Comparison of design calculations of Deep beams using various International Codes

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Abstract: *A deep beam is a structural member whose behaviour is dominated by shear deformations. Until recently, the design of deep beams per U.S. design standards was based on empirically derived expressions and rules of thumb. For structural members exposed to public view or environmental elements, the serviceability performance of the structure is arguably as significant as its strength. Typically, the serviceability performance of reinforced concrete deep beams is quantified by the width and spacing of diagonal cracks that form under the application of service loads. In design, diagonal cracking in service can be limited by comparing the cracking load to the service load and adjusting the section as necessary. Also, web reinforcement can be provided to restrain the width of diagonal cracks if they do happen to form in service. Currently, the minimum web reinforcement provisions in various design specifications are inconsistent and in general, do not address whether the required reinforcement considers serviceability demand as well as strength demand. In this paper, the design of deep beam has been carried out using three codes namely the Indian standard code, the American Concrete Institute code and the Construction Industry Research and Information Association code. The results have been obtained on the various designs that have been done based on these methods and they have been tabulated and the graphs plotted.*

Keywords — *ACI, CIRIA, IS Code, Deep Beam, Shear.*

I. INTRODUCTION

A deep beam is a beam having a depth comparable to the span length. Reinforced concrete deep beams have useful applications in tall buildings, offshore structures, and foundations. The transition from ordinary-beam behaviour to deep-beam behaviour is imprecise; for design purposes, it is often considered to occur at a span/depth ratio of about 2.5. The importance of the shear-span/depth ratio and for buckling and instability the depth/thickness ratio are very important. In practice, engineers typically encounter deep beams when designing transfer girders, pile supported foundations, or bridge bents. Until recently, the design of deep beams per U.S. design standards was based on empirically derived expressions and rules of thumb.

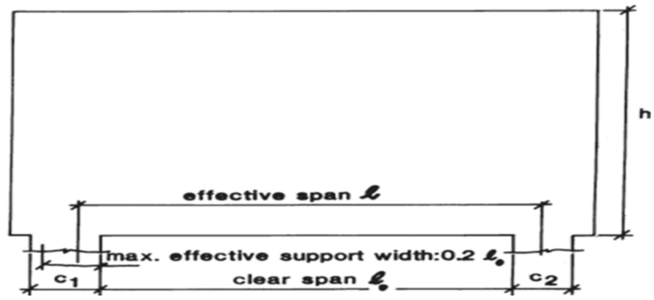

Fig.1: A typical cross section of deep beam.

The structural design standards, AASHTO LRFD (2008) and ACI 318-08, adopted the use of strut-and-tie modelling (STM) for the strength design of deep beams or other regions of discontinuity in 1994 and 2002, respectively. Based on the theory of plasticity, STM is a design method that idealizes stress fields as axial members of a truss. The primary advantage of STM is its versatility. It is valid for any given loading or geometry. However, the primary weakness of STM is also its versatility. The freedom associated with the method results in a vague and inconsistently defined set of guidelines. Because of the lack of a well-ordered design process, many practitioners are reluctant to use STM.

For structural members exposed to public view or environmental elements, the serviceability performance of the structure is arguably as significant as its strength. Typically, the serviceability performance of reinforced concrete deep beams is quantified by the width and spacing of diagonal cracks that form under the application of service loads. In design, diagonal cracking in service can be limited by comparing the cracking load to the service load and adjusting the section as necessary. Also, web reinforcement can be provided to restrain the width of diagonal cracks if they do happen to form in service. Currently, the minimum web reinforcement provisions in various design specifications are inconsistent and in general, do not address whether the required reinforcement considers serviceability demand as well as strength demand. Hence, another goal of the current research project is to improve the serviceability design provisions for deep beams by recommending an appropriate amount of minimum web reinforcement and by outlining a service-load check to assess the likelihood of diagonal cracking.

While current design concepts are based on uniaxial stress-strain characteristics, recent work has shown quite conclusively that the ultimate limit-state behaviour of reinforced concrete (RC) elements such as, for example, beams in flexure (or combined flexure and shear), can only be explained in terms of multiaxial effects which are always present in a structure. It is the consideration of the multiaxial effects that has led to the introduction of the concept of the compressive-force path which has been shown not only to provide a realistic description of the causes of failure of structural concrete, but also to form a suitable basis for the development of design models capable of providing safe and efficient design solutions. In the following, the work is summarised and the concept of the compressive force path is used as the basis for the description of the behaviour of RC deep beams of their ultimate limit state. The implications of the application of the concept in RC deep beam design are also discussed and a simple design method is proposed.

II.PROBLEM FORMULATION

Following are the problems which have been studied in this work.

