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Determination of Moment Resisting RC Frames of Response Reduction Factors

Yenugula Sudheer Kumar[1] | K. Lokesh[2]

[1]PG Student, Dept of CIVIL, Nova College of Engineering & Technology, Jangareddygudem
[2]Assistant Professor, Dept of CIVIL, Nova College of Engineering & Technology, Jangareddygudem

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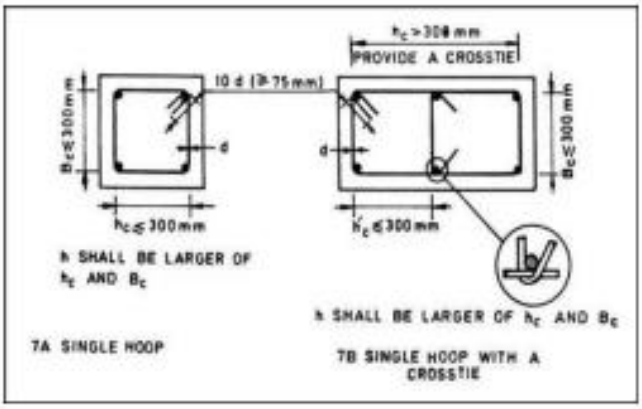
ABSTRACT

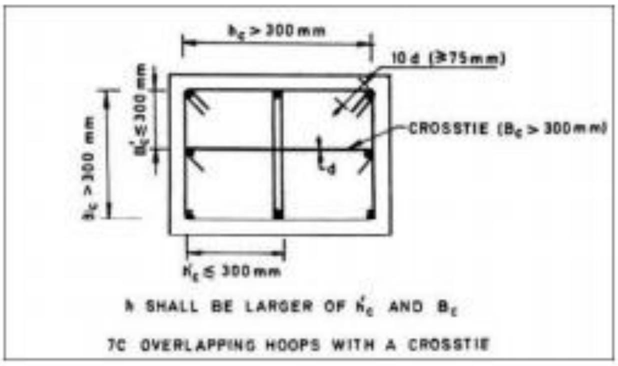
Moment resisting frames are commonly used as the dominant mode of lateral resisting system in seismic regions for a long time. The poor performance of Ordinary Moment Resisting Frame (OMRF) in past earthquakes suggested special design and detailing to warrant a ductile behaviour in seismic zones of high 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 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.

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. Confining reinforcements are mainly provided at the column and beam ends and beam-column joints. The hoops should enclose the whole cross section excluding the cover concrete and must be closed by 135° hooks embedded in the core concrete, this prevents opening of the hoops if spalling of the cover concrete occurs. Seismic codes recommend the use of closely spaced transverse reinforcement in-order to confine the concrete and prevent buckling of longitudinal reinforcement. Ductile response demands that elements yield in flexure and shear failure has to be prevented. Shear failure in columns, is relatively brittle and can lead to immediate loss of lateral strength and stiffness. To attain a ductile nature, special design and detailing of the RC sections is required. IS 13920 recommends certain standards for the provision of confining reinforcements for beams and columns. The code suggests that the primary step is to identify the regions of yielding, design those sections for adequate moment capacity, and then estimate design shears founded on equilibrium supposing the flexural yielding sections improve credible moment strengths.



(a)



(b)

Figure 1: Transverse Reinforcement in columns

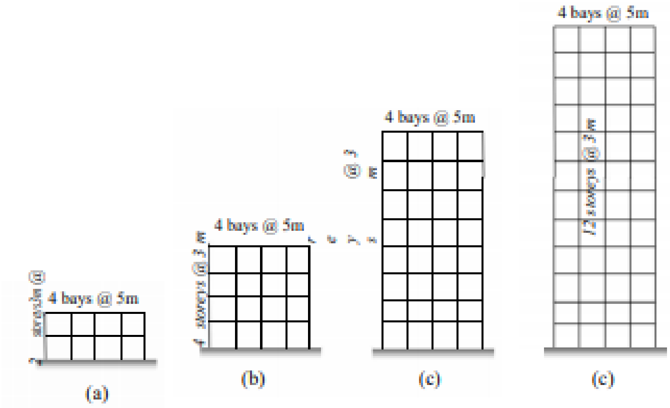
LITERATURE VIEW:

Han and Jee (2005) investigated the seismic behavior of columns in Ordinary Moment Resisting Frames (OMRF) and Intermediate Moment Resisting Frames (IMRF). In their study two three-story OMRF and IMRF were designed as per the minimum design and reinforcement detailing requirements suggested by ACI 318-02. The IMRF interior column specimens exhibited superior drift capacities compared to the OMRF column specimens. According to the test results, the OMRF and IMRF column specimens had drift capacities greater than 3.0% and 4.5%, respectively. Ductility capacity of OMRF and IMRF specimens exceeded 3.01 and 4.53, respectively.

