework.***

Keywords**:** ***Over strength, Ductility, Pushover, ETABS 2017, Slopped terrain, Bi-linear approximation, Response Reduction Factor (R).***

I. INTRODUCTION

Earthquake is an unpredictable natural phenomenon that occurs suddenly by the movement of earth's crust, producing high amount of energy in form of elastic waves. About 90% of earthquakes occur due to tectonic events and primary movements of the faults. The past experiences show that many common buildings were destroyed due to ignorance of lateral forces during the design of building and hence the concept of Earthquake Resistance Design of building comes forward to optimize the loss during earthquake. The basic philosophy of earthquake-resistant design is that a structure should resist earthquake ground motion without collapse, although it may undergo some structural as well as non-structural damage. In other words, the structure should have adequate capacity for stiffness and strength for controlling deflection and deformation which may prevent possible collapse during earthquake. Therefore primary task for a structural engineer, during the designing of an earthquake resistance building is to ensure that the building possesses enough ductility to withstand the earthquake which is likely to be experienced during its lifetime.

North and North-eastern parts of India are hilly regions and they are categorized under seismic zone IV and V. Some of the hilly areas are more prone to the earthquake but due to rapid urbanization and economic growth, hilly area has increased the real estate development which results in the population increment in hilly region enormously. Hence the demand for residential buildings is also increasing rapidly. Due to the topographic challenges, the construction of RCC building in hilly area is different than that of plain area. Without disturbing the geological profile of slope, the construction should be carried out so that the slope can remain stable persistently.

Cuts and fill of earth can be problems for the building construction in sloppy ground which also increases construction cost for retaining and breast wall structure. Building constructed on sloppy area will vary in mass and stiffness along the vertical and horizontal plane and as a result the center of mass and center of rigidity does not coincide on various floors. Due to the steep sloppy topography, construction of hill building structures may not be free from step-backs. Such configuration gives unsymmetrical and irregular building structures and increases the chances of damage during earthquake.

Also the building having unequal column height and having short columns resting at different positions may bring severe problems in building in sloppy areas. Additionally, at setback location stress concentration is higher when building receives earthquake forces. Recent earthquakes, struck in hill regions viz., Bihar-Nepal (1988), Uttarkashi (1990), Kashmir (2005), Sikkim (2011), Nepal (2015) have shown major casualties caused by design flaws and failures in RC as well as masonry structures.

Most of the seismic design is based mainly on the elastic force analysis. In the design process, the nonlinear response of the structure is not taken into account which may be due to geometry as well as material property but its eeffect is included by a factor called response reduction factor (R). The use of concept of response reduction factor reduces the seismic lateral force and incorporates non-linearity with the help of over strength, redundancy, and ductility of structure.

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II. COMPONENTS OF RESPONSE REDUCTION FACTOR

The level of inelasticity is defined by the response reduction factor R. It is a unique factor that depends on structure type and materials used.

The factor (R) reflects the structure capability to dissipate the elastic energy via inelastic behavior, thus the concept of R is to reduce the lateral force and combine non-linearity. Hence, according to ATC 19 (1995), FEMA 273 indicates that the response reduction factor R can be expressed as a function of reduction factors considering strength, ductility and redundancy. The equation to represent the reduction factor is given by

$$R = R_s \times R_\mu \times R_r \qquad (1)$$

Where R_s Strength Reduction factor, R_μ is ductility reduction factor and R_r is redundancy reduction factor.

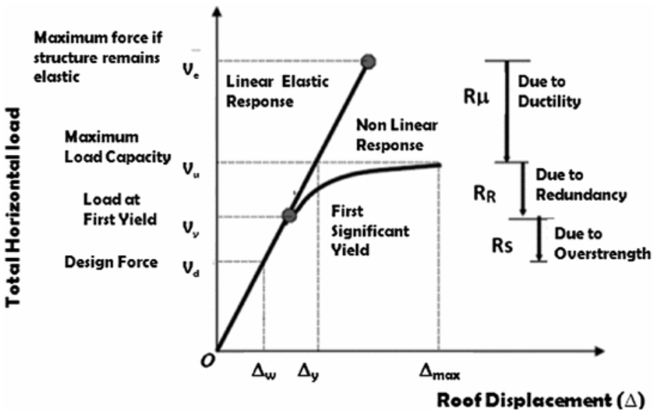

Fig. 1 (Horizontal load vs roof displacement)

A. Strength Reduction Factor (R_s).

The structure are incessantly designed in order to achieve higher strength than that of requirement for service load condition. Hence the strength beyond the designed strength of structure is termed as over strength. The over strength in building ensues due to non-structure element involvement, load combinations, minimum size and spacing of reinforcement, importance of building, material over strength, confinement of concrete etc. Mathematically over strength factor is the ratio of extra strength of structure up to first significant yield load to minimum seismic design strength calculated as per code and is given by

$$R_s = \frac{V_y}{V_d} \qquad (2)$$

Where V_y is a significant first yield load corresponding to actual yielding of structure and V_d is designed base shear.