Problem I:

Length of the beam = 5m

Initial depth of the beam = 5m

Load coming on the beam=1000 kn/m

For this problem we have decreased the depth of the beam by 200 mm in step of the problem to increase the L/D ratio. By keeping the loading length and moment of the beam constant, we have decreased the depth of the beam in every step for a different L/D ratio, then we have drawn graphs between

A) L/D ratio and Tension reinforcement by ACI, IS and CIRIA codes

B) L/D ratio and Shear reinforcement by ACI, IS and CIRIA codes

c) L/D ratio and total reinforcement by ACI, IS and CIRIA codes

Problem II:

Length of the beam=5m

Initial depth of the beam=5m

Initial load coming on the beam is =1000 kn/m

In this study we have decreased the depth of the beam by 200 mm in every step and we have increased the loading by 100 kn/m in every step. This is a very interesting study because here we have changed the loading as well as the depth of the beam in order to get variable moment and variable L/D ratio. For this study we have drawn graphs between the following

A) L/D ratio and tensile reinforcement by ACI, IS, and CIRIA code

B) L/D ratio and shear reinforcement by ACI, IS and CIRIA code

c) L/D ratio and total reinforcement by ACI, IS and CIRIA code 31

Problem: III

Length of the beam=5.5m

Initial load coming on the beam is =1000 kn/m

Initial depth of the beam=5.5m

In this study we have decreased the depth of the beam by 200 mm in every step and we have increased the loading by 100 kN/m in every step. This is a very interesting study because here we have changed the loading as well as the depth of the beam in order to get variable moment and variable L/D ratio. For this study we have drawn graphs between the following

A) L/D ratio and tensile reinforcement by ACI, IS, and CIRIA code

B) L/D ratio and shear reinforcement by ACI, IS and CIRIA code

c) L/D ratio and total reinforcement by ACI, IS and CIRIA code

Problem: IV

Length of the beam=5.5m

Initial load coming on the beam is =1000 kn/m

Initial depth of the beam=5.5m

In this study we have decreased the depth of the beam by 200 mm in every step and we have increased the loading by 100 kn/m in every step. This is a very interesting study because here we have changed the loading as well as the depth of the beam in order to get variable moment and variable L/D ratio. For this study we have drawn graphs between the following

A) L/D ratio and tensile reinforcement by ACI, IS, and CIRIA code

B) L/D ratio and shear reinforcement by ACI, IS and CIRIA code

c) L/D ratio and total reinforcement by ACI, IS and CIRIA code 32 (V)

Problem: V

Length of the beam=4.55m

Initial load coming on the beam is =1000 kn/m

Initial depth of the beam=4.5m

In this study we have decreased the depth of the beam by 200 mm in every step and we have increased the loading by 100 kn/m in every step. This is a very interesting study because here we have changed the loading as well as the depth of the beam in order to get variable moment and variable L/D ratio. For this study we have drawn graphs between the following

A) L/D ratio and tensile reinforcement by ACI, IS, and CIRIA code

B) L/D ratio and shear reinforcement by ACI, IS and CIRIA code

c) L/D ratio and total reinforcement by ACI, IS and CIRIA code

Problem: VI

Length of the beam=4.5m

Initial load coming on the beam is =1000 kn/m

Initial depth of the beam=4.5m

In this study we have decreased the depth of the beam by 200 mm in every step and we have increased the loading by 100 kn/m in every step. This is a very interesting study because here we have changed the loading as well as the depth of the beam in order to get variable moment and variable L/D ratio. For this study we have drawn graphs between the following

A) L/D ratio and tensile reinforcement by ACI, IS, and CIRIA code

B) L/D ratio and shear reinforcement by ACI, IS and CIRIA code

c) L/D ratio and total reinforcement by ACI, IS and CIRIA code

III. METHODOLOGY

The three methods for designing the beams are followed according to the codes of the three countries i.e. The IS code, the ACI code and the CIRIA code. It is a common design practice first to design an RC beam for flexural capacity and then to ensure that any type of failure, other than flexural (that would occur when the flexural capacity is attained), is prevented. The flexural capacity is assessed on the basis of the plane sections theory which not only is generally considered to describe realistically the deformational response of the beams, but is also formulated so that it provides a design tool noted for both its effectiveness and simplicity. However, an RC beam may exhibit a number of different types of failure that may occur before flexural capacity is attained. The most common of such failures are those which may collectively be referred to as shear types of failure and may be prevented by complementing the initial (flexural) design so that the shear capacity of the beam is not exhausted before the flexural capacity is attained, while other types of failure such as, for example, an anchorage failure or a bearing failure (occurring in regions acted upon by concentrated loads), are usually prevented by proper detailing.

Although a generally accepted theory describing the causes of shear failure is currently lacking, there are a number of concepts which not only are widely considered as an essential part of such a theory, but also form the basis of current design methods for shear design. These concepts are the following:

i) Shear failure occurs when the shear capacity of a critical cross section is exceeded

ii) The main contributor to shear resistance is the portion of the cross section below the neutral axis, with strength, in the absence of shear reinforcement, being provided by “aggregate interlock” and “dowel action”, whereas for a beam with shear reinforcement the shear forces are sustained as described.

iii) Once inclined cracking occurs, an RC beam with shear reinforcement behaves as a truss with concrete between two consecutive inclined cracks and shear reinforcement acting as the struts and ties of the truss, respectively, and the compressive zone and tension reinforcement representing the horizontal members.