Sadjadi et al. (2006), conducted an analytical study for assessing the seismic performance of RC frames using non-linear time history analysis and push-over analysis. A typical 5-story frame was designed as ductile, nominally ductile and GLD structures. Most of the RC frame structures built before 1970 and located in areas prone to seismic actions were designed only for gravity loads without taking into account the lateral loads. These structures were referred to as Gravity Load Designed (GLD) frames. The lack of seismic considerations in GLD structures resulted in nonductile behavior in which the lateral load resistance of these buildings may be insufficient for even moderate earthquakes. It was concluded that both the ductile and the nominally ductile frames behaved very well under the considered earthquake, while the seismic performance of the GLD structure was not satisfactory. After the damaged GLD frame was retrofitted the seismic performance was improved.

EXISTING CONFINEMENT MODELS FOR CONCRETE:

Provision for ductility is of utmost importance in the design and detailing of RC structures subjected to seismic loads. To accomplish this, IS 13920 specifies the use of transverse reinforcement or stirrups in structural members like columns. The effects of confinement completely affect magnitude of stress- strain curve of concrete which leads to an increase in compressive force of concrete. But IS code design is completely based on the simplified stress block of unconfined concrete and it does not consider the gain in strength due to confinement. To study the effects of lateral confinement on column capacity an investigative study is carried out. The more accurate the stress-strain model, the more consistent is the assessment of strength and deformation behavior of concrete members. It is to be noted that concrete exhibits different performance in the confined and unconfined conditions. Confined concrete exhibits enhanced strength as well as greater ductility compared to unconfined concrete. This necessitates the use of a stress strain model that distinguishes the behavior of confined and unconfined concrete. The stress-strain diagrams for concrete are developed by considering various confinement models and compared with the stress-strain diagram as per the IS 456 (2000).



(a) (b) (c) (c)

Figure 1: Elevation of frames considered

COMPARISON OF STRESS-STRAIN CURVES FOR THE DESIGNED SECTIONS:

The stress-strain curve of concrete depends on the amount of confinement. In order to show the comparison of stress-strain curve using various models, the RC sections of the building frames discussed in the previous section are considered.

Section	Column Section (mm x mm)	Hoop Volumetric Ratio ( )	Strength Enhancement Factor (K)
400C-2S4B-SM	400 x 400	0.0238	1.4654
450C-2S4B-OM	450 x 450	0.0048	1.0940
450C-4S4B-SM	450 x 450	0.0297	1.5803
500C-4S4B-OM	500 x 500	0.0051	1.1002
550C-8S4B-SM	550 x 550	0.0263	1.5141
650C-8S4B-OM	650 x 650	0.0037	1.0730
600C-12S4B-SM	600 x 600	0.0104	1.3206
700C-12S4B-OM	700 x 700	0.0034	1.0670

Table 1: Confinement Factors for Column Sections as per Kent and Park Model

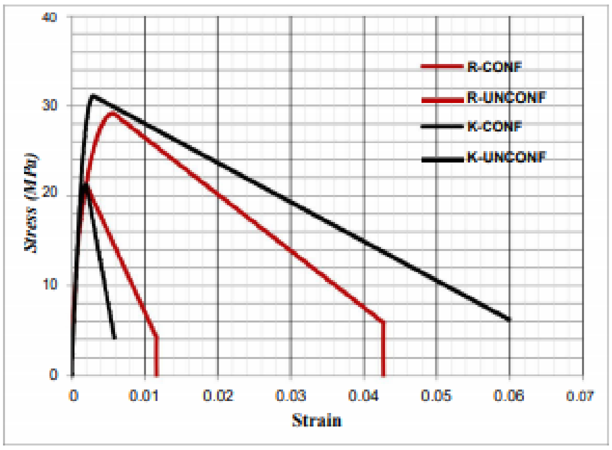


Figure 2: Comparison of stress-strain curves using two confinement models (Razvi and Modified Kent models) for the RC section 400C-2S4B-SM (K1 = 6.47, K = 1.47)

