CONFINEMENT EFFECT ON TENSION STIFFENING OF RC BEAMS UNDER FLEXURE

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ABSTRACT

In structural analysis, especially in indeterminate structures, it becomes essential to know material and geometrical properties of members. The codal provisions recommend elastic properties of concrete and steel and these are fairly accurate enough. Various building codes recommend the tension stiffening effect while calculating the crack width of flexural members. Present aim of study is to determine effect of confinement on tension stiffening of flexural members. The experimental program consists of testing of beams (model size 150 x 150 x 700 mm) with percentage of reinforcement varying from 0.54 to 0.84% which commensurate with existing Codal provisions of IS:456-2000 for flexural member. Effect of confinement is considered in this study. The experimental results are verified by using 3D finite element techniques. Additionally, stress-strain values for reinforcement bars of the experimental models are compared with stress-strain values for the same models obtained by Eurocode2 and FE software ANSYS.

Keyword: *- Indeterminate structures, , stiffness properties, confinement effect, economical design*.

1-INTRODUCTION -1

The whole concrete between adjacent cracks is capable of carrying tensile stresses after cracks are induced in reinforced concrete members. This phenomenon is known as tension stiffening. The principal cause of this is due to the bond between reinforcing bars and the surrounding concrete. In this regard, generation of cracks and tension stiffening are considered as complex phenomenon. Many studies have revealed that neglecting the tension stiffening yields into the softening of structures. This research is an attempt to quantify the effect of confinement on tension stiffening which will be helpful in the economical design of flexural members.

2-LITERATURE REVIEW-2

Various researchers have proposed the work on tension stiffening. Among these, we can quote the research carried out on the effect of reinforcement ratio (Allam et. al. 2013) on tension stiffening, tension stiffening effect in cracking range (Khalfallah and Guerdouh 2014), tension stiffening bond modelling of crack flexural members (Khalfallah S. 2008), tension stiffening mechanisms in RC prisms (Muhamad R. et. al. 2012), tension stiffening and crack formation in RC members (Sato Y. et. al. 2003). Earlier (Leonhardt F. 1977) an empirical function was proposed to estimate tension stiffening which was used for computing mean strains. The minimum value of tension stiffening i.e. lower bound value and upper bound value from FE analysis were proposed (Allam et. al. 2013) taking into account the effect of reinforcement ratio.

An empirical relation is proposed for the determinations of modulus of elasticity ERCC of beam members considering the effect of confinement. Various codes recommend the tension stiffening effect while calculating the crack width of flexural members (Eurocode2 2004, ACI Committee 224R-01, Egyptian code ECP 203-2007, British Standards BS8110-1997). The main inspiration of this research work is due to negligence of confinement effect on tension stiffening by various codal provisions including IS: 456-2000 as well as the past several researchers.

3. EXPERIMENTAL PROGRAM:-3

In the present study, experimental investigation of the RCC models under flexural loadings are carries out. Possible combinations of reinforcement for flexure test for M20 grade of concrete are shown in Table 1. Model size 150x150x700mm is used as per Clause 7.3, IS 516:1959 (Reaffirmed 2004) Methods of Tests for Strength of Concrete. For each combination, 3 models were tested and average results are presented. IS: 456-2000 recommends minimum area of steel as (0.85% of net area)/fy and maximum area of steel 0.4% of gross area. In present study, the effective depth of the section is (150-24) =126mm. The minimum percentage of steel for the section required is 0.34 whereas the maximum percentage of steel required is 0.9. This range is for M20 grade of concrete and Fe415 grade of steel. Based on these recommendations, area of steel for various grades of concrete i.e. M20 and steel Fe415 are tabulated below. The effect of confinement was also considered in the experimental programme. All the specimens were with a stirrup spacing of 100mm and 200mm.

Table 1: Combinations of reinforcement for flexure test (M20)

Model No.	Diameter	No of bars	Ast (sq.mm.)	pt (%)
1	-	-	-	0.00
2	8	2	100.53	0.54
3	8+6	2+1	128.81	0.69
4	8	3	150.79	0.80
5	10	2	157.08	0.84

Fig -1: Casting of beams

Fig -2: Testing of beams

4. RESULTS-4

Based on experiments following results were obtained.