B. Ductility Reduction factor (R_μ).

Ductility is the capacity of the structure to support large inelastic deformation without significant loss of strength and stiffness. The ductile structure shows better performance in seismic load as compared to brittle structure. The ductility factor reduces the demand of elastic force to the level of yield strength of RC structure. The inelastic deformation in a structure system subjected to a ground motion is given by displacement ductility ratio "μ" which is represented by the ratio of maximum absolute displacement to its yield displacement. Ductility reduction factors measure the global nonlinear response of structure and it is the function of both ductility and fundamental time period of any structure. According to Newmark and Hull (1982) ductility reduction factor is given by

$$R_\mu = 1;\ for\ \ T > 0.2\ Sec. \qquad (3)$$

$$R_\mu = \sqrt{2\mu \quad 1}\ ; for\ 0.2Sec < T < 0.5Sec. \qquad (4)$$

$$R_\mu = \mu;\ for\ \ T > 0.5Sec. \qquad (5)$$

Also displacement ductility ratio μ is given by

$$\mu = \frac{\Delta m}{\Delta y} \qquad (6)$$

Where Δm is maximum displacement and Δy is yield displacement of structure obtained by a bilinear idealization of pushover curve.

C. Redundancy reduction Factor (R_r).

According to ATC-19, redundancy of seismic frame should be composed of multiple vertical lines of framing each designed and detailed to transfer seismic induced initial force to the foundation.

ASCE 7-16 provided the value of reduction factor as 1 for certain structure. However, according to ATC-19 higher designed force can be used for less redundant structure by modifying the response reduction factor with redundancy factor as given in table below.

Table 1: Redundancy Factor

Line of vertical framing	Redundancy factor (R_r)
2	0.71
3	0.86
4	1

III. OBJECTIVE AND METHODOLOGY.

The main objective of the research are listed below.

- To conduct model and nonlinear analysis (Pushover Analysis) of different building in slope terrain.
- Evaluation of over strength factor, displacement ductility ratio, ductility reduction factor from the data obtained by bi-linear approximation of pushover curve.
- Estimation of Response Reduction factor using the above parameters and compared to IS 1893:2016 for SMRF building frames.

Various phases for research methodology adopted to conduct the research are as follows.

A. Building Description and Nomenclature.

The considered SMRF frame for the research purposes is of six story in medium soil condition in Zone V which is considered as the most seismically intensive zone. In X-axis the building have 4 bays each length 3.5meter whereas Y-axis is provided with 3 bays having 4meter in length for each bay. The important factor of building is taken as 1. Height of Ground story is taken 3.5m whereas other floors with 3meter height is considered for the research purposes. Others properties considered are listed in table below.

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Table 2: Properties of building elements

Building Type	Residential Building
Beam	350mm. x 300mm.
Column	400mm. x 400mm.
Thickness of Slab	125mm.
Grade of Concrete	M30
Grade of Steel	HYSD 415
Property Modifier for Beam as per IS 1893:2016	0.35
Property Modifier for Column as per IS 1893:2016	0.7
Live Load at floor	3kN/m^3
Live load at Roof	1.5kN/m^3
Floor Finish	1kN/m^2
Outer Wall Load for 230mm thickness considering 20% opening.	8.74kN/m
Partition Wall Load for 115mm thickness considering 20% opening.	4.4kN/m
Parapet Wall Load	2.12kN/m

Table 3: Building Nomenclature

Frame Type	Name
Regular frame in plain terrain	RFM
C-Model in Plain terrain	C-RFM
Stepped Model in Plain terrain	S-RFM
Regular frame Building in 18^0 slope	18D-RFM
C Model frame Building in 18^0 slope	18D-CFM
Stepped frame Building in 18^0 slope	18D-SFM
Regular frame Building in 27^0 slope	27D-RFM
C Model frame Building in 27^0 slope	27D-CFM
Regular frame Building in 27^0 slope	27D-SFM
Regular frame Building in 36^0 slope	36D-RFM
C Model frame Building in 36^0 slope	36D-CFM
Regular frame Building in 36^0 slope	36D-SFM
Regular frame in plain terrain	T-RM
C-Model in Plain terrain	C-TM
Stepped Model in Plain terrain	S-TM

B. Modeling of structures.

Depending upon how closely the model matches real structure, mathematical model determines the accuracy of results of structure analysis. Generally, the model is extended in all three directions to describe the geometry of structure. Finite element software ETABS 2017 "an integrated software for structural analysis and design" is used for modeling of building frame structure. A few models of buildings are illustrated below.