A common feature of both the above concepts and the plane section theory that form the basis of flexural design is that they rely entirely on uniaxial stress-strain characteristics for the description of the behaviour of concrete.
This view may be justified by the fact that beams are designed to carry stresses mainly in the longitudinal direction, with the stresses developing in at least one of the transverse directions being small enough to be assumed negligible for any practical purpose. As will be seen, however, such a reasoning underestimates the considerable effect that small stresses have on the load-carrying capacity and deformational response of concrete. Ignoring the small stresses in design does not necessarily mean that their effect on structural behaviour is also ignored. It usually means that their effect is attributed to other causes that are expressed in the form of various design assumptions.

The following are the steps in brief which are involved in the process of design of deep beams:

1. Check of deep beam: According to IS 456, a simply supported beam is termed as deep when ratio of its effective span L to overall depth D is less than 2. Continuous beams are considered as deep when the ratio L/D is less 2.5.This is same as that of British code but ACI 318 defines simple beams with ratio L/D less than 1.25 as deep beams. Continuous beams are considered as deep when the clear span/depth ratio (i.e. L/D) is less than 2.5.

Determination of Design Bending Moment:

In a simply supported beam, the bending moment is calculated as in ordinary beams. For a total load w uniformly distributed on the beam

$$M_{max} = \frac{wL^2}{8}$$

In a continuous beam the bending moment, according to American practice for a uniformly distributed load, w per unit length is as follows:

At mid Span, $M_{max} = \frac{wL^2}{24}(1 - e^2)$, Positive

At face of support, $M_{max} = \frac{wL^2}{8}(1 - e)(2 - e)$, Negative

Where, e is the ratio of width of support to effective span.

2. Check for compression in concrete

Even though stresses in compression in concrete in deep beams are always low, a routine check should be made to estimate the maximum compression in concrete by the standard beam formula.

3. Determination of Area of Tension Steel

The area of steel to carry the tension is determined by the empirical method of assuming a value for the lever arm. IS 456 Clause 29.2 follows the committee euro international du Benton and gives the following values for z, the lever arm length.

For simply supported beams,

Z=0.2(L+2D), when L/D is between 1 and 2

=0.6 L, when L/D is less than 1.

For Continuous Beams,

Z=0.5L, When L/D is less than 1

=0.2 (L+1.5D) when L/D is between 1 and 2.5

From these Values,

$M_u = A_s f_s z$,

Where $f_s = 0.87 f_y$ in limit state design.

Also,

The value recommended as the value of z by Kong is the lesser of the two values given by the following equations:

It will be z=0.6L when L/D<1 and z=0.6D when L/D ≥ 1.

The CIRIA guide recommends the CEB values given in IS 456. The values of steel area obtained are kept very conservative as the tension steel is also assumed to contribute to the shear resistance of the beam in British practice.

We get the equations:

$$A_s = \frac{M_u}{(0.87 f_y)(0.6D)} = \frac{1.9 M_u}{f_y D}$$

$$A_s = \frac{M_u}{(0.87 f_y)(0.6L)} = \frac{1.9 M_u}{f_y L}$$

Typical detailing guideline for a section of a deep beam for tension:

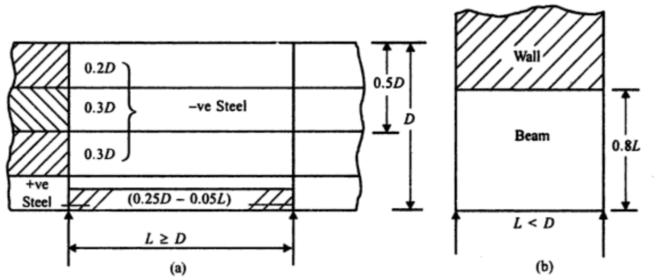

Fig.2 Placement of tension steel in deep beams

4. Design for Shear in IS 456:

No separate checking for shear is specified in IS 456. We assume that arching action of the main tension steel and the web steel together with concrete will carry the shear. In simply-supported beam the arching action as shown in Fig. 3.2 can be depended on if the main tension steel is properly detailed. However, in continuous beams, this arch action is not present and ACI recommends that we should design them as in ordinary beam. Unlike the IS code, the British practice requires numerical calculations for design of deep beams for shear. The design is based on the results of research carried out by Kong and others. It is applicable only to simply-supported beams of span depth ratio not exceeding two. The shear analysis is carried out by assuming a structural idealization of 'critical diagonal tension failure line' along the natural load path which in the case of concentrated loads is taken as the line joining the load and the support.