Table 2: Load and deflection at various stages of loading (M20 100mm Spacing)

Model No.	Load 1st crack (kN)	Deflection (mm)	Yield load (kN)	Deflection (mm)	Failure load (kN)	Deflection (mm)
1	47.36	0.19	48.44	1.24	49.34	4.20
2	47.34	0.19	50.11	2.36	52.34	5.30
3	49.31	0.19	50.55	2.36	51.33	5.00
4	45.11	0.17	46.21	2.06	47.97	5.20
5	50.31	0.17	52.47	1.94	54.00	6.80

Table 3: Load and deflection at various stages of loading (M20 200mm Spacing)

Model No.	Load 1st crack (kN)	Deflection (mm)	Yield load (kN)	Deflection (mm)	Failure load (kN)	Deflection (mm)
1	68.65	0.26	78.49	1.13	82.43	1.80
2	83.00	0.27	94.00	1.90	95.00	2.00
3	92.00	0.29	101.43	1.90	114.83	3.97
4	95.30	0.28	98.92	1.98	114.65	3.98
5	110.49	0.31	124.17	1.93	142.98	3.97

5. INVESTIGATION OF TENSION STIFFENING-5

Various codal provisions recommend the use of tension stiffening. However, IS:456-2000 remains silent about the same. The experimental evaluation of tension stiffening in any case is a difficult task. Keeping in mind this fact, it was decided to use Eurocode2 for the evaluation of tension stiffening for the models considered in the experimental study. Eurocode2-2004 [6] gives the following equation for the mean tensile strain (ε_{sm} _ ε_{cm}) for calculating the crack width of a flexural member.

$$(\varepsilon_{sm}-\varepsilon_{cm})=(f_s-K_t(f_{cteff}(1+\eta\rho_{eff})\rho_{eff}))/E_s \geq 0.6 f_s E_s \ldots\ldots (1)$$

where K_t is the factor expressing the duration of loading K_t= 0.6 for short term loading and K_t= 0.4 for long term loading, f_s is the stress in the tension reinforcement computed on the basis of a cracked section, n is the modular ratio E_s/E_c and f_{cteff} is the mean value of tensile strength of the concrete effective at the time when the cracks may first be expected to occur,

$$\rho_{eff}=A_s/A_{ceff} \ldots\ldots (2)$$

A_{ceff} = effective tension area, is the area of concrete surrounding the tension reinforcement.

The term $(K_t(f_{cteff}(1+\eta\rho_{eff})\rho_{eff}))/E_s$ represents the tension stiffening part.

The models considered in the experimental study take into account the effect of confinement with a stirrup spacing of 50mm, 100mm and 200mm. The average tension stiffening values are evaluated using for these models by Eurocode2- 2004, FE analysis and are represented in the form of graphs in Figures (1), (2), (3) and (4).