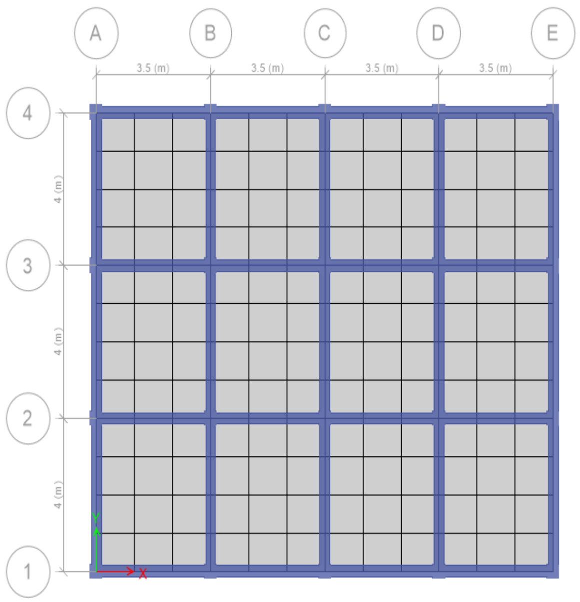

Fig. 1. (Plan of regular, stepped and trench building model.)

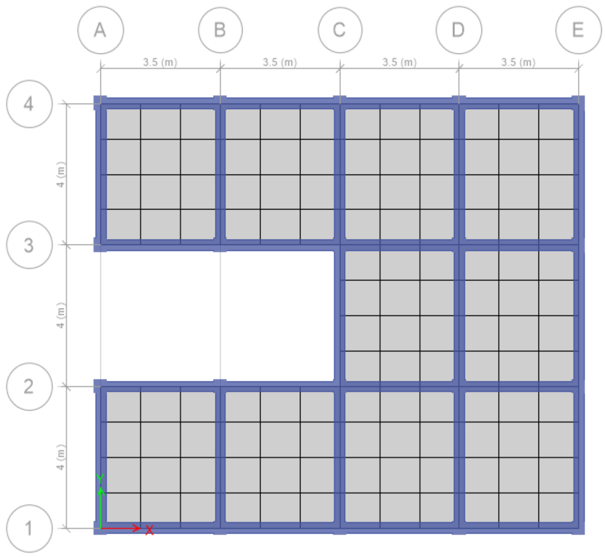

Fig. 2. (Plan of C-Model frame building)

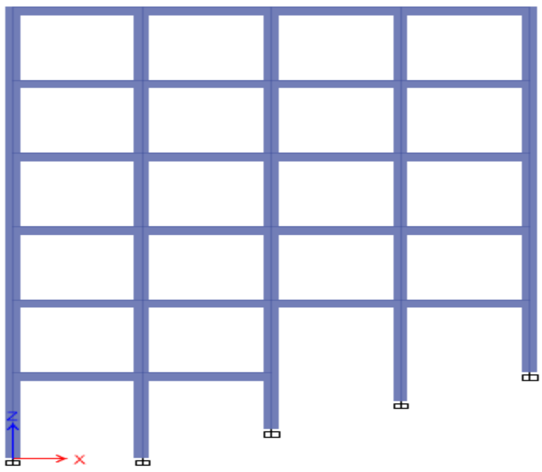

Fig. 3. (Elevation of 18D-RFM)

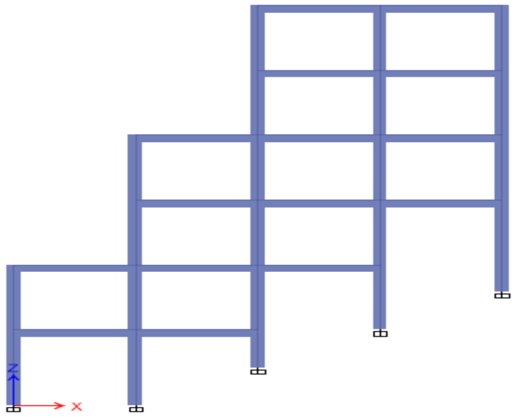

Fig. 4. (Elevation of 27D-SFM)

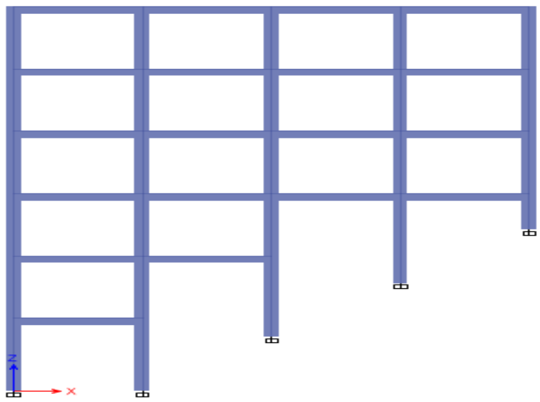

Fig. 5. (Elevation of 36D-RFM)

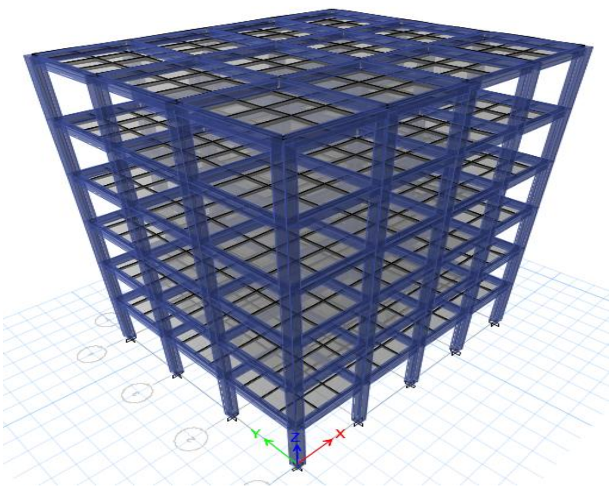

Fig. 6. (3D RFM)

