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DETERMINATION OF MOMENT RESISTING RC FRAMES OF RESPONSE REDUCTION FACTORS

Y. SUDHEER KUMAR[1], K. LOKESH[2]

*[*1]PG Student, Department of Civil Engineering, Nova College of Engineering and Technology, Affiliated to JNTU Kakinada, Vegavaram, Jangareddygudem, West Godavari (District), A.P-534447.*

*[*2]Guide, Assistant Professor of Civil Engineering, Nova College of Engineering and Technology, Affiliated to JNTU Kakinada, Vegavaram, Jangareddygudem, West Godavari (District), A.P-534447*

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Abstract - Moment resisting frames are commonly used as the dominant mode of lateral resisting system in seismic regions for a long time. The poor performance of Ordinary Moment Resisting Frame (OMRF) in past earthquakes suggested special design and detailing to warrant a ductile behavior in seismic zones of high earthquake (zone III, IV & V). Thus when a large earthquake occurs, Special Moment Resisting Frame (SMRF) which is speciallydetailed with a response reduction factor, R = 5 is expected to have superior ductility. The response reduction factor of5 in SMRF reduces the design base shear and in such a case these building rely greatly on their ductile performance. To ensure ductile performance, this type of frames shall be detailed in a special manner recommended by IS 13920. The objectiveof the present study is to evaluate theR factors of these frames from their nonlinear base shear versus roof displacement curves (pushover curves) and to check its adequacy comparedto code recommended R value. The accurate estimation of strength and displacement capacity of nonlinear pushover curves requires the confinement modelling of concrete as per an accepted confinement model. A review of various concrete confinement models is carried out to select appropriate concrete confinement model. It is found that modified Kent and Park model is an appropriate model andit is incorporated in the modelling of nonlinearity in concrete sections. The frames with numberof storeys 2, 4, 8, and 12 (with four bays) are designed and detailed as SMRF and OMRF as per IS 1893 (2002). The pushover curves of each SMRF and OMRF frames are generated and converted to a bilinear format to calculate the behavior factors. The response reduction factorsobtained show in general that both the OMRF and SMRF frames, failed to achieve the respective target values of response reduction factors recommended by IS 1893 (2002) marginally. The components of response reduction factors such as over-strength and ductility factors also evaluated for all the SMRF and OMRF frames. It was also found that shorter framesexhibit higher R factors and as the height of the frames increases the R factors decreases.

Keywords: *OMRF, SMRF, Response Reduction Factor, Pushover, Ductility, Confinement models.*

1.INTRODUCTION

Column shear failure has been identified as the frequently mentioned cause of concrete structure failure and downfall during the past earthquakes. In the earthquake resistant design of reinforced concrete sections of buildings, the plastic hinge regions should bestrictly detailed for ductility in order to make sure that severe ground shaking during earthquakes will not cause collapse of the structure. The most important design consideration for ductility in plastic hinge regions of reinforced concrete columns is the provision of adequate transverse reinforcement in the form of spirals or circular hoops or of rectangular arrangements of steel. The cover concrete will be unconfined and will eventually become ineffective after the compressive strength is attained, but the core concrete will continue to carry stress at high strains. Transverse reinforcements which are mainly provided for resisting shear force, helps in confining the core concrete and prevents buckling of the longitudinal bars. The coreconcrete which remains confined by the transverse reinforcement is not permitted to dilate in the transverse direction, thereby helps in the enhancement of its peak strengthand ultimate strain capacities. Thus confinement of concrete by suitable arrangements of transverse reinforcement results in a significant increase in both the strength and the ductility of compressed concrete.