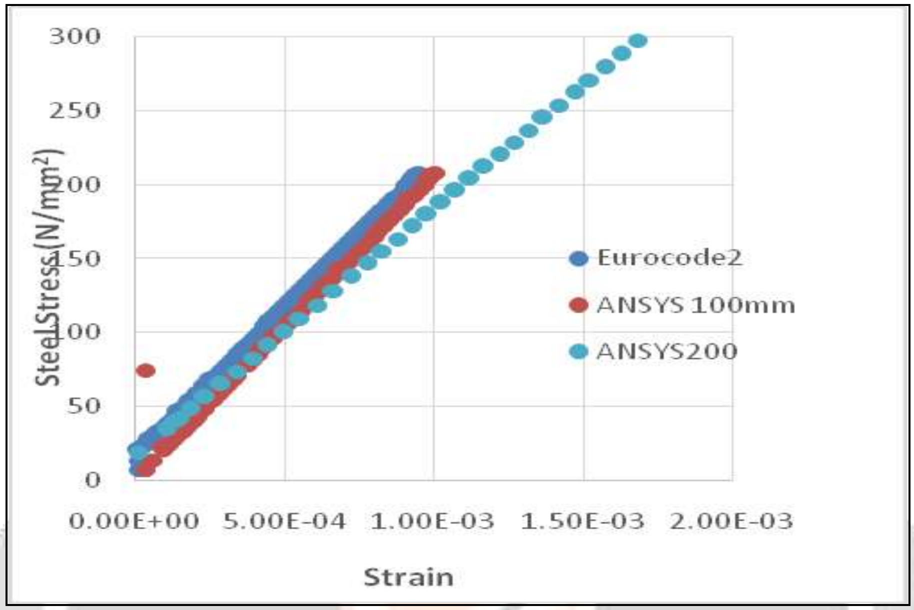

Chart-1. Steel stress versus strain for beam model 2

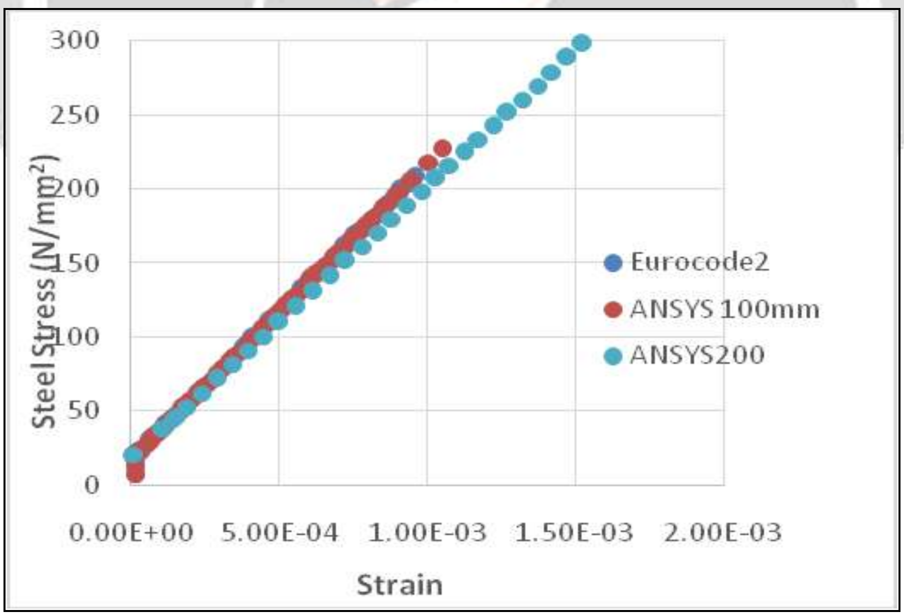

Chart- 2 Steel stress versus strain for beam model 3

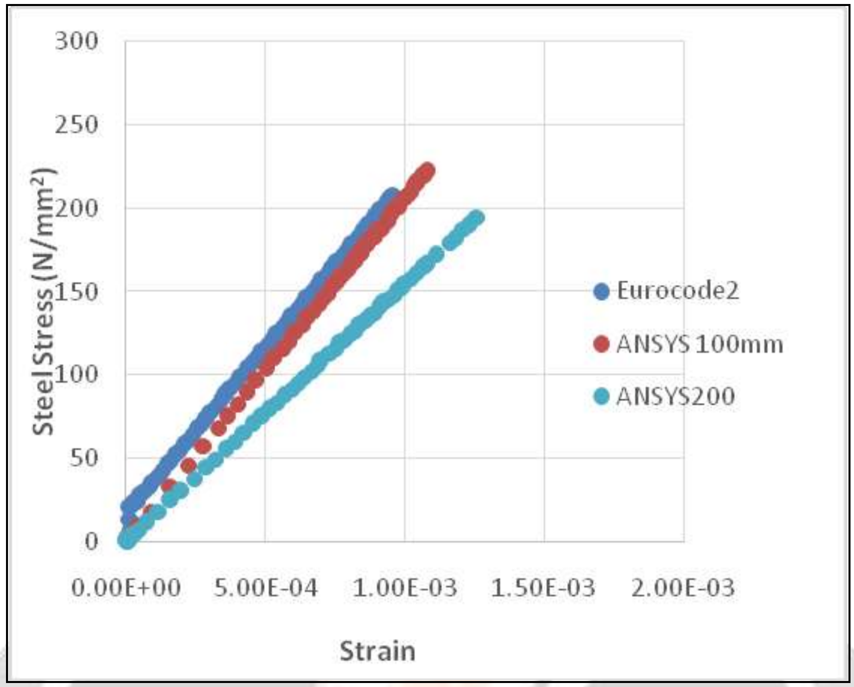

Chart-3 Steel stress versus strain for beam model 4

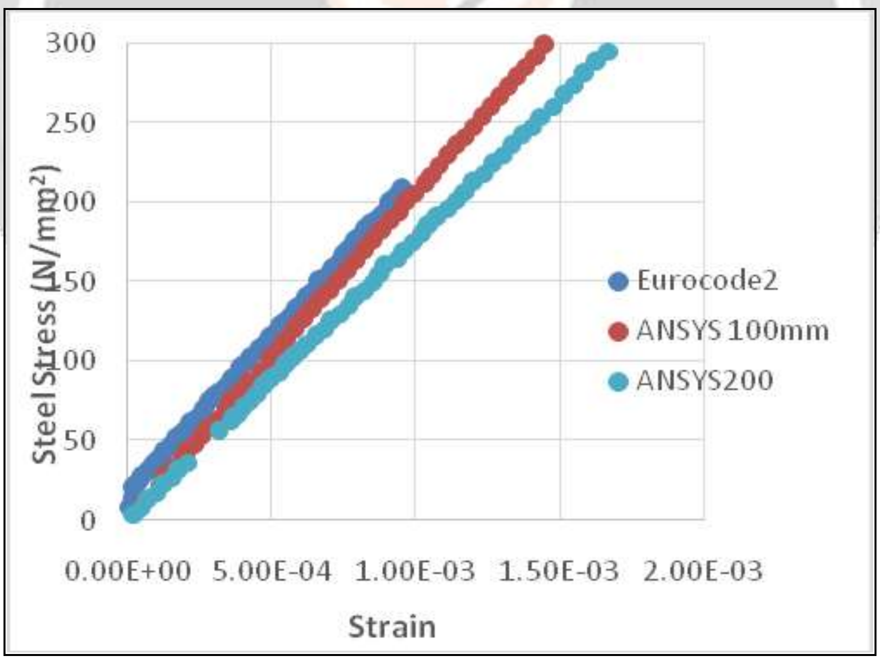

Chart-4 Steel stress versus strain for beam model 5

6. FE ANALYSIS-6:

The realistic and practical modeling of steel and surrounded concrete is one of the most challenging problems in structural analysis. Such a modeling is unavoidable in studying structural behavior. The grade of concrete selected in the present study is M20. For concrete, the element used was SOLID65. The element is defined by eight nodes having three degrees of freedom at each node i.e. translation in x, y, and z directions. This element is a highly non-linear element and specifically used for materials like concrete and it takes into account cracking in three orthogonal directions due to tension, compression and plastic deformation. Strain ratio between the concrete and steel is supposed to be equal assuming perfect bond, therefore it is accepted that there is a unique adherence between the concrete and steel. Hence there is no element defined between concrete and steel. The beam model created in the software is presented in Figure (3).