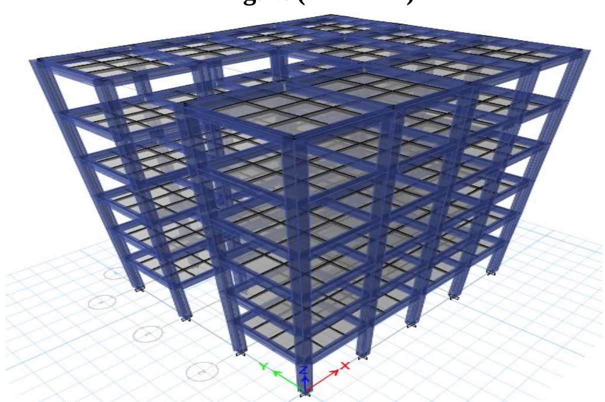

Fig. 7. (Regular 3D C-RFM)

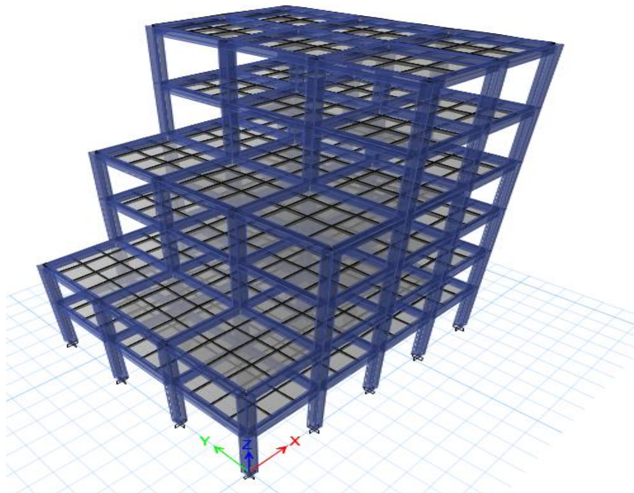

Fig. 8. (Regular 3D S-RFM)

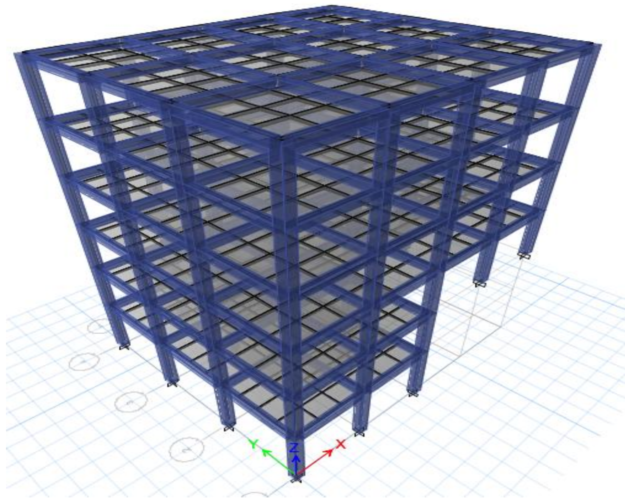

Fig. 6. (3D T-RM)

C. Pushover Analysis

It is the non-linear static analysis method which is applied to determine the capacity of structures. Pushover analysis can be either force control or displacement control according to the physical nature of the load and behavior of the structure. Force control is applied when the load is known (gravity load) and the structure is expected to support that load. Displacement control is applied when the specified drift is an attempt to find, where magnitude of applied load is not known or where structure can be expected unstable or lose strength. Pushover analysis examines the progressive stiffness degradation of any structure as it is loaded into the post elastic range of behavior. The present research paper follows displacement control method where a pre define seismic load pattern is distributed in the building height and then these loads monotonically increase in constant proportions with the displacement control until a certain level of deformation in X and Y direction is achieved. Three nonlinear load cases are considered for pushover analysis. Gravity non-linear load case (DL+FF+0.25LL), PX as push in X-Direction and PY as Push in Y direction. In PX and PY initial condition for nonlinear cases starts from Gravity non-linear load as shown in Fig. 8 below. P-delta is taken as geometrical non-linearity option.