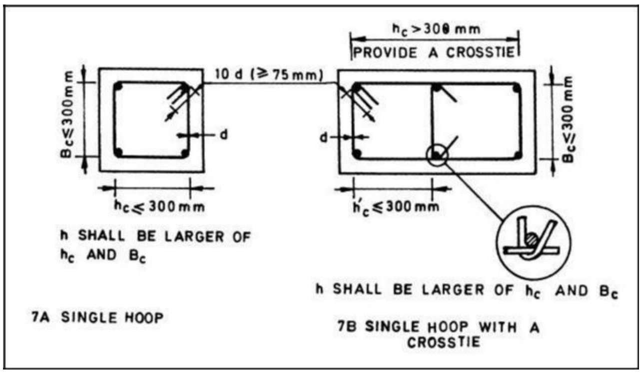

Fig -1: (a)

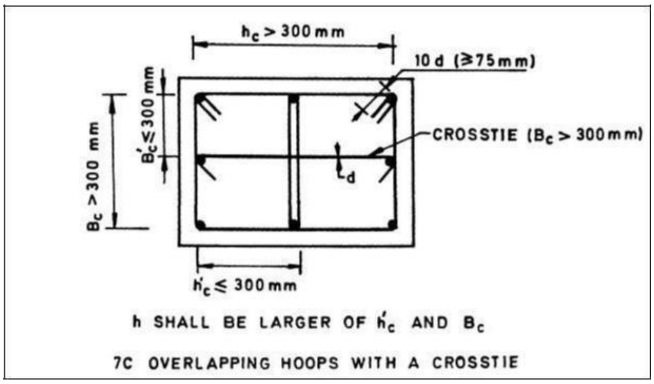

Fig -1: (b)

Fig-1:(a) & (b) Transverse Reinforcement in columns (Reference: IS 13920(2002))

1.1 SCOPE OF WORK

The present study is limited RC plane frames without shear wall, basement, and plinth beam. The stiffness and trength of Infill walls is not considered. The soil structure interface effects are not taken into account in the study. The flexibility of floordiaphragms is ignored and is considered as stiff diaphragm. The column bases are assumed to be fixed in the study. Open Sees platform (McKenna *et al.*, 2000) is used in the present study. The non-linearity in the material properties are modeled using fiber models available in Open Sees platform.

2. REVIEW OF EXISTING CONFINEMENT MODELS FOR CONCRETE

The confinement in the concrete plays a major role in the strength and ductility of the RC members. In order to show the effect of considering the confinement in the stress-strain curve and its effects in the strength and ductility, various sections specially detailed for confinement has to be designed. Hence a number of building frames are considered and designed as both Special Moment Resisting Frames (SMRF) and Ordinary Moment Resisting Frames (OMRF). The configuration of the frames and the reinforcement details of RC sections are also presented in this Chapter. Confinement stress-strain curves for various SMRF and OMRF sections are also developed as per various available models. Each plane frame is designed as both SMRF and OMRF. OMRF frames are designed with a response reduction factor of 3 and SMRF with a response reduction factor of 5 in compliance with IS 1893 (2002). The design of RC sections are done as per IS 456 for OMRF frames and the design and ductile detailing of SMRF frames are done conforming to IS 13920 specifications. For convenient and easy presentation of frames, a naming standard has been used. The frame designated as 4S4B-SMRF represents SMRF building with four storeys and four bays. The designation, type of design, R factor and analysis, design and detailing provisions followed are tabulated in the Table-1.

Table -1: Details of the Moment Resisting Frames considered

Sl No:	Frame Tag	No. of storey	No. of bays	Frame type	R	Analysis Design & Detailing
1	2S4B-SMRF	2	4	SMRF	5	IS 1893 & IS 13920
2	2S4B-OMRF	2	4	OMRF	3	IS 1893 & IS 456
3	4S4B-SMRF	4	4	SMRF	5	IS 1893 & IS 13920
4	4S4B-OMRF	4	4	OMRF	3	IS 1893 & IS 456
5	8S4B-SMRF	8	4	SMRF	5	IS 1893 & IS 13920
6	8S4B-OMRF	8	4	OMRF	3	IS 1893 & IS 456
7	12S4B-SMRF	12	4	SMRF	5	IS 1893 & IS 13920
8	12S4B-OMRF	12	4	OMRF	3	IS 1893 & IS 456

Table -2: Response Spectrum Factors Considered for the Frames

Factors	SMRF	OMRF
Seismic Zone	IV	IV
Zone Factor	0.24	0.24
Type of Building, Z	Regular office Building	Regular office Building
Importance Factor, I	1	1
Response Reduction Factor, R	5	3
Type of Soil	Medium	Medium
Damping	5%	5%