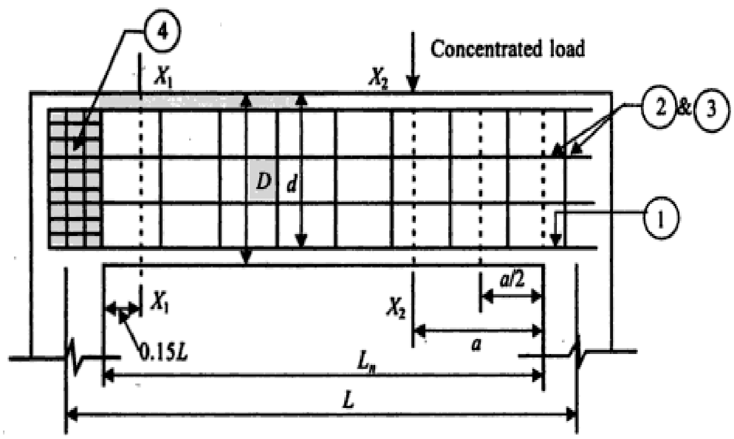

Fig.3 Design for shear in deep beams by ACI Method

IV. RESULTS AND DISCUSSIONS

The deep beams of three dimensions were chosen for the analysis. The beam of length 4.5m, 5m & 5.5m were taken and were designed. While performing the design calculations their results were enlisted and were plotted .Also the results were compared to see the variation in the behaviour. The calculations have been done based on the IS code, CIRIA code and the ACI code keeping the moment Vu constant and then they have been recalculated by varying them.

1.1 **Moment and Shear constant for a 5m deep beam:**

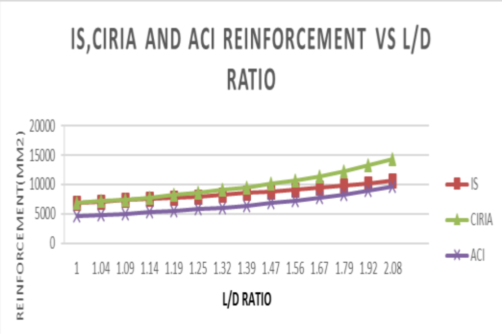

Fig. 4: Comparison of Reinforcement vs L/D ratio for IS,CIRIA and ACI

By keeping moment and shear force constant as we increase L/D ratio CIRIA code gives the maximum tension reinforcement, ACI code gives the minimum reinforcement and IS code gives the moderate reinforcement

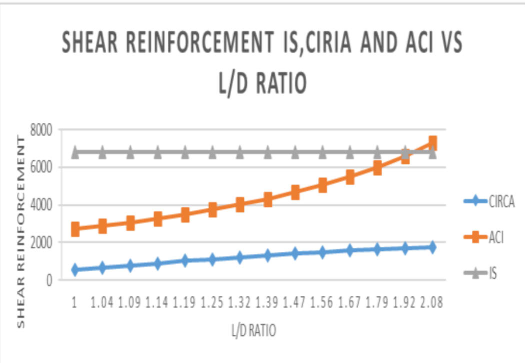

Fig. 5 : Comparison of Shear Reinforcement vs L/D ratio for IS,CIRIA and ACI

Up to L/D ratio 1.9 CIRIA code gives the maximum shear reinforcement, when L/D ratio is more than 2 ACI code gives more shear reinforcement.

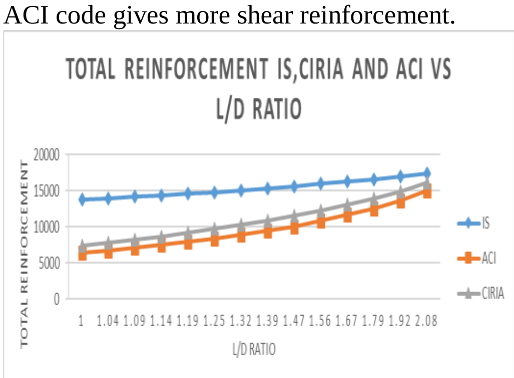

Fig. 6: Comparison of Total Reinforcement vs L/D ratio for IS,CIRIA and ACI

In the given plot of total reinforcement, for IS and ACI plots show consistency and a similar nature whereas IS code give a higher value for the same L/D ratio in the given plot.

1.2 Moment and Shear variable for a 5m deep beam: In this study we have decreased the depth of the beam by 200 mm in every step and we have increased the loading by 100 kn/m in every step. This is a very interesting study because here we have changed the loading as well as the depth of the beam in order to get variable moment and variable L/D ratio.

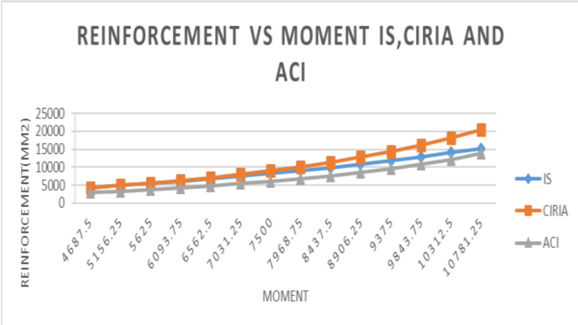

Fig. 7: Comparison of Reinforcement vs Moment(Mu) for IS,CIRIA and ACI

The plot of ACI and IS shows consistent and similar behaviour whereas the CIRIA plot gives higheer values of steel at higher values of moment.