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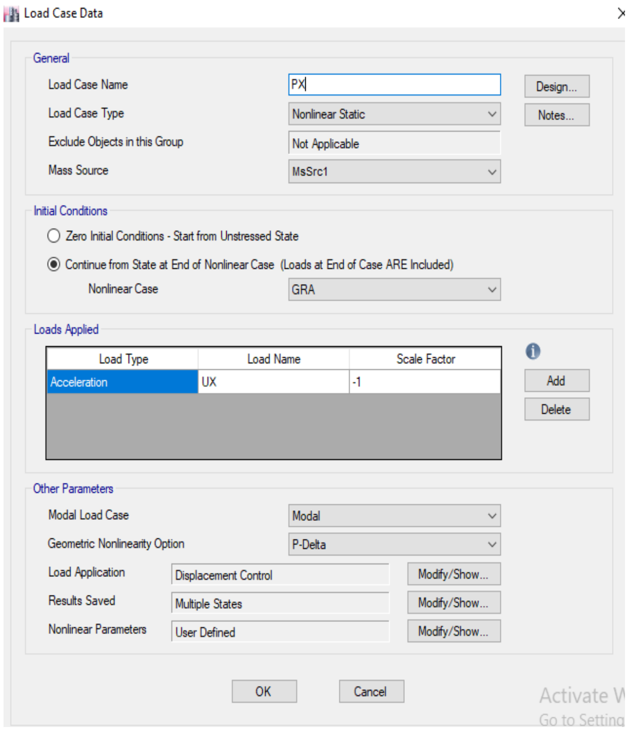

Fig. 8. (Pushover nonlinear load case in X-direction)

Modeling parameters and numerical acceptance criteria for nonlinear procedure reinforcement concrete beam and column are taken from table 6-7 and 6-8 of ASCE/SEI Concrete Provision. Beam members are assigned with M3 hinges and Column members are assigned with interacting P-M2-M3. Hinge relative distance is determined by using the hinge length relations given by Park and Pauley [2].

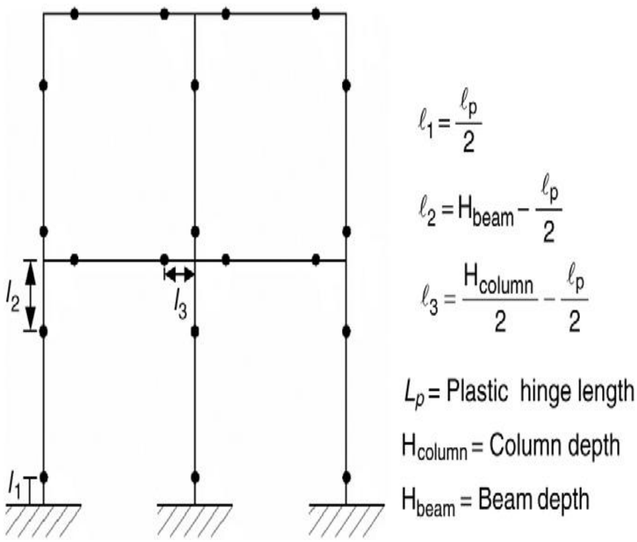

Fig. 9. (Hinge location at beam and column)

The plastic hinge length l_p is given by

$$l_p = 0.5H \qquad (7)$$

And some guidelines like ATC-32 use the length of plastic hinge given by proposed by Priestley et al. [2].

$$l_p = 0.08L + 0.022\, f_{ye} \times d_{bl} \geq 0.044\, f_{ye} \times d_{bl} \qquad (8)$$

Where H is sectional depth, L is the critical length from the critical section of the plastic hinge to the point of contra flexure, f_{ye} and d_{bl} are the yield strength and the diameter of longitudinal reinforcement.

IV. RESULT AND DISCUSSION

The research mainly lines up is to check the validity of the value of response reduction factor mentioned in IS 1893:2016. Hence, after pushover analysis of 15 models, their respective pushover curve as a result is obtained in X and Y directions. Bi-linear approximation of pushover curve is performed to obtain the parameters for calculation of Response Reduction factor. The fundamental time period and designed base shear is obtained by model analysis of structure by simple static method. The acquired value as a result are tabulated below in table-4 and 5.

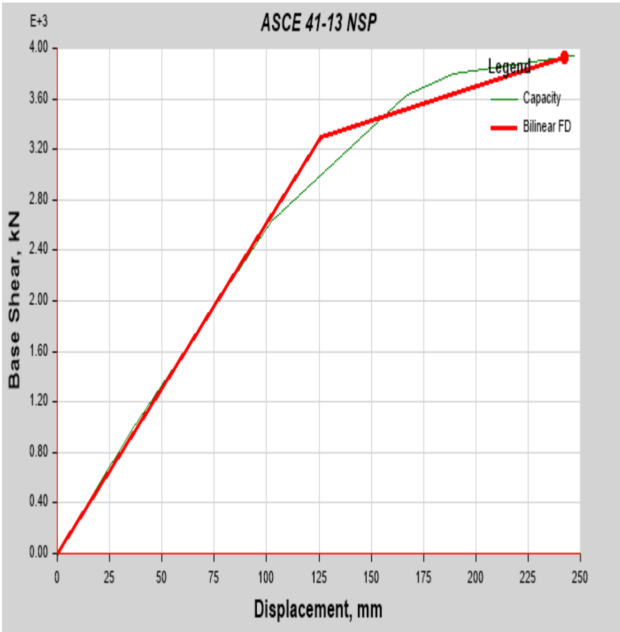

Fig. 10. (Bi-linear approximation of PX curve)

