1. Abstract

A study on structural behavior of RCC deep beam in context to different design codes. The behavior of deep beam is significantly difference from shallow beam. In deep beams the plane section does not remain plane after deformation. In this paper we study the strength, behavior and crack pattern of RC deep beam. Deep beams play a very significant role in design of mega and as well as small structures. Some times for architectural purposes buildings are designed without using any column for a very large span. In such case if ordinary beams are provided they can cause failure such as flexural failure. The behaviour of deep beams is significantly different from that of beams of more normal proportions, requiring special consideration in analysis, design and detailing of reinforcement. To study the concept and the theory of deep beams to understand the concept of crack and its failure of deep beam subjected to different types of loading.

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2. Some Common Notation used

The following symbols are used:

l	Effective span
D	Overall depth of the beam
L_d	Development length for the design stress in the reinforcement
t	Thickness of the beam
L	Overall length of the beam
f_{ck}	Characteristic cube compressive strength of concrete
M_u	Moment of resistance
d	Effective depth
z	Lever arm
A_{st}	Area of steel
$\emptyset$	Nominal diameter of bar
σ_s	Stress in bar section considered of design load
τ_{bd}	Design bond stress
$f'c$	cylinder compressive strength of concrete;
fc	effective compressive strength of concrete;
fy	yield stress of reinforcing bars;
h	overall beam depth;
a	shear span;
b	beam width;

3. Introduction

RC deep beam are very useful members widely used in buildings, bridges, infrastructures, foundations works, tall buildings, offshore structures etc.Concrete deep beams carry heavy load within a very short supported span. In other words, a reinforced concrete deep beam can be expressed as a beam having a depth comparable to the span length.

Reinforced concrete deep beams differ from other beams primarily in their behaviour to take up the load. Due to the geometry of deep beams, the failure in deep beams is totally governed by shear rather than flexural failure. Before a deep beam could take up its full flexural strength, diagonal cracks are formed which tend to cause shear failure. Hence, shear strength is considered as an important factor in the design of concrete deep beams. Their strength is likely to be significantly greater than predicated by theoretical equations. I. S. code design method accounts for these differences.

The very basic ideology of classifying a concrete deep beam has not become universally common. The design of reinforced concrete deep beam for shear which is adopted by various design codes differs mainly in classifying RC deep beams. Different countries follow dissimilar ideology to define a deep beam in their relevant code books. The structural behaviour of deep beams has been proved to be different when compared with slender or short beams. One of the important parameters controlling this change is its “shear span to effective depth” (a/d) ratio which depends on the depth of the beam. Since this ratio is small in deep beams, there is a significant change in the strain distribution across the deep beams depth. This variation of strain is non-linear and is not seen in ordinary slender beams. Shear deformation which is insignificant in ordinary beams is considered to be substantial in deep beams and hence it cannot be ignored as this factor is also associated with the depth and effective span of the beam. It has been proved by many researchers that the width of the deep beam increases its stiffness and shear strength and reduces the lateral buckling. Studies on the effect of web reinforcement strength on the shear carrying capacity of beams have been carried out by many researchers. Web reinforcement of different type of materials, shapes and orientation has been experimentally tried in deep beams in many earlier works.

The shear behavior of deep beams is very complex and there is still no agreement on the role of size effect in shear due to lack of information Deep beams are classified as no flexural member in which plane section do not remain plane in bending. Therefore the principle of still analysis developed for slender beams are neither applicable nor adequate to check the strength of deep beam. An important characteristic of deep beams is require high shear strength. The greater shear strength of deep beam is due to internal arch action. Which transfers the load directly to support their concrete struts.

Because of the high stiffness of the deep beam it is for example applied to distribute the loads of a building on the piles below or to prevent relative movement or settlement. A common problem in these structures is clearly visible cracks in serviceability conditions. This has its effect on the durability and on the aesthetics of the structure. The deep horizontal members predominantly fail in shear rather than flexure. Web reinforcement plays a vital role in enhancing the shear capacity and mode of failure. It is unclear that IS 456 2000 provisions for minimum web reinforcement ensures ductile failure and inherently satisfies the serviceability criteria. In addition, there is a lack of comprehensive provision for the design and prediction of shear-capacity of RC deep beams. The shear action in the beam web leads to diagonal compression and tension in a direction perpendicular thereto. The deep beams do not fail immediately due to the formation of diagonal cracks. After diagonal cracking, the concrete between the diagonal cracks can serve as a concrete compression strut. The external shear is assumed to be transferred by the concrete compression strut. By detailing the end anchorage of longitudinal bars and bearing zones of deep beams, premature failures such as shear tension failure (due to insufficient anchorage of reinforcing bars) and bearing failure can be effectively avoided. The usual failure mode of deep beams is crushing of the concrete strut.

The shear behaviour of deep beams is very complex and there is still no agreement on the role of size effect in shear due to lack of information. Deep beams are classified as nonflexural members, in which plane sections do not remain plane in bending. Therefore, the principles of stress analysis developed for slender beams are neither applicable nor adequate to determine the strength of deep beams.

