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Assessment of Methods for Development of Confinement Model of Low Strength Reinforced Concrete Columns: A Review

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ABSTRACT
Reinforced Concrete is composed of concrete and steel, where compressive strength of concrete and tensile strength of steel are utilized to achieve the required member strength. The high tensile property of steel is thus used to confine and increase compressive strength and ductility of RC columns. Confined concrete is defined as concrete that is restrained laterally by any internal or external means i.e. reinforcement consisting of steel stirrups or spirals, Fiber Reinforced Polymer (FRP), Circular Concrete Filled Steel Tube, RC shell jacketing etc. An appropriate amount of confinement increases the strength, ductility and energy dissipation capacity of RC members. This paper focuses on finding out strength and ductility enhancement of low strength RC columns by reinforcement using existing confinement models. Confinement models are stress-strain curves developed for concrete compression member under uniaxial or dynamic loading, confined with transverse reinforcement. Different models along with their experimental validations are discussed in this paper to get state of the art knowledge of confinement studies possible for low strength concrete. The models recommended from this study are used to evaluate existing structures made with low strength concrete.
Keywords - confined concrete, axial loads, ductility, low strength concrete, confining models

I. INTRODUCTION

Since designing of structures for response in elastic range to greatest likely earthquake is highly uneconomical. It is necessary to design structures which can dissipate energy in the inelastic region of deformation, which requires ductile design of certain members. Careful use of transverse reinforcement can induce ductile behavior (by confining the core area) in concrete sections.

As reinforced concrete columns transfer load from slabs and beams to foundation of the structure, plastic hinge formation is discouraged in columns and is reflected in different building codes as "strong column-weak beam" concept. The flexural strength design of columns in a frame structure are thus factored for the flexural strength of beams joining at a beam-column joint. This awareness for prevention of plastic hinging in columns requires confinement of concrete through transverse reinforcement[1].

Surveys conducted after 2005 Kashmir earthquake has particularized that low strength than specified design strength of concrete has been found extensively and is one of the major cause of destruction. Different reports have made it evident that lower concrete strength than specified design, less reinforcement ratio than code provision, poor structural configuration, honey combing in concrete etc. [2][3] were the major cause of large scale destruction in the region[4].

Confining models are needed for evaluation of these structures for the provided transverse, longitudinal reinforcements and concrete strength. The existing models for evaluation of strength and ductility with varying confinement have been extensively used for normal to high strength concrete. For use in assessment of low strength concrete columns a critical review of existing confining models with their experimental validation is discussed.

1.1. Scope of literature review

Models considering confinement in normal to low strength concrete and with low transverse reinforcement ratios are considered as it is general code of practice found in existing structures. Also it is noteworthy that some recent confining models need much computational efforts which in some cases imply undue accuracy. Also the data needed in such models cannot be easily obtained in case of existing structures. Therefore, such models are avoided in forth mentioning.

