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DETERMINATION OF MOMENT RESISTING RC FRAMES OF RESPONSE REDUCTION FACTORS

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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 behaviour in seismic zones of high earthquake (zone III, IV & V). Thus when a large earthquake occurs, Special Moment Resisting Frame (SMRF) which is specially detailed with a response reduction factor, R = 5 is expected to have superior ductility. The response reduction factor of 5 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 objective of the present study is to evaluate the R factors of these frames from their nonlinear base shear versus roof displacement curves (pushover curves) and to check its adequacy compared to 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 and it is incorporated in the modelling of nonlinearity in concrete sections. The frames with number of 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 behaviour factors. The response reduction factors obtained 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 frames exhibit 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*

I.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 be strictly 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 core concrete which remains confined by the transverse reinforcement is not permitted to dilate in the transverse direction, thereby helps in the enhancement of its peak strength and 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.

II.SPECIAL AND ORDNARY MOMENT RESISTING FRAMES (SMRF AND OMRF)

According to Indian standards moment resisting frames are classified as Ordinary Moment Resisting Frames (OMRF) and Special Moment Resisting Frames (SMRF) with response reduction factors 3 and 5 respectively. Another main difference is the provision of ductile detailing according to IS 13920 as explained in Section 1.1 for the SMRF structures. The differences between these two are given in Table 1.1. Different international codes classify buildings in different ways which are elaborated in Section 2.2.

Table 1.1 Differences between SMRF and OMRF

SMRF	**OMRF**
It is a moment-resisting frame specially detailed to provide ductile behaviour and comply with the requirements given in IS 13920	It is a moment-resisting not meeting special detailing requirement for ductile behavior.
Used under moderate-high earthquakes	Used in low earthquakes
R = 5	R = 3
Low design base shear.	High design base shear.
It is safe to design a structure with ductile detailing.	It is not safe to design a structure without ductile detailing.

RESPONSE REDUCTION FACTORS FOR SMRF AND OMRF FRAMES

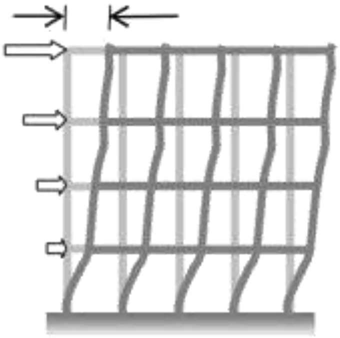
III.RESPONSE REDUCTION FACTOR

Chugh (2004) conducted ductility studies on RC beams using several confinement models.The response of a statically determinate structure to stress will be linear until yielding takes place. But as soon as the yielding occurs at any section, the behaviour of the structure becomes inelastic and linear elastic structural analysis can no longer be applied. As per the above study, it is mentioned that during an earthquake, yielding of the reinforcement can be expected at many sections. It would be too costly to design a structure based on the elastic spectrum. To reduce the seismic loads, IS 1893 introduces a “response reduction factor” *R*. But this reduction can be made, only if adequate ductility is developed through proper design and ductile detailing of the elements. So in-order to obtain the exact response, it is recommended to perform Non-Linear Analysis.

MODELLING OF RC MEMBERS FOR NONLINEAR STATIC ANALYSIS

OpenSees (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.

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 Fig: 4.1.The loading is increased in increments with a specific predefined pattern such as 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 this curve known as pushover curve. A typical Pushover curve is shown in Fig 4.1. The maximum base shear the structure can resist and its corresponding lateral drift can be found out from the Pushover curve.

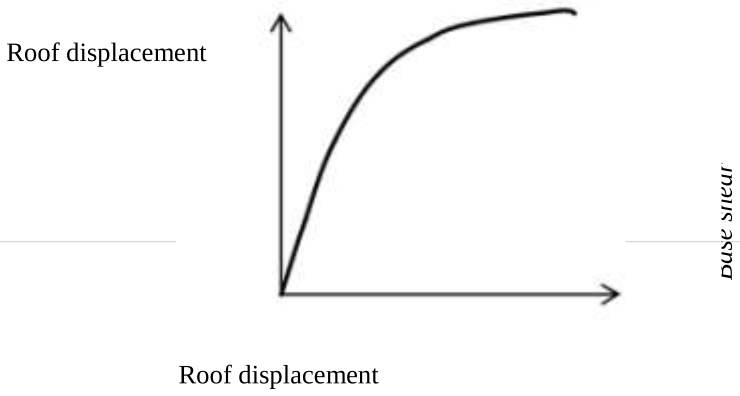


Fig: 4.1: Lateral Load Distribution and a Typical Pushover Curve

Bilinear Approximation of Pushover Curve

Most pushover methods adopt a bilinear approximation of the actual push-over curve to obtain an idealized linear response curve, as shown in Fig: 4.2. This is done in such a way that the area under the actual curve will be equal to the area under the bilinear approximate curve.