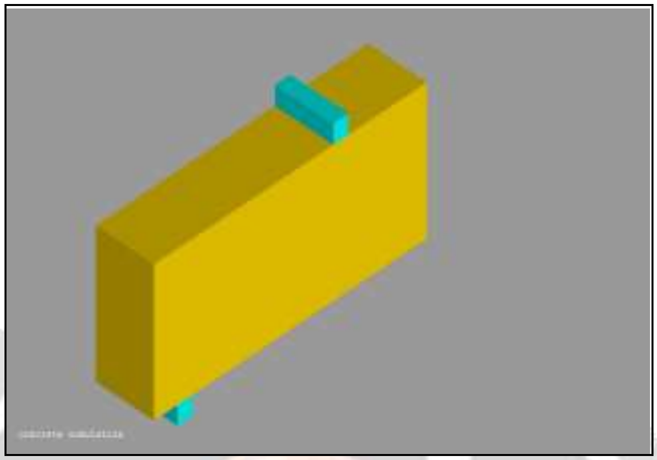

Fig-3 FE model for concrete

As it is very well known that concrete is a highly non-linear material, for accurate modeling in ANSYS-12, there is a provision of multi-linear isotropic hardening constant (MISO). This property has been utilized in this FE model. For the main steel, the bilinear kinetic hardening constant (BKIN) property has been used. The Bilinear Kinematic Hardening (BKIN) option assumes the total stress range is equal to twice the yield stress. This option is recommended for general small-strain use for materials that obey von Mises yield criteria. The typical MISO and BKIN properties are shown in Figures (4) and (5) respectively.

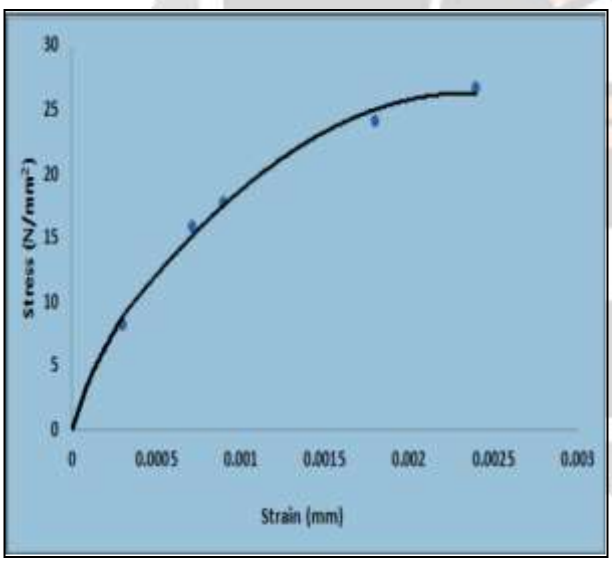

Fig-4 A Typical stress-strain curve for Model 2 of M20

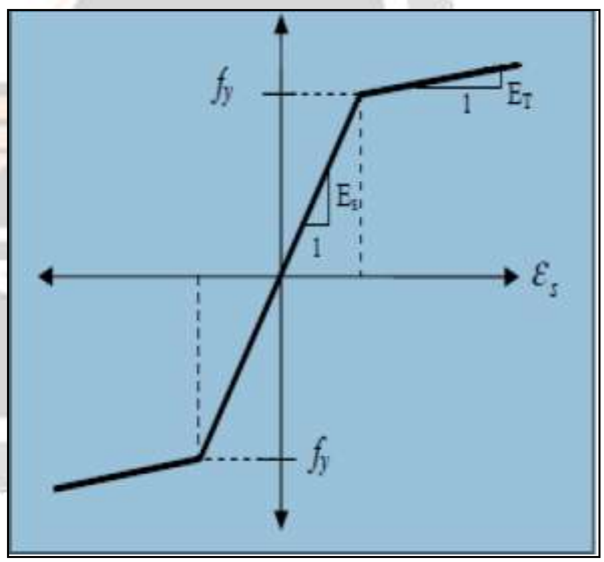

Fig-5 Modeling of reinforcing bar

The results from ANSYS models have been used for evaluation of tension stiffening of all the four models. For all these models, non-linear analysis with modified Newton-Raphson approach was followed. The stress-strain results of main reinforcement bars have been studied in the models for analytical evaluation of tension stiffening. A total number of sixty one sub-steps have been assigned for each model. It was observed that the tension reinforcement in each model gained the strain at a rapid rate with incremental load in each sub-step. The strain values for model 1 (Table 2) in the initial sub-steps (Sub step 1) were in the range of 3.77x10-6 to 1.21x10-5. However in the later sub-steps (Sub step 15), rate for model 1 (Table 2) was steady with the values in the range of 3.25x10-4 to 3.98x10-4. In the initial sub-steps, there were no cracks induced in the models and due to tension