II. REINFORCED CONCRETE CONFINEMENT MODELS

Various confinement models for concrete columns under axial concentric compression are generated based on experimentation. The difference in results of different models can be attributed to the test sample particulars and the considered variables in development of model. Kent and Park (1971) [5] proposed model based on small scale specimens tested at quasi-static rate of strain. They assumed that confinement increases ductility and has no effect on strength. The curve ascends in parabolic shape (Hognestad's Parabola) to peak strength at strain e_{co} of 0.002. Then it descends with either confined descending curve with more ductility or unconfined curve. Sheikh and Uzumeri (1982)[6] introduced effective confined area for determining the maximum confined strength based on large scale specimen testing with general practicing detailing of longitudinal and transverse reinforcement. But this model predicts unsafe stress at higher axial loads. The stress-strain curve of Scott et al. (1982) [7] also known as modified Kent and Park model considered both strength and ductility enhancement and was based on full scale model testing at both low and high straining rates. Mander et al. (1988)[8] proposed confined concrete model taking effective transverse confined pressure along with additional account for cyclic loading and strain rate effects on stress-strain curve. Mander model was successful in application to any cross section as it defined transverse confining pressure based on geometry of the section. Mander et al. based their model on tests performed on normal strength concrete with compressive strength of average 30 MPa. Fafitis and Shah (1985)[9] implied empirical approach to generate stress-strain curve on their experimental findings. Saatcioglu and Razvi (1992)[10] proposed model based on argument that transverse confining pressure generated by reinforcement against laterally expanding concrete changes with stress increment. They based their argument by testing on samples with compressive strength ranging from 30 to 130 MPa. Cusson and Paultre (1995)[11] based their model on actual stress in transverse reinforcement rather than using yield strength. Many more confining concrete models are generated with consideration of different analytical and physical properties of constituent materials with the introduction of new data variables. It can be observed that the empirical approach adopted by Fafitis and Shah (1985) and the one based on actual stress in ties adopted by Cusson and Paultre (1995) and others cannot be adopted for evaluation of existing structures. The physical engineering model based approach by Sheikh and Uzumeri (1982), Mander et al. (1988) and others are the best options for the purpose.Most of the confining models were generated by testing on small scale specimens which do not reflect actual column yet some used real column dimensions to verify their work such Mander et al. (1984), Scott et al. (1982) and are considered more suitable in this case.

Table 1 shows experimental samples and their confining details used to design stress-strain confining models previously discussed. Different selected models in chronological order are presented with brief description of their suitability towards low strength concrete confinement.

Confining Model	Sample Size (mm*mm)	Compressive Strength (MPa)	Transverse Reinf. Ratio ρ_s (%)	Tensile strength of steel (MPa)
Sheikh and Uzumeri (1982) [6]	305*305	27.58	0.8-2.4	414
Scott et al. (1982) [7]	450*450	25	1.4-3.09	275 (undeformed)
Mander et al. (1988) [12]	450*450	23	1.97	309
Razvi and Saatcioglu (1989) [13]	160*160	29-39	1.34-2.78	373
Cusson and Paultre (1994) [11]	235*235	52-123	1.4-5.0	392-770

1.2. KENT AND PARK (1971):

This model is based on experimental work on normal strength concrete. It takes into account both confined and unconfined concrete strength to be same f'_c. It is thus considered suitable for use in assessment of existing structures with normal and low strength concrete. This model presents different equations for ascending and descending branches where descending branch for confined and unconfined concrete differ as shown in the Fig. 1. The presented equations can be easily used with available data from existing structures.

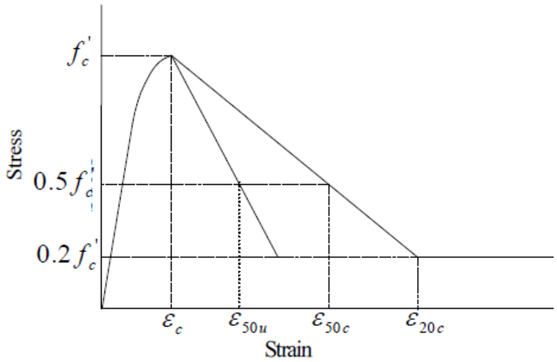

Figure 1 Stress-strain curve by Kent and Park (1971)

1.3. Sheikh and Uzumeri (1982):

This model is also based on experimental work of normal strength concrete with low transverse reinforcement ratio. It proceeds the work of Soliman and Yu (1967) and was the first one to introduce term of effective confined core area. This model takes care of different configurations, spacing and steel strength of transverse steel as shown in the Fig. 2.