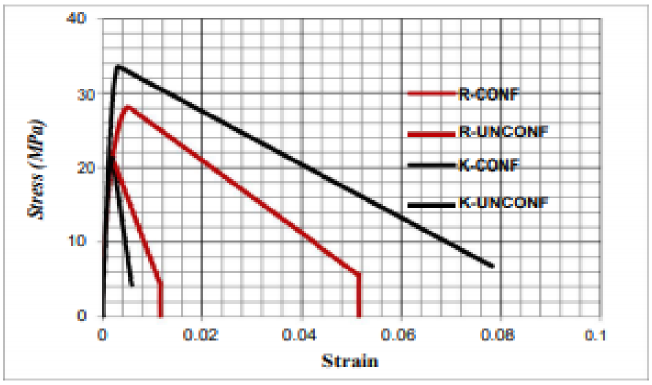


Figure 3: Comparison of stress-strain curves using two confinement models (Razvi and Modified Kent models) for the RC section 550C 8S4B SM (K1 =6.16, K = 1.51)

Parametric Study:

A parametric study is conducted to understand the variation of stress – strain curve of concrete when the parameters such as spacing of stirrups, grade of concrete and grade of transverse steel. Figure 4 shows the variation of stress-strain curve of concrete with the variation in spacing of transverse reinforcement from 75 mm to 120mm. As the spacing is decreased from 120mm to 75mm the peak strength of confined stress-strain curve is increased by 16.7% and the ultimate strain increased by about 90%.

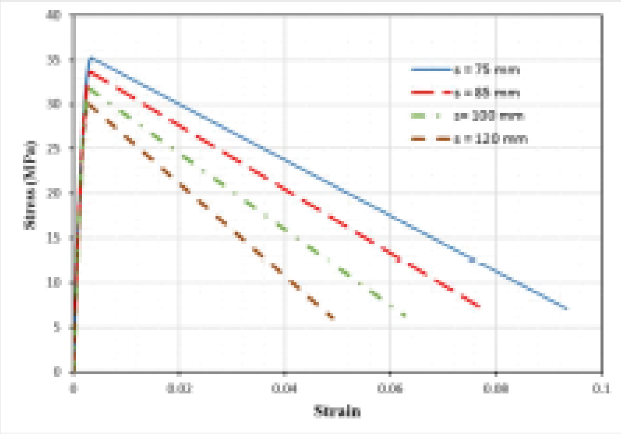


Figure 4: Variation in stress-strain curve with the spacing of stirrups for the RC section 450C4S4B-SM with the parameters, Fe415 steel and M25 concrete

IS 456 (2000) recommends a stress-strain curve which does not consider the effect of confinement. In order to study the difference between the stress-strain curves prescribed by IS code and modified Kent model and Razvi model, the corresponding stress-strain curves are plotted in single graph as shown in Figure 5. Percentage increase in concrete strength according to Modified Kent model is about 58% while it is 32% for Razvi model compared to that of IS code. Rajeev and Tesfamariam (2012), Alam and Kim (2012), Durga et al. (2013) used modified Kent and Park model for seismic response study of RC frames. Based on the experimental study conducted by Sharma et al. (2009) it was concluded that response estimations using the Modified Kent and Park model closely matched the experimental results in the Indian scenario. This model is used further in the present study for the estimation of ductility parameters.

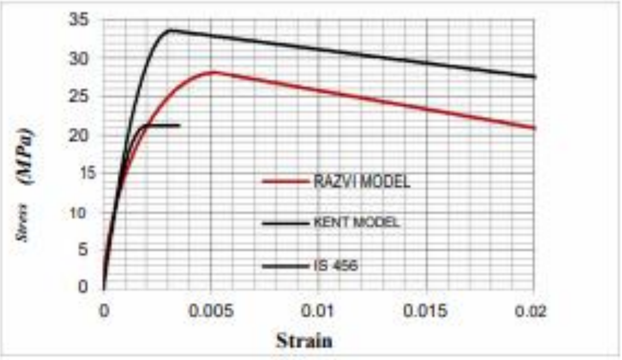


Figure 5: Comparison of Stress Strain Curves Of Confined Concrete of 450C-4S4B-SM (K = 1.58, K1 = 6.67) Section between Razvi Model, Kent Model and IS 456

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. 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).

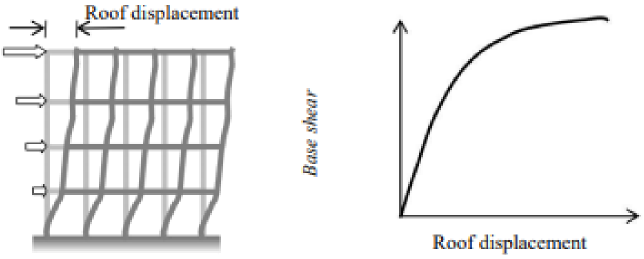


Figure 6: Lateral Load Distribution and a Typical Pushover Curve

CONCLUSIONS:

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 stressstrain 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.

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