Table -3: Details of time periods, seismic weight and design base shear

Frame Type	Height (m)	Time Period, T (sec)	/		Seismic Weight, W (kN)	Design Base Shear, (kN)
2S4B-SMRF	6	0.2875	2.5	0.06	3537.3	212
2S4B-OMRF	6	0.2875	2.5	0.1	3804.7	380.4
4S4B-SMRF	12	0.483	2.5	0.06	5356.11	321.36
4S4B-OMRF	12	0.483	2.5	0.1	5408.9	540.89
8S4B-SMRF	24	0.813	1.672	0.04	10790.02	431.613
8S4B-OMRF	24	0.813	1.672	0.0668	11156.45	745.25
12S4B-SMRF	36	1.1022	1.233	0.0295	17146.31	505.87
12S4B-OMRF	36	1.1022	1.233	0.0493	17649.81	853.035

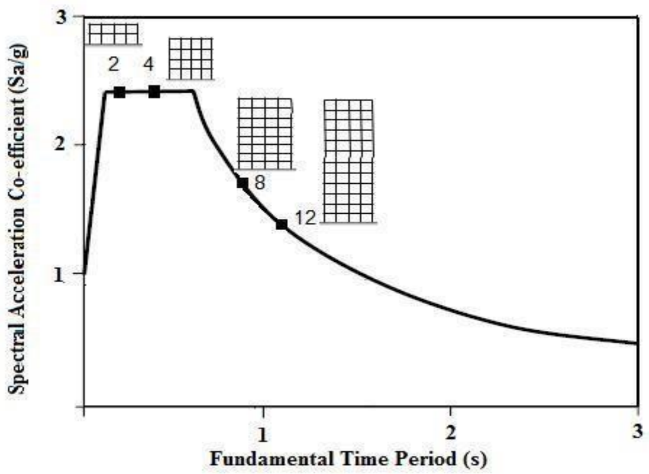

Fig-2:Variation in Time Period and Spectral Acceleration Co-efficient withnumber of storeys

Table -4: Reinforcement Details for Columns

Section Tag	Building Configuration	Section Size(mm x mm)	Longitudinal Reinforcement	Shear Reinforcement
400C-2S4B-	2S4B-SMRF	400 x 400	8 # 16 mm	2 legged 10mm @ 85mm
SM				c/c
450C-2S4B-				2 legged 8mm @ 230mm
OM	2S4B-OMRF	450 x 450	4 # 25 mm	c/c
450C-4S4B-				2 legged 12mm @ 85mm
SM	4S4B-SMRF	450 x 450	4 # 25 mm	c/c
500C-4S4B-				2 legged 8mm @ 190mm
OM	4S4B-OMRF	500 x 500	8 # 20 mm	c/c
550C-8S4B-				2 legged 12mm @ 75mm
SM	8S4B-SMRF	550 x 550	8 # 20 mm	c/c
650C-8S4B-				2 legged 8mm @ 190mm
0M	8S4B-OMRF	650 x 650	8 # 25 mm	c/c
600C-				2 legged 10mm @ 75mm
12S4B-SM	12S4B-SMRF	600 x 600	12 # 20 mm	c/c