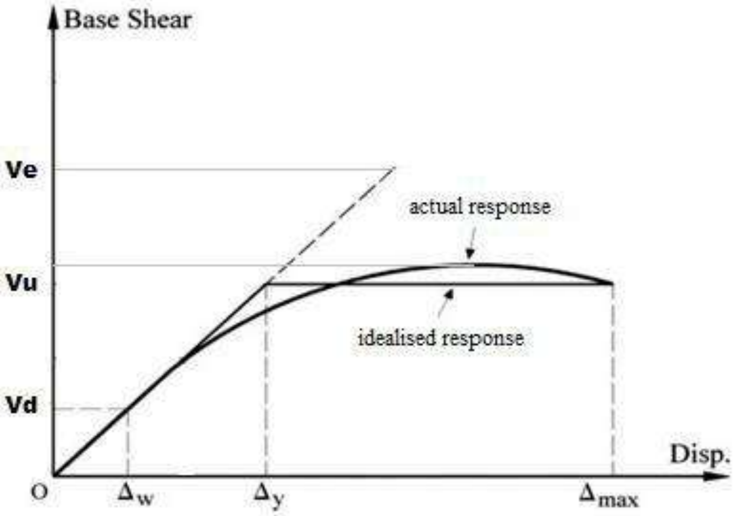


Fig: 4.2: Bilinear Approximation of Pushover Curve

Behaviour factors (Performance parameters)

Table 4.2: Parameters of the pushover curves for SMRF and OMRF Frames

Frame	(mm)	(mm)	(kN)	(kN)	= —	= —
SMRF Frames						
2S4B	200.23	50.02	425.52	212.02	4.00	2.01
4S4B	520.28	110.02	572.41	321.36	4.73	1.78
8S4B	626.36	200.12	692.8	431.6	3.13	1.61
12S4B	612.93	155.64	861.64	505.87	3.94	1.70
OMRF Frames						
2S4B	135.02	43	569.41	380.47	3.139	1.49
4S4B	316.02	106	689	540.8	2.981	1.27
8S4B	483.369	180	876.029	745.26	2.55	1.36

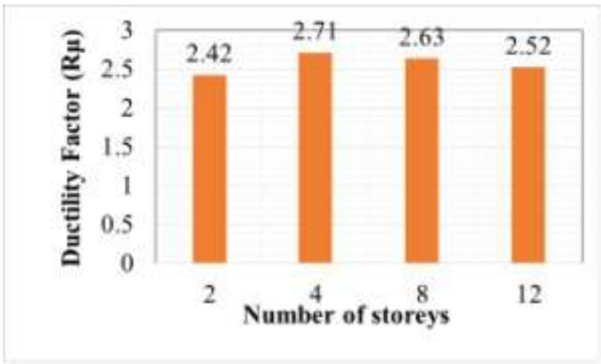
12S4B	505	190	952.5	853.03	2.65	1.116

Table 4.3: Response reduction factors and the components (Behaviour factors)

Frame				***R***
SMRF frames				
2S4B	2.007	2.42	1	4.856
4S4B	1.781	2.71	1	4.827
8S4B	1.605	2.63	1	4.229
12S4B	1.703	2.52	1	4.305
OMRF frames				
2S4B	1.49	2.007	1	2.99
4S4B	1.27	2.062	1	2.63
8S4B	1.176	1.893	1	2.226
12S4B	1.116	1.974	1	2.202