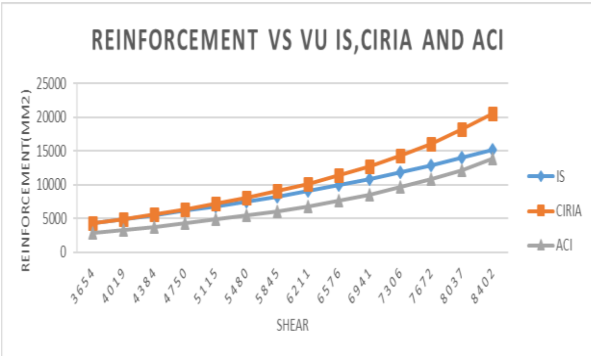

Fig. 8: Comparison of Reinforcement vs Shear(Vu) for IS,CIRIA and ACI

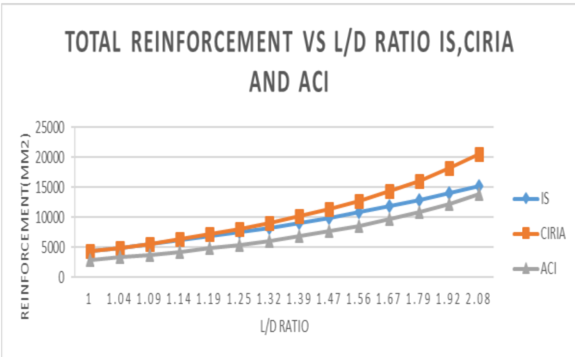

Fig. 9: Comparison of Total Reinforcement vs L/D ratio for IS,CIRIA and ACI

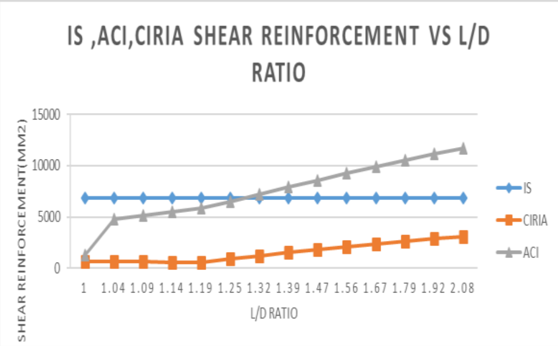

Fig. 10: Comparison of Shear Reinforcement vs L/D ratio for IS,CIRIA and ACI

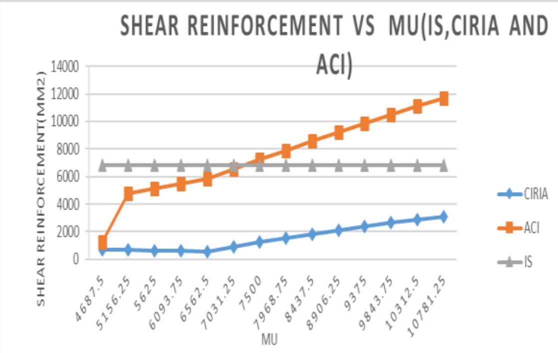

Fig. 11: Comparison of Shear Reinforcement vs Moment(Mu) for IS,CIRIA and ACI

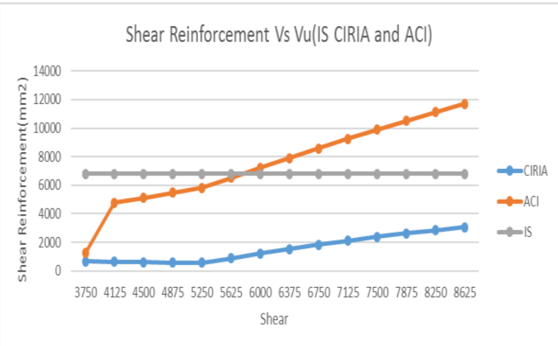

Fig. 12 : Comparison of Shear Reinforcement vs Shear(Vu) for IS,CIRIA and ACI

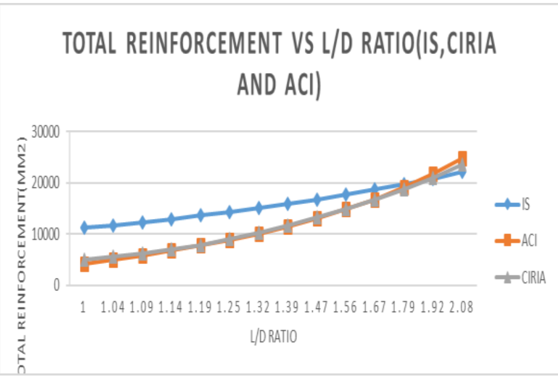

Fig. 13: Comparison of Total Reinforcement vs L/D ratio for IS,CIRIA and ACI

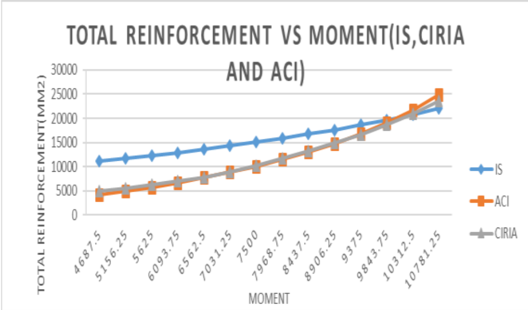

Fig. 14: Comparison of Total Reinforcement vs Moment(Mu) for IS,CIRIA and ACI

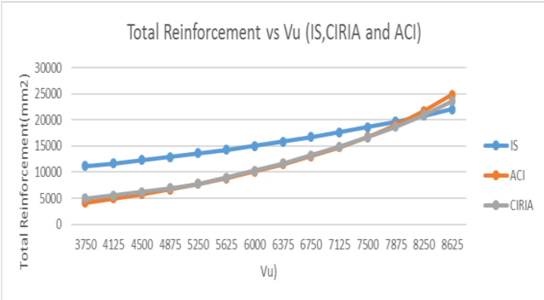

Fig. 15: Comparison of Total Reinforcement vs Shear(Vu) for IS,CIRIA and ACI