Table -5: Reinforcement Details for Beams

Section Tag	Building Configuration	Section Size (mm x mm)	Longitudinal Reinforcement: Top	Longitudinal Reinforcement: Bottom	Shear Reinforcement
350B-2S4B-SM	2S4B-SMRF	300 x 350	7 # 20 mm	5 # 16 mm	2 legged 10mm @ 100mm c/c
350B-2S4B-OM	2S4B-OMRF	300 x 350	8 # 20 mm	5 # 16 mm	2 legged 8mm @ 230mm c/c
375B-4S4B-SM	4S4B-SMRF	300 x 375	6 # 20 mm	2 # 20 mm	2 legged 10mm @ 100mm c/c
375B-4S4B-OM	4S4B-OMRF	300 x 375	6 # 20 mm	3 # 20 mm	2 legged 8mm @ 230mm c/c
400B-8S4B-SM	8S4B-SMRF	300 x 400	6 # 20 mm	3 # 20 mm	2 legged 10mm @ 100mm c/c
400B-8S4B-OM	8S4B-OMRF	300 x 400	5 # 25 mm	8 # 12 mm	2 legged 8mm @ 230mm c/c
600B-12S4B-SM	12S4B-SMRF	300 x 600	6 # 20 mm	10 # 12 mm	2 legged 10mm @ 100mm c/c
600B-12S4B-OM	12S4B-OMRF	300 x 600	5 # 25 mm	10 # 12 mm	2 legged 8mm @ 230mm c/c

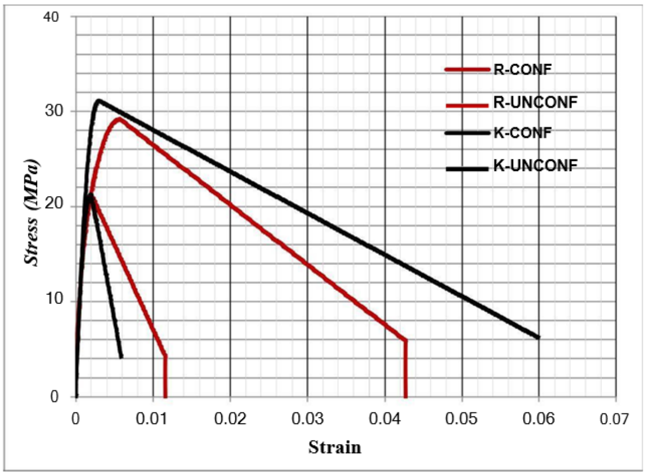

Fig-3: Comparison of stress-strain curves using two confinement models (Razvi andModified Kent models) for the RC section 400C-2S4B-SM (K1 = 6.47, K = 1.47)

3. RESPONSE REDUCTION FACTORS FOR SMRF AND OMRF FRAMES

The second objective of the present study is to evaluate the response reduction factors for buildings designed and detailed as per IS code. The elastic forces are reduced by a response reduction factor to calculate the seismic design base shear. The buildingshall be detailed as special moment resisting frames (SMRF) if the *R* factor assumed is 5. Once the design is being done, it is required to ensure that the designed building exhibit the adequate behaviour factors or response reduction factors. The actual response reduction factors can be calculated using a pushover analysis, modelling the nonlinearity in the materials. This chapter discusses the nonlinear modelling, static push over analysis of the designed RC frames (SMRF and OMRF) and the estimation of response reduction factors.

3.1 Modelling of RC-members for nonlinear static analysis

Open Sees (Open System for Earthquake Engineering Simulation) platform is used for modelling of the structure.OpenSees is an object oriented open-source software framework used to model structural and geotechnical systems and simulate their earthquake response. It is primarily written in C++ and uses some FORTRAN and C numerical libraries for linear equation solving, and material and element customs. The progressive capabilities for modelling and analysing the nonlinear response of systems using a wide range of material models, elements, and solution algorithms makes this open source platform more popular. Concrete behaviour is modelled by a uniaxial modified Kent and Park model with degrading, linear, unloading/reloading stiffness no tensile strength. Steel behaviour is represented by a uniaxial Giuffre–Menegotto–Pinto model. The strain hardening ratio is assumed as 5%. Fiber Section modelling of element is done according to Spacone *et.* al, (1996).The ultimate strain for confined concrete is taken as 0.02 as per ATC-40 specifications and that for unconfined concrete is considered as 0.005 as per Priestley (1997).

3.2 Pushover Analysis

Pushover analysis is a static, nonlinear procedure to analyse the seismic performance of a building where the computer model of the structure is laterally pushed until a specified displacement is attained or a collapse mechanism has occurred as shown in Figure-5. The loading is increased in increments with a specific predefined pattern suchas uniform or inverted triangular pattern. The gravity load is kept as a constant during the analysis. The structure is pushed until sufficient hinges are formed such that a curve of base shear versus corresponding roof displacement can be developed and thiscurve known as pushover curve. A typical Pushover curve is shown in Figure-5. The maximum base shearthe structure can resist and its corresponding lateral drift can be found out from the Pushover curve.