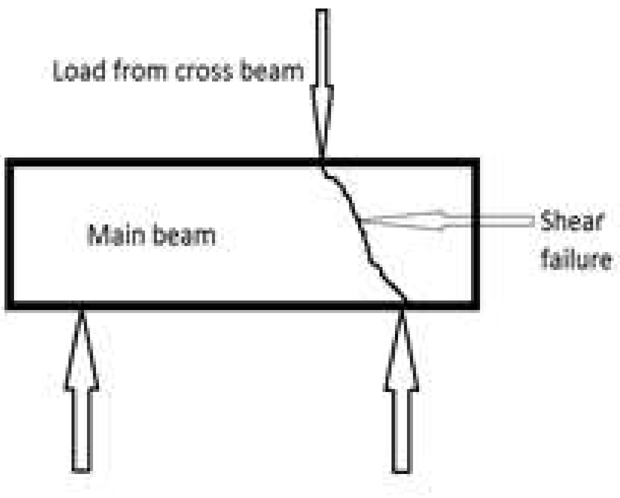


Figure 1 *Deep beam*

4. Review of Literature

Several research efforts have been made to understand the shear strength of deep beams and size effect. Due to complex behaviour of deep beams limited information has been reported over the years and further evidence is needed on the role of the many parameters involved, as demonstrated by some recent studies. The study on deep beams has been an interesting topic by varying the parameters. However, some studies have been reported on the investigations on the behaviour of deep beams in shear recently. As for the definition of deep beams, ACI 318 defines deep beams as those loaded on one face and supported on other face and the shear span-to- depth ratio is less than or equal to two. Due to their geometric proportions deep beams fail in shear. A disturbance in internal stresses is caused by shear action with compression in one direction and tension in the perpendicular direction. This leads to an abrupt shear failure of beam as the beam depth increases

(Yang and Chung, 2003). The development of crack pattern is much faster than small size deep beams and then leading to sudden failure (Bakir and Boduroglu, 2004). Several modifications have been incorporated in the shear design of deep beams in the codes of practice. ACI 318-2005 and IS 456-2000 consider the contribution of concrete, percentage longitudinal and transverse reinforcement, shear span-to-depth ratio for estimating the shear strength of deep beams, while BS 8110 does not specify any guidelines for design of deep beams. However, it explicitly says that for design of deep beams specialist literature should be referred. Unlike in ACI 318 and IS 456, BS 8110 considers size effect in shear design of RC beam. However, the maximum depth is limited to 400mm. Therefore, in order to understand the shear design of deep beams and to evaluate size effect serious research efforts are needed.

Failure in deep beams is generally due to crushing of concrete in either reduced region of compression zone at the tip of inclined cracks or by fracture of concrete along the crack. In deep beams with shear span-to-depth ratio 2.5, there seems to be some reserve strength in the post-cracking region, resulting in relatively less brittle in nature (Khaldoun, 2000, Lin and Lee, 2003). Therefore, to estimate the reserve strength and ductility of deep beams in shear, the influence of various parameters need to be investigated.

Ashour and Morley (1996) carried out an upper bound mechanism analysis on continuous reinforced concrete deep beams. The effect of horizontal and vertical web reinforcement on the load carrying capacity is mainly influenced by the shear spa-to effective depth ratio. In deep beams, the horizontal shear reinforcement is effective than the vertical shear reinforcement. Ashour (2000) reported analysis of shear mechanism in simply supported RC deep beams.

Concrete and steel reinforcement are modelled as rigid perfectly plastic materials. The failure modes were idealized as assemblage of rigid blocks separated by failure zones of displacement discontinuity. The shear strength of deep beams is derived as a function of location of the instantaneous centre of relative rotation of moving blocks.

5. Difference b/w Dee beam & Simple beam

- Two –dimensional action, because of the dimension of deep beam they behave as two-dimensional action rather the one-dimensional action.
- Plane section do not remain plane, the assumption of plane section remain pane cannot be used in the deep beam design. The distribution is no longer linear.
- Shear deformation, the shear deformation cannot be neglected as in the ordinary beam. The stress distribution is not linear even in the elastic stage, at the ultimate limit state the shape of concrete compressive stress block is not parabolic shape again.

6. Requirement &Uses

Reinforced concrete deep beams have useful applications in many structures, such as tall buildings, foundations, offshore structures, and several others .Deep beams are widely used as transfer girders in offshore structures and foundations, walls of bunkers, load bearing walls in buildings, plate elements in folded plates, pile caps, raft beam wall of rectangular tank, hopper, floor diaphragm and shear walls.

7. Behaviour of RC Deep Beams

The behavior of deep beams is significantly different from that of beams of more normal proportions, requiring special consideration in analysis, design and detailing of reinforcement.