2.1 Moment and Shear constant for a 5m deep beam:

In this case a 4.5 m deep beam was taken analysed keeping Moment and shear constant.The corresponding plots are

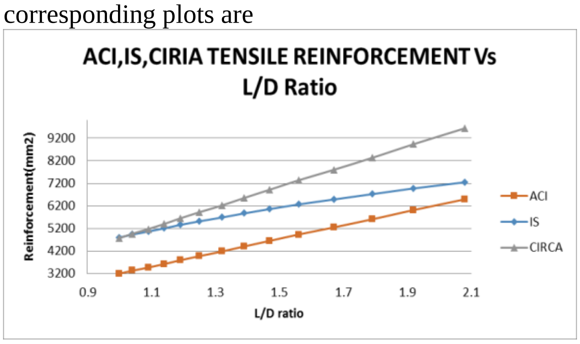

Fig. 16: Comparison of L/D ratio vs Tensile Reinforcement for a 4.5 m deep beam when Mu & Vu constant

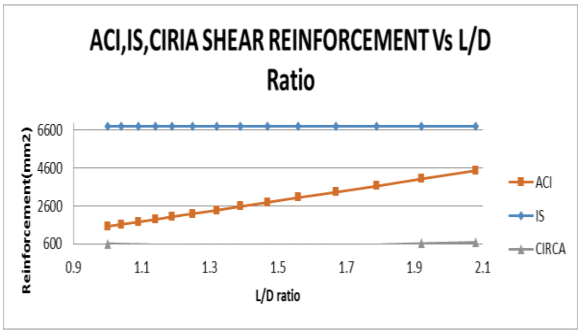

Fig. 17: Comparison of L/D ratio vs Shear Reinforcement for a 4.5 m deep beam when Mu & Vu constant

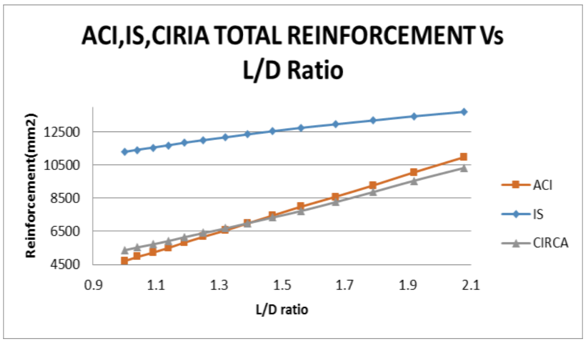

Fig.18: Comparison of L/D ratio Vs Total Reinforcement for A 4.5 m deep beam when Mu & Vu constant

2.2 Moment and Shear variable for a 4.5 M deep beam:

In this case a 5 m deep beam is taken and is analysed taking the values of Moment (Mu) and Shear (Vu) varying.

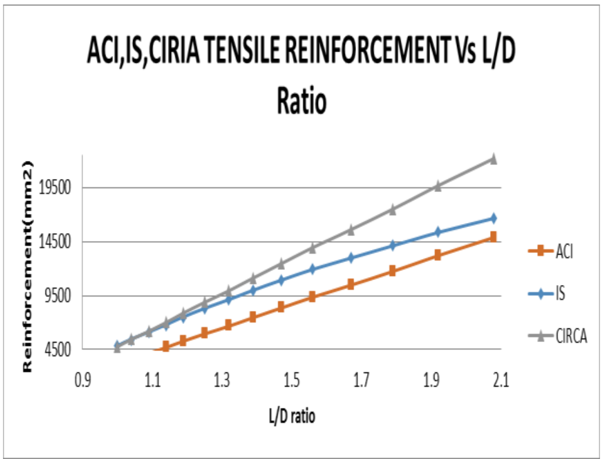

Fig. 19: Comparison of L/D ratio Vs tensile reinforcement for a 4.5 m deep beam when Mu & Vu varying