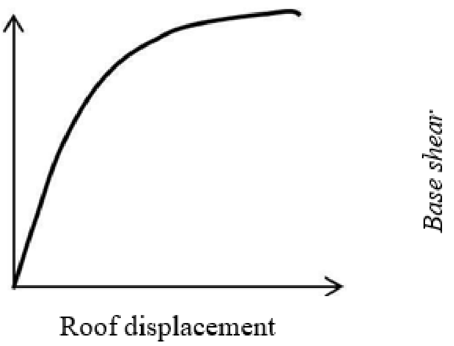

Fig-4: Lateral Load Distribution and a Typical Pushover Curve

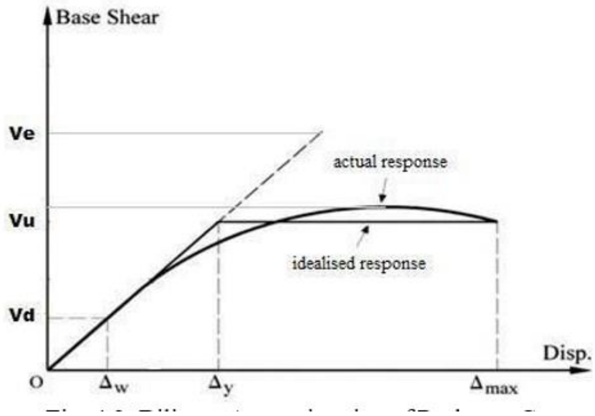

Fig-5: Bilinear Approximation of Pushover Curve

4. RESULTS AND DISCUSSION

4.1 Effect of confinement model for concrete in lateral load behaviour

It can be seen from the previous Chapter that the effect of confinement significantly change the peak strength and ultimate strain of the stress-strain curve of concrete. In order to study the effect of concrete confinement in the pushover curve, pushover analysis of the 12 storeyed SMRF frame is conducted by modelling the concrete in theconfined core using the two concrete stress-strain models namely, modified Kent and Park model and also the unconfined stress-strain model suggested by IS 456 (2000). Figure 7 shows the pushover curves for the selected frame in both cases. It can be seen that difference in strength between the two pushover curves is only marginal but the change in the displacement capacity is significant. The pushover curve that uses the unconfined stress-strain model underestimates the displacement capacity of 12 storey SMRF frames by 83%. As the accuracy of displacement capacity estimation plays a major role in the estimation of response reduction factors, the SMRF and OMRF framesare modelled by the confinement model and subsequent sections explains the further details.

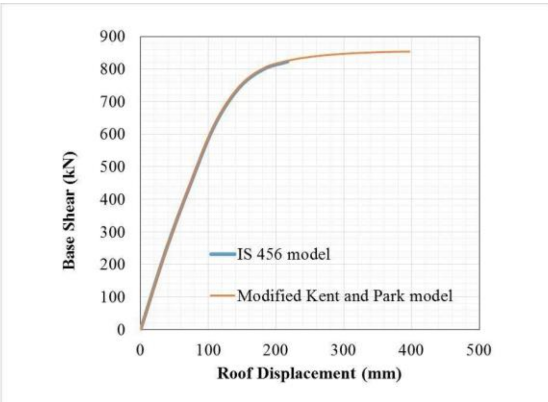

Fig-6: Effect of confinement in lateral load behaviour of 12 storeyed SMRF frames