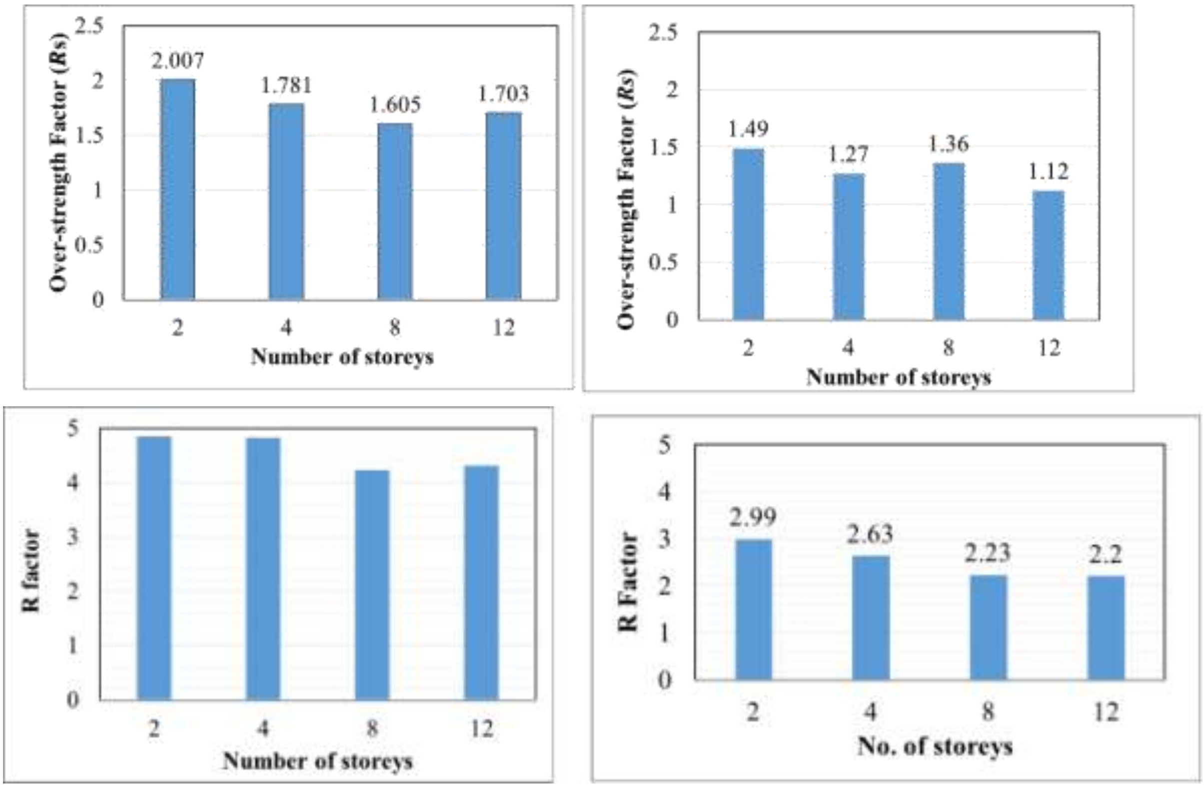
Performance parameters versus number of storeys (SMRF and OMRF frames)

(a) Over-strength factor -SMRF



(b) Over-strength factor -OMRF

(c) Ductility factor -SMRF (c) Ductility factor -OMRF



(e) Response reduction factor -SMRF (f) Response reduction factor -OMRF

Fig: 4.8: Variation of Performance parameters for SMRF and OMRF frames with number of stories

IV.CONCLUSIONS

REVIEW OF EXISTING CONFINEMENT MODELS FOR CONCRETE

Objectives of the thesis are to review the existing confinement models for concrete and to apply an appropriate confinement model to SMRF and OMRF buildings designed as per IS 1893 (2002). A literature is conducted that discusses the various topics such as the confinement models, response reduction factors or behaviour factors and various confinement models for the stress-strain relationship of concrete and pushover analysis.

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 SMRF and OMRF frames (2, 4, 8 and 12 storeys with 4 bays) are designed and detailed as per IS code.

The various existing stress-strain models are studied in-order to evaluate their relative differences in representing the actual strength and deformation behaviour of confined concrete. It has been noted that the stress-strain model suggested by IS 456 does not consider the strength enhancement due to confinement while in reality concrete exhibits different performance in the confined and unconfined conditions.

A parametric study is conducted to understand how the various parameters such as spacing transverse reinforcement, grade of transverse reinforcement and grade of concrete influence the stress-strain curve.

- 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. 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%.

PUSHOVER CURVES FOR SMRF AND OMRF FRAMES

The second objective is to estimate the response reduction factors for the specially and ordinary moment resisting frames. The designed RC frames are modelled for nonlinearity using the Modified Kent and Park confinement model. Nonlinear Static Pushover Analysis is carried out for all the frames to generate the pushover curves.

- 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.
- While considering the base shear capacity, OMRF buildings exhibit higher values than SMRF buildings of about 10-34%.The provision of R factor ‘3’ increases the design base shear in OMRF buildings. Due to the higher design base shear, the RC sections in the OMRF building will be heavier. This is the reason for the higher base shear capacity.
- The behaviour factors of the frames are evaluated from the pushover curve and a story-wise comparison is carried out. For both SMRF and OMRF buildings it is found that the over-strength factors exhibits a

decreasing trend as the number of stories increases. The shorter frames show higher over-strength value compared to taller frames.

- 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.

RESPONSE REDUCTION FACTORS FOR SMRF AND OMRF FRAMES

A study of the variation of Response Reduction Factor with number of stories is conducted. In SMRF buildings it is observed that as the number of storeys increases the *R* factor tends to decrease. The shorter frames exhibits higher *R* values compared to taller frame. 2- storey SMRF building shows the highest *R* factor of 4.856 which is almost close to the IS(1893) code suggested value of '5'.

- 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* value of '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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