7.1. Stress distribution

The stress distribution in the section of the deep beam is nonlinear, the linear elastic theory for the general beam analysis cannot be applied. Therefore ACI code requires that deep beams be designed via non-linear analysis or by Strut-Tie models.

The bending stress distribution across any transverse section deviates appreciably from the straight line distribution assumed in the elementary beam theory. Consequently a transverse section which is plane before bending does not remain approximately plane after bending and the neutral axis does not usually lie at the mid depth.

The ultimate failure due to shear is generally brittle in nature in contrast to the ductile behavior and progressive flexural failure with large number of cracks observed in normal beams. Because of their proportions, they are likely to have strength controlled by shear. On the other hand, their strength is likely to be significantly greater than predicated by usual equations.

7.2. Shear strength of Deep Beams

Shear strength of deep beams may be as much as 2 to 3 times greater than that predicated using conventional equations developed for members of normal proportions. For deep beams, however a significant part of the load is transferred directly from the point of application to the supports by diagonal compression strut.

Diagonal cracks that form roughly in a direction parallel to a line from the load to support isolate a compression strut, which acts with the horizontal compression in the concrete and the tension in the main reinforcement to equilibrate the loads. The geometry of this mechanism and the relative importance of each contribution to shear strength clearly depend on the properties of the member as well as the placement of the loads and reactions.

7.2.1**.** Factors Influencing Shear Behaviour in RC Deep Beams

7.3. Distribution of flexural stresses

The reinforcement of deep beams differs from that of normal beams. The main flexural steel is placed near the tension edge, as usual, although because of the greater depth of the tension zone it may be advisable to distribute such steel over, the bottom third of the member. As per I. S. 456-2000, flexural steel is placed within a zone of depth equal to (0.25D-0.05L) adjacent to the bottom face of the beam where 'D' is the overall depth and 'L' is the effective span.

As an example, Figure shows the distribution of horizontal flexural stresses at the mid span of simply supported beams having different span/depth (l/h) ratios, when carrying a uniformly distributed load of intensity 'w' per unit length. The mid span moment being ($wl^2/8$), the usual extreme fiber stress at mid span of a square panel (l/h = 1.0) would be $f_t = f_c = 6M/bh^2 = 0.75$ w/b which indicates that the tensile stresses at bottom fiber are more than twice this intensity.

In the case of deep beams, shear flexure and shear modes dominated by tensile cleavage failure are common. It is found that the smaller the span/depth ratio (i.e. less than 2.5), the more pronounced deviation of the stress pattern from that of Bernoulli and Navier as shown in Figure 2. Significantly warping of the cross-sections occurs because of high shear stresses, consequently flexural stresses are not linearly distributed, even in the elastic range, and the usual methods for calculating section properties and stresses cannot be applied.

Similar deviations occur for the distribution of shear stresses. For the determination of principal tensile stresses, the vertical stresses, particularly at the support points of the wall-beam panel, are of great importance. This type of structure is rather sensitive with respective to the loading