4.1 Comparison of Pushover curves for SMRF and OMRF buildings

The pushover curves obtained for the eight study frames are shown in Figure 8, shows the comparison of pushover curve for OMRF and SMRF frames for 2S4B frame. The strength capacity of OMRF frame is about 33.88 %more than that of an SMRF frame. The displacement capacity for the two storey frame detailed as SMRF frame is about 47.44% higher than that of the OMRF frame. The difference in the strength capacity is due to the increase in longitudinal reinforcement of the OMRF frame compared to that of SMRF frame. TheSMRF is designed for a lower design base shear as the response reduction factor assumed is 5 instead of 3 for the OMRF frame. The same trend is followed other frames also as seen in the Figure 8, OMRF structures possess 10-34% more capacity than SMRF in resisting base shear. This is because of the fact that OMRF frames are designed with R factor '3' and the amount of longitudinal reinforcement is higher compared to SMRF.It can also be noted from the curves that the maximum displacement shown by SMRF frames is higher in all the cases compared to their corresponding OMRF frames as a result of the enhanced confinement achieved through special design and ductile detailing. SMRF buildings exhibit about 30-65% more deformation capacity than OMRF buildings.

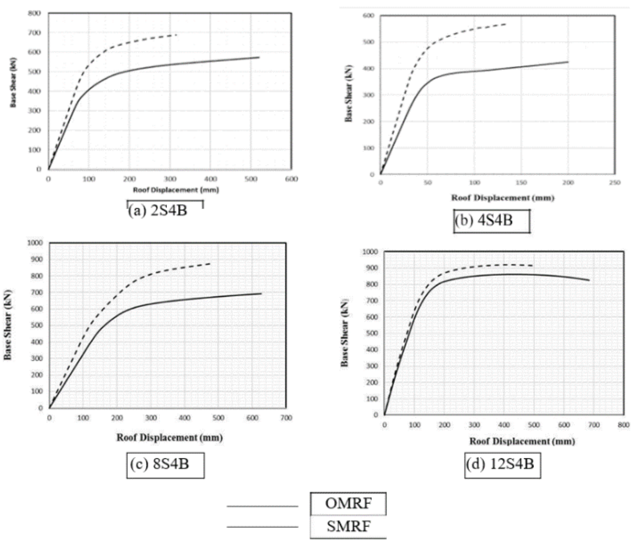

Fig-7: Pushover curve of SMRF and 7MRF frames

5. CONCLUSIONS

- It was found that Razvi model and Modified Kent and Park model it was observed that the latter shows higher percentage increase in column capacity and deformation.
- The percentage Strength enhancement due to confinement in Modified Kent and Park model for various column sections is in the range of 32% – 58%.
- The parametric study on Modified Kent and Park model showed that the ultimate strain is more dependent on the spacing of transverse reinforcement than the grade of transverse steel and concrete. Hence to ensure the ductile detailing, the spacing of stirrups shall be treated as an important factor.
- The increase in strength enhancement factor (that define the measure of confinement) by 1.2 times increases the ultimate strain by 46.89%.
- The pushover analysis of the 12 storeyed SMRF frame modelling the concrete in the confined core using the two concrete stress-strain models namely, modified Kent and Park model shows that the unconfined stress-strain model (IS code) underestimates the displacement capacity of 12 storey SMRF frames by 83%.
- The pushover curves of SMRF buildings are compared with that of their corresponding OMRF buildings. It is observed that the drift capacity of SMRF buildings is higher than OMRF buildings in all the cases.
- The percentage increase of displacement capacity of SMRF over the corresponding OMRF is in the range of 29-65%.
- This validates the fact that SMRF buildings which are specially designed and detailed as per IS 13920 guidelines exhibits more ductility compared to the less stringently designed OMRF buildings.
- It was found that the ductility factors do not show any specific trend with variation in the number of stories for both SMRF and OMRF frames.
- The *R* factor for SMRF buildings varies in the range of 4.23 to 4.86. OMRF buildings also exhibit decrease in *R* factor with increase in number of storeys. The value varies in the range 2.2 to 2.99 which is less than the suggested *R* valueof '3' as per IS 1893 guidelines.
- In general, the present study shows that both the OMRF and SMRF frames, failed to achieve the respective target values of response reduction factors recommended by IS 1893 (2002).
- The study of effect of number of storeys in the base shear strength and displacement capacity of the SMRF and OMRF frames show that for addition of every 4 storeys in the SMRF frames, it showed about 20-25% increase in base shear capacity while about 13-15% increase in displacement capacity.

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