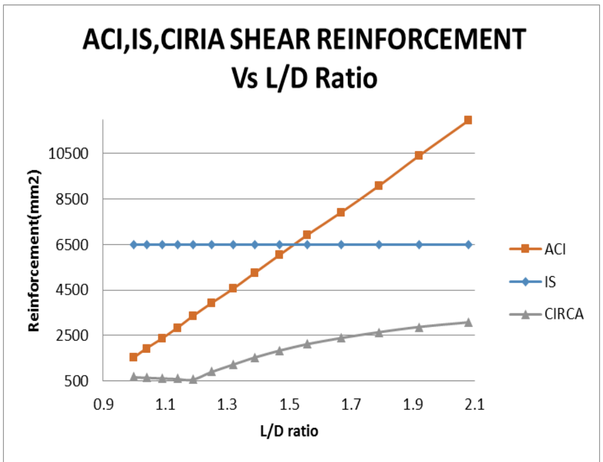

Fig. 20: Comparison of L/D ratio Vs Shear reinforcement for a 4.5 m deep beam when Mu & Vu varying

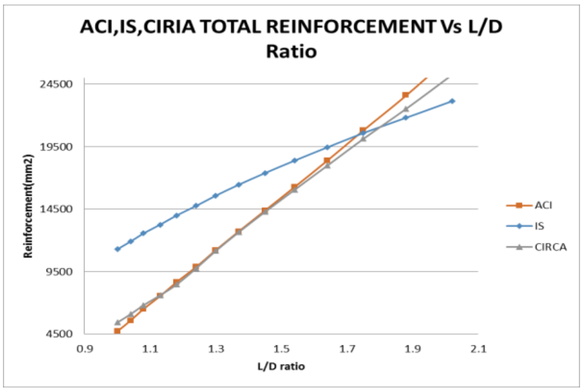

Fig. 21: Comparison of Total reinforcement Vs L/D ratio for a 4.5 m deep beam when Mu & Vu varying

3.1 Moment and Shear constant for a 5.5 M deep beam:

In this final case a 5.5 m deep beam has been taken and the Moment and shear values has been kept constant.

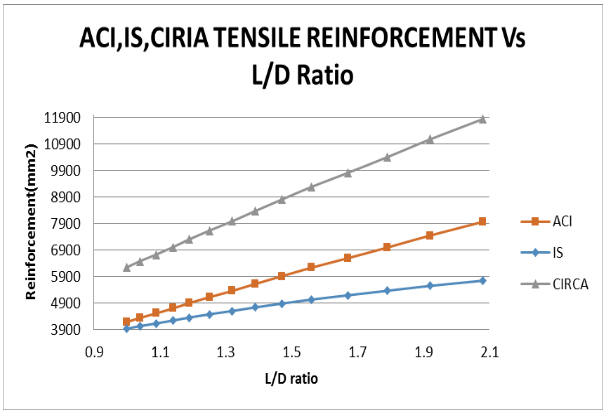

Fig. 22: Comparison of L/D ratio Vs Tensile Reinforcement for a 5.5 M deep beam when Mu & Vu constant

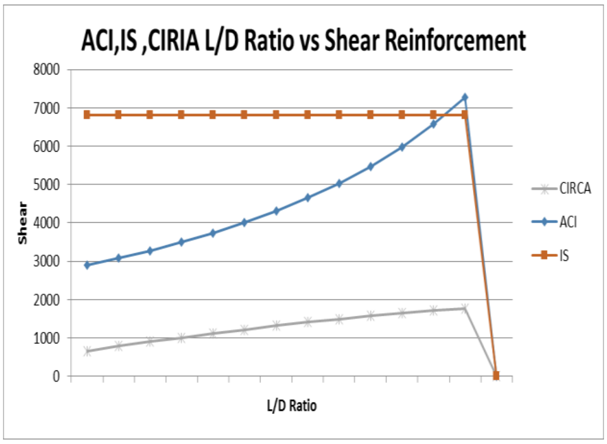

Fig. 23: Comparison of L/D ratio Vs Shear Reinforcement for a 5.5 M deep beam when Mu & Vu constant

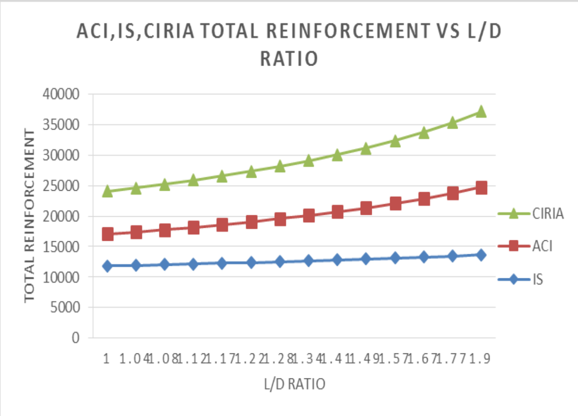

Fig. 24: Comparison of Total Reinforcement Vs L/D ratio for a 5.5 M deep beam when Mu & Vu constant.