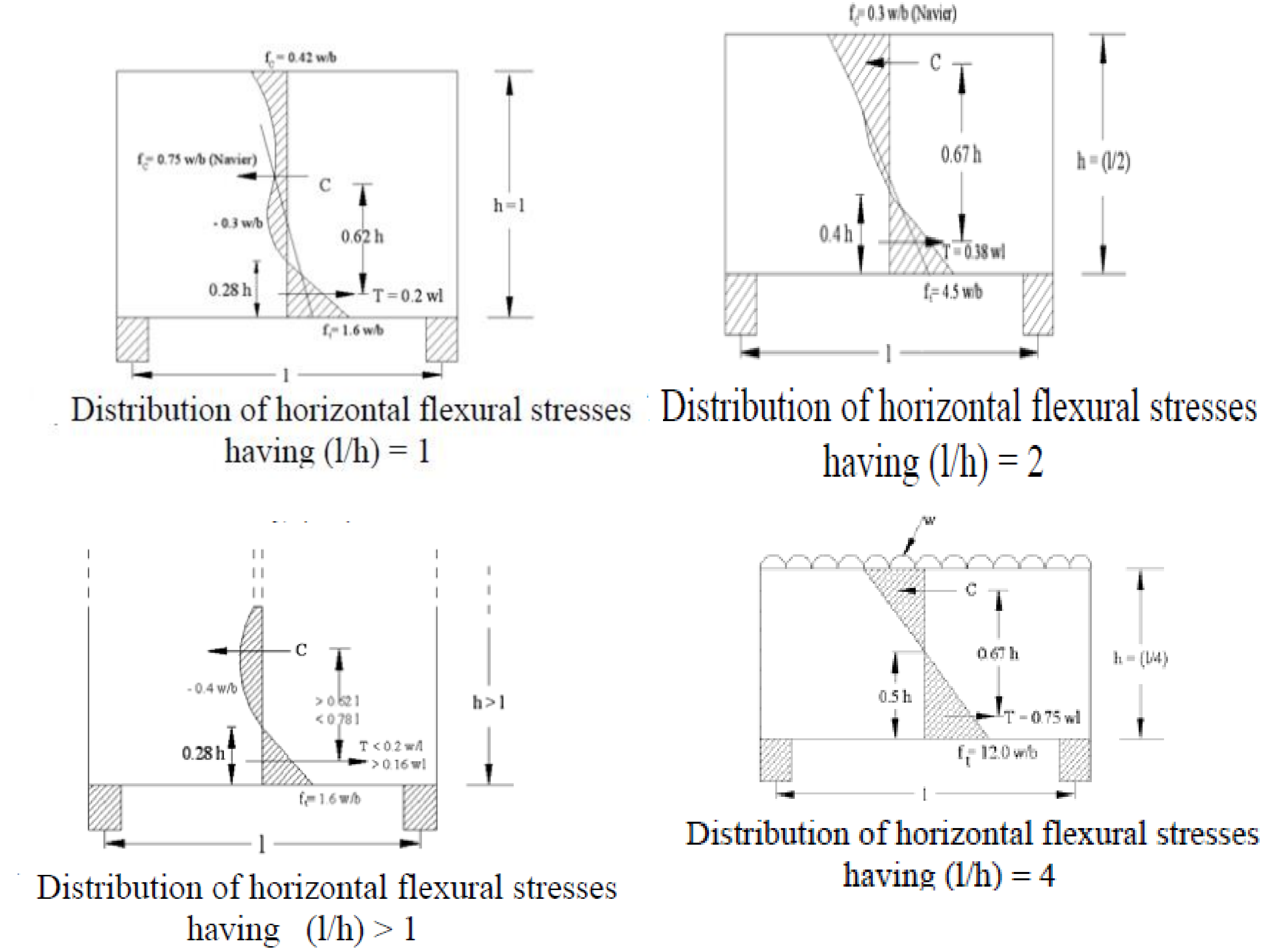


Figure 2 *the distribution of horizontal flexural stresses at mid span*

at the boundaries. The length of the bearings of the beam in would affect the principal stresses, which can be very critical in the immediate vicinity of this support. One of the most significant aspects of stress analysis would be the manner of application of the load, which is uniformly distributed in the case depicted in Figure 2.

8. General behavior of deep beam in shear failure (under two-point loading)

Concrete strain variation at mid-span section indicates that before first cracking, the beam behaves elastically, shows non-linear distribution of strain and more than one neutral axes (Figure 3). The number of neutral axes decreases with incremental loads and at ultimate stage only one neutral axis is present. Concrete strain variation at the plane of rupture shows the deep beam behaviour also before cracking and persistance of diagonal tension till failure. However, the extent of crack width and the deflection pose no problem at the service loads. If, however, the crack width is limited to 0.3 mm, the corresponding load will be in the range of 60–70% of the ultimate load.

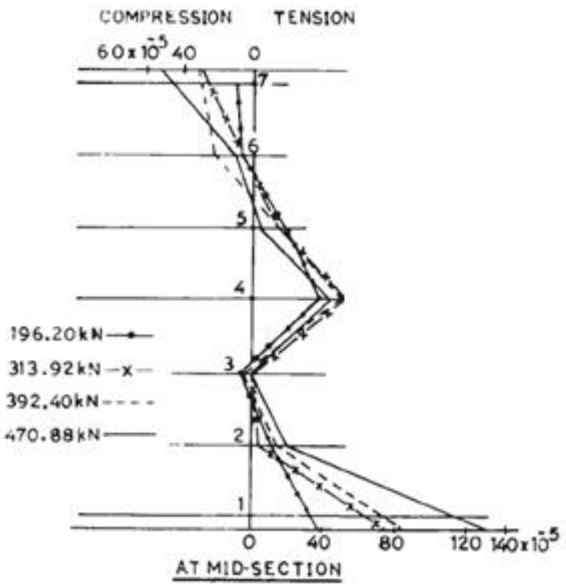


Figure 3 strain distribution under two point loading

9. Different code guidelines

9.1. As per IS-456 (2000) Clause 29,

9.1.1. Deep beam

A beam shall be deemed to be a deep beam when the ratio of effective span to overall depth, is less than:

1.) 2.0 for a simply supported beam; and

2.) 2.5 for a continuous beam.

A deep beam complying with the requirements shall be deemed to satisfy the provisions for shear:-

9.1.2. Lever Arm

The lever arm z for a deep beam shall be determined as below:

a) For simply supported beam

   Z =0.2 (l+2D) when $1 \le \frac{l}{D} \le 2$

   Or

   Z =0.6 l when $\frac{l}{D} < 1$

b) For continuous beams

   Z = 0.2 (l+1.5D) When $1 \le \frac{l}{D} \le 2.5$

   Or

   Z = 0.5 l When $\frac{l}{D} < 1$

Where 1 is the effective span taken as centre to centre distance between supports or 1.15 times the clear span, whichever is smaller, and *D* is the overall depth.