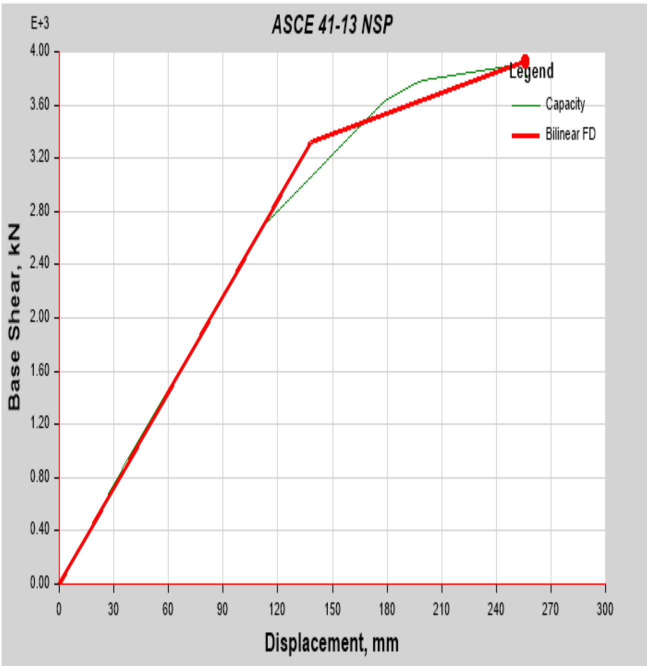

Fig. 11. (Bi-linear approximation of PX curve)

Table- 4: Calculation of Response Reduction Factor in X-direction

Model	T(Sec)	V_y(KN)	V_d(KN)	Δm(mm)	Δy(mm)	R_s	μ	R_μ	R_r	R
RFM	1.46	3298.44	597.95	242.34	126.21	5.52	1.92	1.92	1	10.59
C-RFM	1.41	3117.23	575.47	239.76	125.81	5.42	1.91	1.91	1	10.32
S-RFM	1.25	3114.23	681.37	230.77	121.11	4.57	1.91	1.91	1	8.71
18D-RFM	1.23	2334.93	581.37	172.37	81.93	4.02	2.10	2.10	1	8.45
18D-CFM	1.19	2268.78	639.66	179.83	83.57	3.55	2.15	2.15	1	7.85
18D-SFM	1.06	2204.26	630.23	162.22	81.80	3.50	1.98	1.98	1	7.05
27D-RFM	1.04	2674.28	773.16	189.37	90.63	3.46	2.09	2.09	1	7.23
27D-CFM	1.00	2461.00	872.64	195.58	87.61	2.82	2.23	2.23	1	6.30
27D-SFM	0.92	2605.87	953.81	201.10	92.43	2.73	2.18	2.18	1	5.00
36D-RFM	0.86	2834.01	856.61	116.75	48.18	3.31	2.42	2.42	1	6.49
36D-CFM	0.83	2668.07	985.74	137.48	51.00	2.71	2.70	2.70	1	5.67
36D-SFM	0.76	1897.39	837.39	94.84	37.86	2.27	2.51	2.51	1	4.54
T-RM	0.92	2013.64	948.72	84.95	27.09	2.12	3.14	3.14	1	4.87
C-TM	0.74	1973.65	884.76	130.78	45.85	2.23	2.85	2.85	1	4.84
S-TM	0.87	1680.48	817.39	57.06	23.22	2.06	2.46	2.46	1	4.07

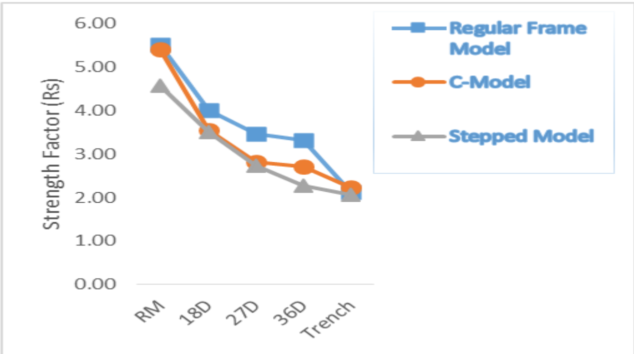

Fig. 11. (Variation of Strength factor along X-Direction)

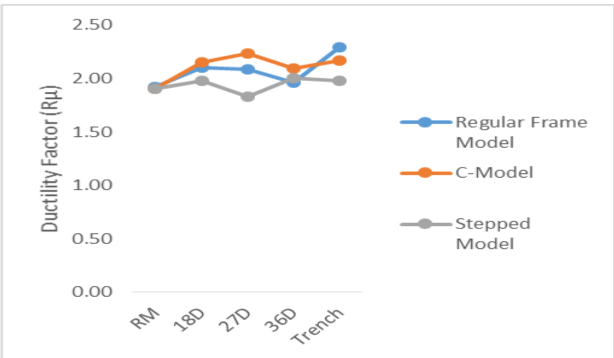

Fig. 12. (Variation of Ductility Reduction Factor along X-direction)