3.2 Moment and Shear variable for 5.5 m deep beam:

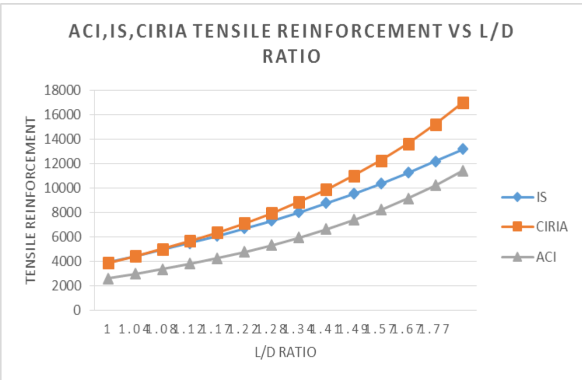

Fig. 25: Comparison of Tensile Reinforcement Vs L/D ratio for a 5.5 M deep beam when Mu & Vu varying

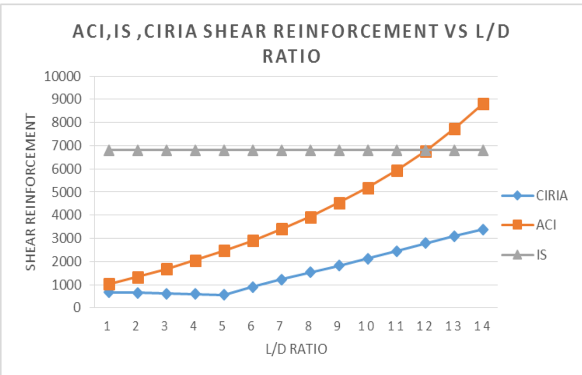

Fig. 26: : Comparison of Shear Reinforcement Vs L/D ratio for a 5.5 M deep beam when Mu & Vu varying

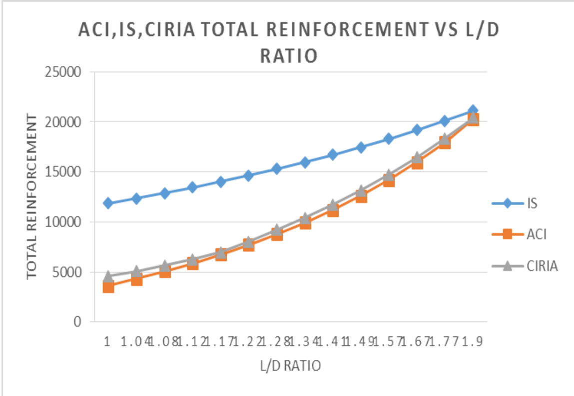

Fig. 26: : Comparison of Total Reinforcement Vs L/D ratio for a 5.5 M deep beam when Mu & Vu varying

The above plots give us an indication of the anomalies that arise in the behaviour of the results while designing the same beam from different design codes. When the load coming on the beam and length of the beam is constant as L/D increases flexural steel requirement also increases and CIRCA code gives the maximum tensile reinforcement and that of ACI is minimum and IS code gives moderate values for a 5m length deep beam. In shear IS code gives maximum shear reinforcement and that of CIRCA gives minimum reinforcement but the total reinforcement given by IS code is maximum and that of ACI code is minimum. When we start to vary the load there is change in moment and shear then something changes. Up to a L/D ratio 1.25 IS code gives maximum shear reinforcement and after L/D ratio 1.25 ACI code gives maximum shear reinforcement. But in comes to total reinforcement up to L/D ratio 1.9 IS code gives maximum reinforcement but as the L/D ratio increases the total reinforcement given by ACI starts to govern.

The above results are compatible with the experiment Analysis and Design of R.C. Deep Beams Using Code Provisions of Different Countries and Their Comparison in International Journal of Engineering and Advanced Technology (IJEAT) by Sudarshan D. Kore, S.S.Patil. **ISSN: 2249 – 8958, Volume-2, Issue-3.**

V. CONCLUSIONS

From the study on deep beams by various international codes following conclusions are drawn:

1. When the load coming on the beam and length of the beam are constant as L/D increases flexural steel requirement also increases and CIRIA code gives the maximum tensile reinforcement and that of

ACI is minimum and IS code gives moderate values.

2. When it comes to shear (by keeping maximum shear force constant) as the L/D ratio increases shear reinforcement also increases and IS code gives the maximum shear reinforcement and CIRIA code gives minimum shear reinforcement and ACI code gives moderate reinforcement value.
3. When the load coming on the beam and length of the beam is constant IS code gives maximum total reinforcement and ACI code gives minimum total reinforcement and CIRIA code gives the moderate reinforcement value.
4. When the load is varied, as L/D ratio increases ACI code gives maximum tensile reinforcement and CIRIA code gives the minimum tensile reinforcement and IS code gives moderate reinforcement.
5. When load is varied it is observed that up to L/D ratio 1.25 IS code gives maximum shear reinforcement but as L/D ratio increases from 1.25 shear reinforcement given by ACI code is maximum, CIRIA code gives minimum shear reinforcement irrespective of L/D ratio.
6. When it comes to total reinforcement (when load coming on the beam is varied) as the L/D ratio increases total reinforcement given by ACI code is maximum and that of given by CIRIA code is minimum and IS code gives moderate reinforcement.
7. It is observed that generally the tensile reinforcement given by CIRIA is maximum in all cases and in all cases the shear reinforcement given by IS code is maximum.
8. Over all IS code gives the maximum total reinforcement that means for the same size and loading condition code out of all three codes for the study that we have taken in consideration if we design using IS code we will get maximum reinforcement.

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