9.1.3. Reinforcement

9.1.3.1**.** Positive Reinforcement

The tensile reinforcement required to resist positive bending moment in any span of a deep beam shall:

a) Extend without curtailment between supports;

b) Be embedded beyond the face of each support, so that at the face of the support it shall have a development length not less than $0.8L_d$, where $L_d = \frac{\emptyset\sigma_s}{4\tau_{bd}}$ is the development length, for the design stress in the reinforcement; and

c) Be placed within a zone of depth equal to 0.25 *D – 0.05* ***l*** adjacent to the tension face of the beam where *D* is the overall depth and ***l*** is the effective span.

9.1.3.2. Negative Reinforcement

a) *Termination of reinforcement* - For tensile reinforcement required to resist negative bending moment over a support of a deep beam:

1) It shall be permissible to terminate not more than half of the reinforcement at a distance of 0.5 *D* from the face of the support and

2) The remainder shall extend over the full span.

b) Distribution-When ratio of clear span to overall depth is in the range 1.0 to *2.5,* tensile reinforcement over a support of a deep beam shall be placed in two zones comprising:

1) A zone of depth 0.2 *D,* adjacent to the tension face, which shall contain a proportion of the tension steel given by

$$0.5\ (\frac{l}{D} - 0.5)$$

2) A zone measuring 0.3 *D* on either side of the mid-depth of the beam, which shall contain the remainder of the tension steel, evenly distributed.

For span to depth ratios less than unity, the steel shall be evenly distributed over a depth of 0.8 *D* measured from the tension face.

9.1.3.3. Vertical Reinforcement

If forces are applied to a deep beam in such a way that hanging action is required, bars or suspension stirrups shall be provided to carry all the forces concerned.

9.1.3.4. Side Face Reinforcement

Side face reinforcement shall comply with requirements of minimum reinforcement of walls.

9.2. As per New Zealand Code

- Deep Beams are members loaded on one face & supported on the opposite face, so that compression struts can develop between the loads & supports,
- clear span , Ln equal to or less than 3.6 times the effective depth for simply supported or continuous beams ,
- clear span equal or less than 1.6 times the effective depth for cantilever beams.
- The beam is designed with strut and tie method.

9.3. The Canadian code (CSA-A23.3-2004.)

- deep beam as a beam in which the ratio of the clear span L_0 to the overall depth (h) is less than the limits given below.

For Simple spans : $L_0 / h < 1.25$,

For Continuous spans: $L_0 / h < 2.5$.

9.4. As per APPENDIX-A of ACI-318

- The deep beam is defined as the ratio of effective span to depth is less than or equal to four.
- Strut and tie Method.

9.5. The CIRIA Guide

Beams having an effective span/ depth ratio (l/h) of:

- less than 2 for single-span beams,
- less than 2.5 for continuous beams.

10. Effect of different parameter in shear strength of deep beam

10.1. Effect of main and web reinforcements

It was probably for the first time that Kong and his associates, in 1970–72, considered the main reinforcement as an integral part of the shear reinforcement for calculation purposes. The main steel not only acts as tension reinforcement in flexure, but contributes substantially to the shear strength of beams. Further, web reinforcement controls crack widths and deflection.

However, first cracking is generally not influenced by its provision. Of all types of web reinforcement, the inclined type placed perpendicular to the plane of rupture (critical diagonal crack) has been found to be the most effective arrangement to offer resistance to sliding (Ray, 1980; 1982a, b 1983;

1984). The next practical and effective type is the horizontal web steel which with nominal vertical web steel may further increase the effectiveness of the beam and so its strength. It was observed (Ray, 1980; 1982a, b; 1983; 1984) that in beams with web openings, horizontal web reinforcement distributed equally on either side of the opening location showed better results. In beams with unusually high web reinforcement, special attention should be paid to the detailing of anchorage and bearings at the load and support points. Otherwise, web steel must be limited to a certain amount.

Failure will be gradual and slow in beams with web reinforcement, while it is sudden in beams without web reinforcement. A vertical web reinforcement placed near the vertical edge of a beam with web opening located in its neighbourhood, guards against any premature failure due to rotation of the corner of the beam. From electrical strain measurements on main steel it was observed (Ray, 1980; 1982) that the general trend of the stress-strain characteristics under different load levels resembled stress-strain behaviour of steel but shear failure occurred at steel strains below the yield-point values normally expected in shear failures. It was further seen (Ray, 1980; 1982) that after cracking of the beams the steel strain rapidly increased at the location near the supports and the steel strain in the flexural zone remained almost constant (i.e. tension was uniform). The inclined cracks began to develop at higher loads.