reinforcement, the capacity of the models enhanced to a considerable extent. First cracks induced in the experimental models 1, 2, 3, 4 and 5 at a load value of 68.65 kN, 83 kN, 92 kN, 95.30 kN and 110.49 kN respectively as mentioned in table 2. The loads for the same models from FE analysis were 65.69 kN, 76.48 kN, 105.88 kN, 101.63 kN and 110.7 kN respectively. The experimental values of first crack load for experimental models in Table 3 are also close to FE software results. The strain values corresponding to the first crack loads were due to the fact that FE analysis considers the contribution of the un-cracked concrete under the neutral axis at the crack position. However, it neglects the contribution of un-cracked concrete between cracks.
The average tension strain values obtained using Eurocode2 are in good agreement with the FE software values. It is evident from chart (1), (2), (3) and (4) that Eurocode2 values are closer to models of stirrup spacing of 100mm only. The variation in Eurocode2 and FE software values is with an error of ±7%. For the models with 200mm stirrup spacing, there is a considerable deviation in the strain values in the tension reinforcement. The strain in tension reinforcement bars is presented in chart (5). The average strain values in the tension reinforcement are obtained corresponding to 200 N/mm2 stress in steel. It is observed that there is increase in the strain values of tension reinforcement bars as the confinement i.e. stirrup spacing goes on increasing. As per the past researchers findings, the fact that tension stiffening is strongly affected by flexural reinforcement ratio is also verified. This concluding remark can be extended to the degree of confinement also. However, an extensive experimental as well as analytical study is necessary for the evaluation of effect of confinement in reinforced concrete flexural beams.

Chart-5. Strain in Tension Reinforcement for all models

7. CONCLUSIONS-7:

- The average strain values for tension reinforcement bars of models with 100mm stirrup spacing in this study are in good agreement with Eurocode2-2004. However, the effect of confinement is necessary to be taken into account as an important parameter.
- The tension stiffening is strongly affected not only by percentage of tension reinforcement but also by the confinement effect.

8.REFERENCES:

1. [1] Allam S., Shoukry M., Rashad G. and Hassan A. (2013), "Evaluation of tension stiffening effect on the crack width calculation of flexural RC members", Alexandria Engineering Journal, 52, 163-173.
2. [2] ACI Committee 224, "Control of Cracking in Concrete Structures", ACI Report 224R-01, American Concrete Institute, Farmington Hills, MI, 2001, pp. 46.

3. [3] BS 8110: Part 2: 1997, “Structural Use of Concrete, Part 2, Code of Practice for Special Circumstances”, British Standard Institution, London, 1998.
4. [4] Eurocode 2, “Design of Concrete Structures – Part 1: General Rules and Rules for Buildings; The European Standard EN1992-1-1”, 2004.
5. [5] IS 456:2000, “Code of practice for plain and reinforced concrete”, New Delhi, India.
6. [6] Khalfallah S., (2008), “Tension stiffening bond modelling of cracked flexural reinforced concrete beams”, Journal of Civil Engineering and Management, 14(2), 131-137.
7. [7] Khalfallah S. and Guerdouh D., (2014), “Tension stiffening approach in concrete of tensioned members”, International Journal of Advanced Structural Engineering, 6(1), 1-6.
8. [8] Leonhardt F., (1977), “Crack Control in Concrete Structures IABSE Surveys, No.S4/77”, International Association for Bridges and Structural Engineering, Zurich, 1977, pp. 26.
9. [9] Sato Y. and Vecchio F., (2003), Journal of Structural Engineering, 129(6), 717-724.
10. [10] ECP 203-2007, “The Egyptian Code for Design and Construction of Reinforced Concrete Structures”, Ministry of Housing, Egypt.