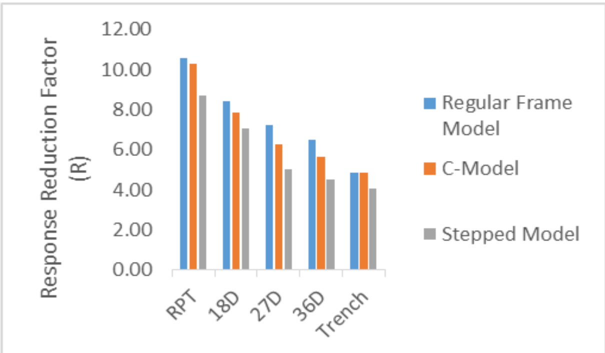

Fig. 13. (Response Reduction Factor along X-direction)

A. Sample Calculation

Of all the formulae given by the researcher to calculate ductility, over strength and redundancy factor, sample calculation of RMF is performed from output data of Bi-linear Idealized Pushover curve along X-direction. A similar method is adopted for other remaining models.

Designed Base Shear in X- direction (V_d) =597.95kN.
First yield load corresponding to actual yielding of structure (V_y) =3298.44kN.
Maximum displacement (Δm) = 242.34mm.
Yield displacement of structure (Δy) =126.21mm.
Fundamental Time Period (T) =1.92Sec.
Now,
Strength Reduction Factor,

$$R_s = \frac{V_y}{V_d}$$

$$= \frac{3298.44}{597.95}$$

$$= 5.92$$

Displacement ductility ratio,

$$\mu = \frac{\Delta m}{\Delta y}$$

$$= \frac{242.34}{126.21}$$

$$=1.92$$

According to Newmark and Hull if the value of Time Period is greater than 0.5

$$R_\mu = \mu$$

Therefore, Ductility Reduction Factor,

$$R_\mu = 1.92$$

Finally,
The reduction factor is given by,

$$R = R_s \times R_\mu \times R_r$$

$$= 5.52 \times 1.92 \times 1$$

$$=10.59$$

Here, according to Table-1.
R_r is taken as unity.

The value of response reduction factor for regular frame 6 story model is 10.59 as per analysis was done for the research purpose. The value seems to be double as compared to value mentioned in IS 1893:2016 for SMRF Regular Frame Model (RFM) building.

Table- 4: Calculation of Response Reduction Factor in Y-direction.

Model	T(Sec)	V_y(KN)	V_d(KN)	Δm(mm)	Δy(mm)	R_s	μ	R_μ	R_r	R
RFM	1.53	3324.78	570.76	255.70	137.90	5.83	1.85	1.85	1	10.80
C-RFM	1.52	3124.66	551.40	274.88	146.00	5.67	1.88	1.88	1	10.67
S-RFM	1.40	2806.67	509.10	189.14	115.48	5.51	1.64	1.64	1	9.03
18D-RFM	1.37	2127.34	522.14	180.62	88.22	4.07	2.05	2.05	1	8.34
18D-CFM	1.33	2091.32	574.25	217.16	98.20	3.64	2.21	2.21	1	8.05
18D-SFM	1.14	1976.98	555.02	140.37	76.76	3.56	1.83	1.83	1	6.51
27D-RFM	1.17	2536.11	684.08	204.48	91.25	3.71	2.24	2.24	1	8.31
27D-CFM	1.16	2180.86	743.32	210.04	86.90	2.93	2.42	2.42	1	7.09
27D-SFM	0.98	2168.72	829.85	165.70	78.10	2.61	2.12	1.80	1	4.71
36D-RFM	1.01	2513.56	724.89	190.71	79.53	3.47	2.40	2.40	1	8.31
36D-CFM	0.99	2449.44	922.26	143.70	62.34	2.66	2.31	2.31	1	6.12
36D-SFM	0.81	1894.78	815.13	163.22	75.76	2.32	2.15	1.82	1	4.23
T-RM	1.20	2485.49	794.49	136.34	60.87	3.13	2.24	2.24	1	7.01
C-TM	0.91	2465.32	720.46	156.35	72.75	3.42	2.15	1.82	1	6.21
S-TM	0.92	2282.64	789.13	155.64	63.26	2.89	2.46	1.98	1	5.95

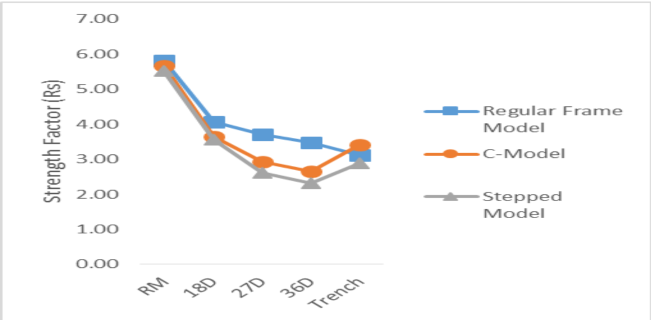

Fig. 14. (Variation of Strength factor along Y-Direction)