10.2. Effect of Horizontal Web Reinforcement

The horizontal web reinforcement at close spacing near the bottom faces of the beam has been observed to be effective *(Smith and Vantsiotis 1983)*. The shear strength increases with increase in the percentage of web reinforcement *(Madan et al. 2007)*. Both the vertical and horizontal web reinforcement are efficient in resisting the shear capacity of deep beams, but the horizontal shear reinforcement is most effective when aligned perpendicular to the major axis of the diagonal crack (*Arabzadeh et al. 2011)*. Provision of shear reinforcement within the middle region of the shear span can improve the ultimate shear strength of deep beam *(Aguilar et al. 2003)*. On the other hand the horizontal web reinforcement is less effective in providing shear strength than the vertical web reinforcement *(ACI Committee 2008)*. Minimum percentage of web reinforcement for strength and serviceability is 0.30% *(Birrcher et al. 2013)*. Fig. 4 shows the benefits of distribution of horizontal web reinforcement. Shear strength is plotted on columns whereas; named as per distribution and percentage of horizontal shear reinforcement. 0.30% distribution in 0.30 times depth (0.30d) exhibits high strength over 0.20% distribution in 0.30d and uniformly distributed over the depth.

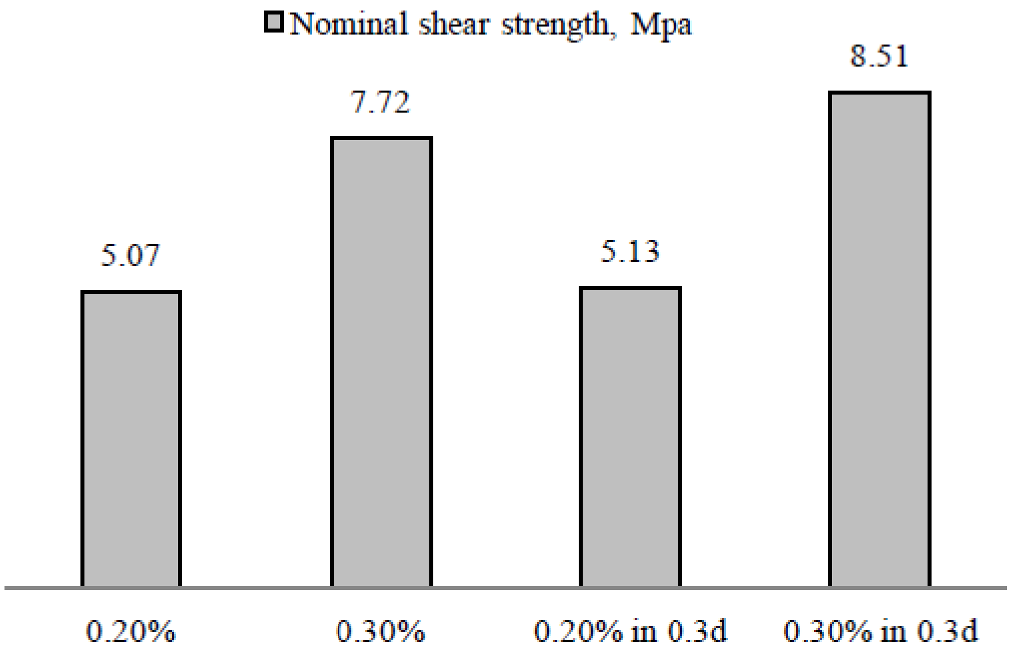
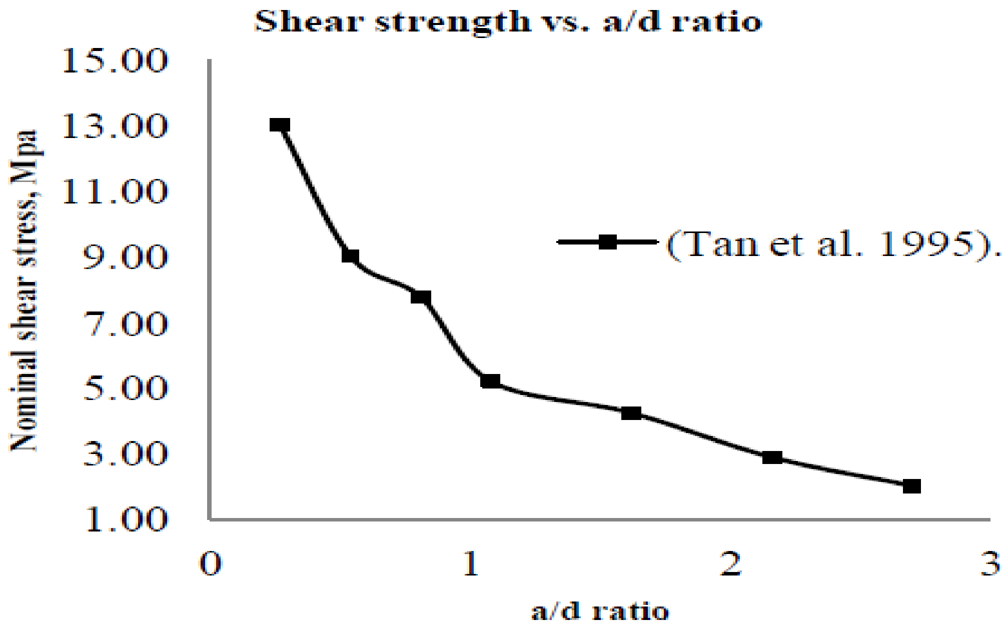