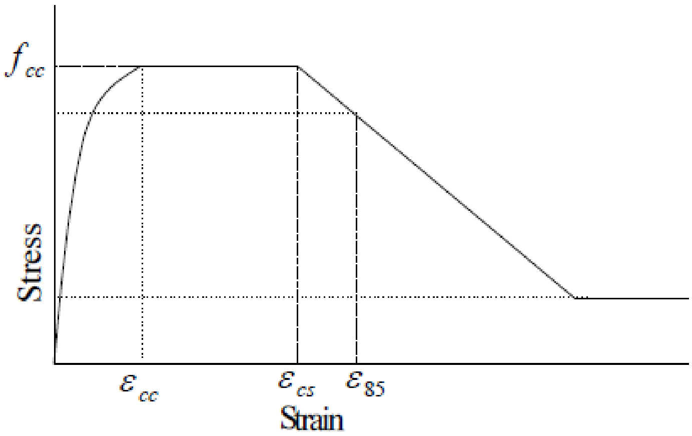

Figure 2: Stress-strain curve presented by Sheikh and Uzumeri (1982)

1.4. Mander et al. (1988):

As Sheikh and Uzumeri (1982) using effective lateral confining pressure, Mander proposed a new stress-strain model comprising of single equation for ties, spirals and for any type of sectional geometry. They used equations to determine sectional properties and determine induced confinement accordingly. Mander model also presents equations for cyclic loading along with monotonic one. It is so far, most successful model in predicting strength and ductility of normal to high strength concrete. The stress-strain curve presented is shown in Fig. 3.

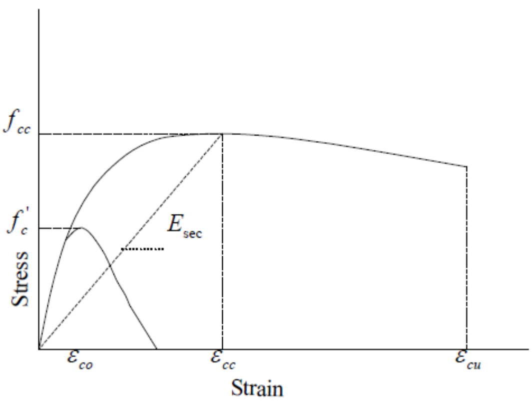

Figure 3: Stress-strain curve presented by Mander et al. (1988)

1.5. Saatcioglu and Razvi (1992):

They presented an analytical model based on theory that variation in stress changes confinement pressure. In other words the lateral passive pressure generated by expanding concrete and transverse reinforcement is erratic. The considered variables in their testing were transverse reinforcement ratio, spacing, yield strength of confining steel, transverse reinforcement arrangement, strength of concrete and shape of section. It is also one of the easiest to use models with different equations for different cross section. As their testing was based on wide range of concrete strengths (30 to 130 MPa), the model is considered suitable for estimating all types of concrete strengths. The presented stress-strain curve is shown in Fig. 4.

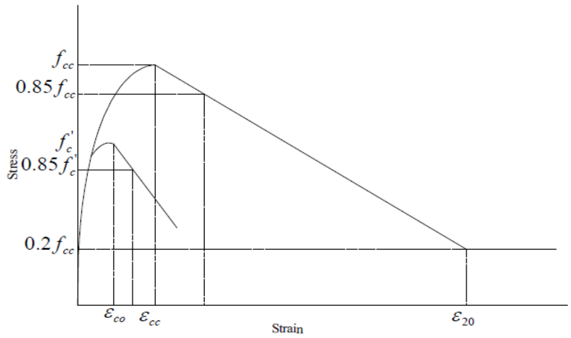

Figure 4: Stress-strain curve by Saatcioglu and Razvi (1992)

III. CONCLUSION

The models discussed above are chosen for use in assessment of structural members confinement made of low strength concrete. Among these models, Mander et al. (1988) and Saatcioglu and Razvi (1992) are considered more suitable for use in predicting strength and ductility. These models consider a wide range of variables with normal strength of steel and different loading rates. It is found necessary that experimental testing for validity of these models for low strength concrete beams and columns be conducted for structural health assessment of existing structures.

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