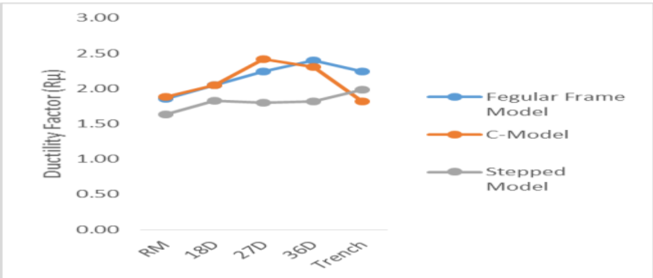

Fig. 15. (Variation of Ductility Reduction Factor along X-direction)

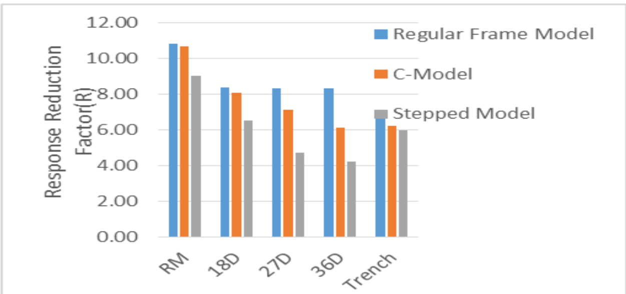

Fig. 16. (Response Reduction Factor along Y-direction)

V. CONCLUSION

The results obtained from research leads to the following conclusions.

- From graphs, it can be observed that structure having uniform vertical geometric profile have more lateral load resisting capacity as compared to non-uniform geometric profile, in other words, it can be said that rigid structure have higher over strength capacity.
- The over strength factor for regular frame model is higher than that of building in slope and in trench cut terrain in all cases in both direction, This result is obtained may be due to the low designed base shear and high yielding horizontal load of regular model.
- As the angle of slope increases formation of the unequal length of columns are additional which may affect the stiffness and strength of building and hence the yielding of structure is earlier. Thus over strength reduction factor decreases with increasing the angle.
- The ductility Reduction factor does not show any specific trend in with increasing the angle of slope. However the ductility reduction factor for geometrical irregular frame models are noticed higher than that of regular model except in 27D stepped model in X- Direction and T-CM. The causes behind this may be due to low displacement of structure during the application of lateral load.
- It is also noticed that strength reduction factor have an inverse relation with ductility factor.
- The geometrically regular structure has higher response reduction factor as compared to geometrical irregular structure. In case of frame in slope the reduction factor decreases with increasing the angle of slope in both stepped and C-Model frame. This trend is similar to trench model too.

- The reduction factor is observed higher as mentioned in IS 1893:2016 in all cases except in 36D-SFM, T-RM, C-TM and S-TM. This may be due to fundamental time period of structure. As a fundamental time period decreases the design base shear increases, and the strength reduction factor base shear has inverse relation with design base shear which may affect the response reduction factor.
- The response Reduction factor is very sensitive to the geometry configuration of structure.

The conviction in the conclusion gain by the study is limited by the fact that the research conducted is deterministic with simple parameters. However, in actual their statistical variation are noticeable. The values obtained from the research just illustrate the trend, not the actual value. Consequently, different approaches do exist and would yield somewhat different value of response reduction factor.

REFERENCES

1. R. Park and T. Paulay, Reinforced Concrete Structure, New York: John Wiley & Sons; 1975. 769 pages.
2. Priestley et al., Seismic design and retrofit of bridge. New York John Wiley and Sons, 1969.
3. ATC-19, Structural Response Modification Factor, ATC-19 Report, Applied Technology Council, 1995, Redwood City California.
4. S. A. Barakat et al., “A steps towards the evaluation of the seismic response reduction factor in multi-story reinforced concrete frame”, Natural Hazards, 1997, pp. 65–80.
5. S.N. Tande et al., “An investigation of seismic response reduction factor for earthquake resistant design”, International journal of Latest Trends in Engineering and Technology, 2013, pp.319-396.
6. H. Chaulagain et al., “Response reduction factor of irregular RC building in Kathmandu Valley”, Earthquake Engineering and Engineering Vibration, 2014, pp. 455-470.
7. K. Tamboli et al., “Evaluation of Response Reduction factor and Ductility factor of RC Braced Frame”, Journal of Materials and Engineering Structure, 2015, pp. 120-129.
8. R.L Vankate and R.K Ingle, “Evaluation of Response reduction factor of RC framed buildings by pushover analysis”, International Journal of Advances in Mechanical and Civil Engineering, 2016, pp.100-105.
9. A. Ruhulla et al., “Assessment of Seismic response reduction factor according to redundancy of RC building”, International Journal of Scientific Research in Science, Engineering and Technology, 2018, pp.962-966.
10. M. Shendkar et al., Response Reduction Factor of RC Frame Structure with semi interlock masonry and unreinforced masonry infill”, Index Copernicus Journal, 2018, pp.24-28.
11. Sarjuban et al., “Seismic Response Reduction Factor evaluation for Irregular RC Structure”, International Journal of Research and Technology, 2019, pp.242-246.

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