Figure 4 *Effect of distribution of horizontal web reinforcement on shear strength (Rao and Prasad 2010)*

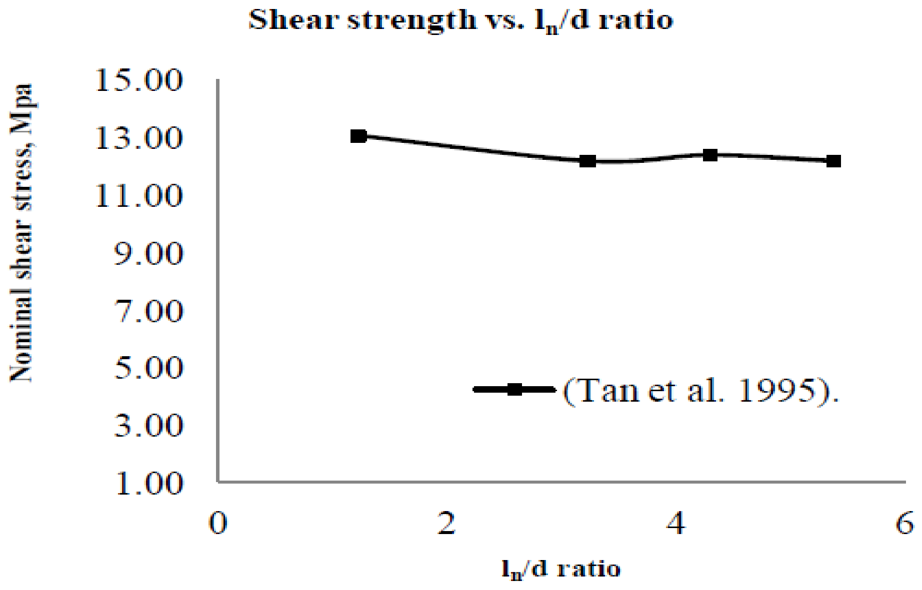
10.3. Effect of Shear Span-to-Depth Ratio & Effective Span-to-Depth Ratio

Reserve strength and normalised shear strength decrease when a/d increases. The fact holds good for fiber reinforced concrete deep beams, where the fibers used as an alternative for tension reinforcement *(Andermatt and Lubell, 2013)* and web reinforcement *(Madan et al. 2007).* Flexural behaviour was dominated when shear span-to-depth ratio is greater than 1.0 and increasing effective span-to-depth ratio *(Tan et al. 1995)*. While the a/d ratio increases, shear failure mode seems to be combined with flexure and with high le/d ratio flexure failure mode was predominant. The modes of failure either shear compression or shear tension is determined by shear span-to-depth ratio *(Shin et al. 1999)*. Fig. 5(a) and (b) depicts clearly that shear span-to-depth ratio is highly influencing parameter of deep beams shear strength. In Fig.5 (a) there is an asymptotic



(a)

decrease in shear strength when the shear span-to-depth ratio increases.



(b)

10.4. Effect of Distribution of Web Reinforcement in Web

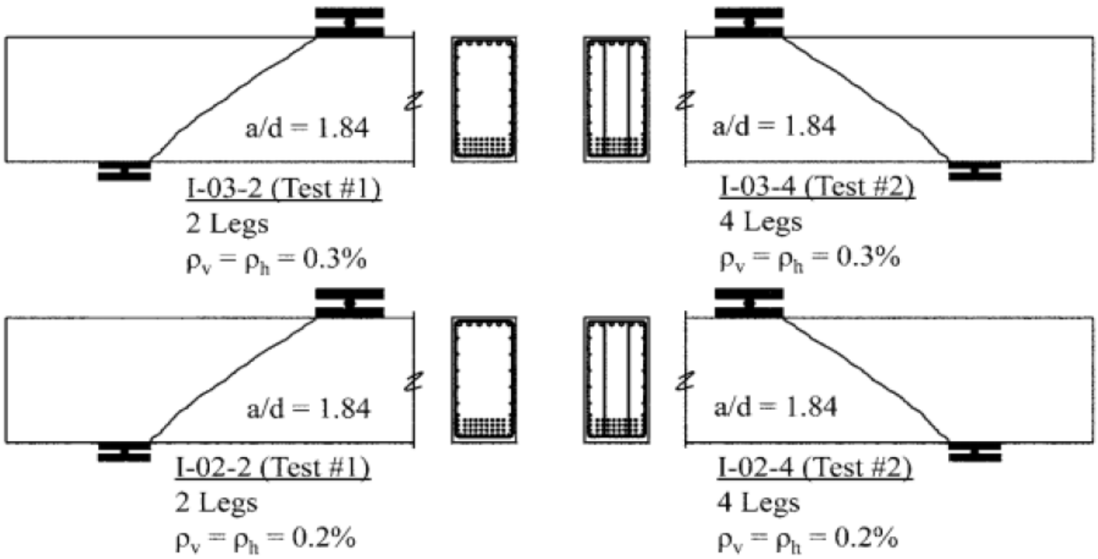


Figure 5 Influence of shear span-to-depth ratio (a) and effective span-to-depth (b) ratio on shear strength

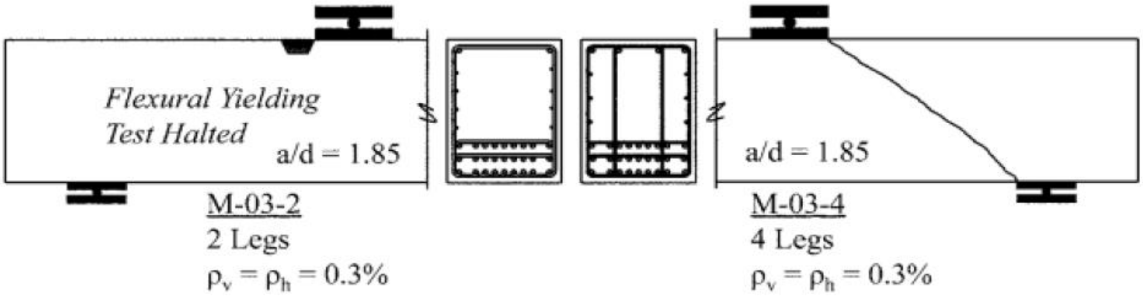


Fig. Distribution of stirrups in web *(Tuchscherer et al. 2011)*

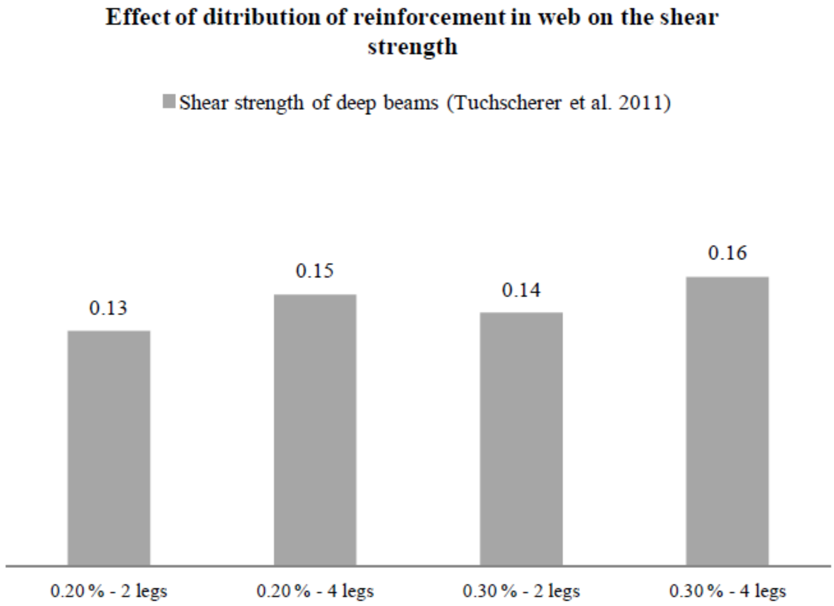


Figure 6 effect of distribution of stirrups in web (Tuchscherer et al.2011)

Beams with and without distributed stirrups across the web is shown in fig. 6. Closely spaced stirrups in web did not enhance shear capacity or serviceability performance *(Tuchscherer et al. 2011)*. Fig. shows the shear strength of four tests on the first two beams of Fig.6 . Besides, Fig. 6 gives a clear depiction about the effect of distribution of stirrups on the shear strength. Columns in Fig.6 are named as percentage of web reinforcement and legs of stirrups.

Web reinforcement had no influence on the magnitude of diagonal cracking strength *(Zhang and Tan 2007).* Web reinforcement provided vertically was most effective than the horizontal. Orthogonal reinforcement exhibited good control over diagonal cracking, enhanced shear strength and increased beam stiffness *(Tan et al. 1997).*

10.5. Effect of Length of Loading or Bearing Plates

A CCC (Compression-Compression-Compression) or CCT (Compression-Compression-Tension) node, tri-axially confined by surrounding concrete, can achieve bearing stresses that are much higher than the compressive strength of concrete. No evidence of reduction in shear strength when there was a reduction in width of load or support-bearing plate *(Tuchscherer et al. 2010).*

10.6. Effect of Side Cover

Influence of the side cover thickness on shear strength of beams was reported *(Rahal, 2007).* Consequence of the thick side cover tension face corner portion crushed on the other hand intact vertical side. Thickness of the side cover increases number of diagonal crack decreases conversely no effect on the width of the diagonal cracks. Spalling of concrete supposed to get in beams with high strength and large thickness web cover. The fact is that no spalling will occur until code predicted ultimate load hence reduction in the shear strength was not recommended.

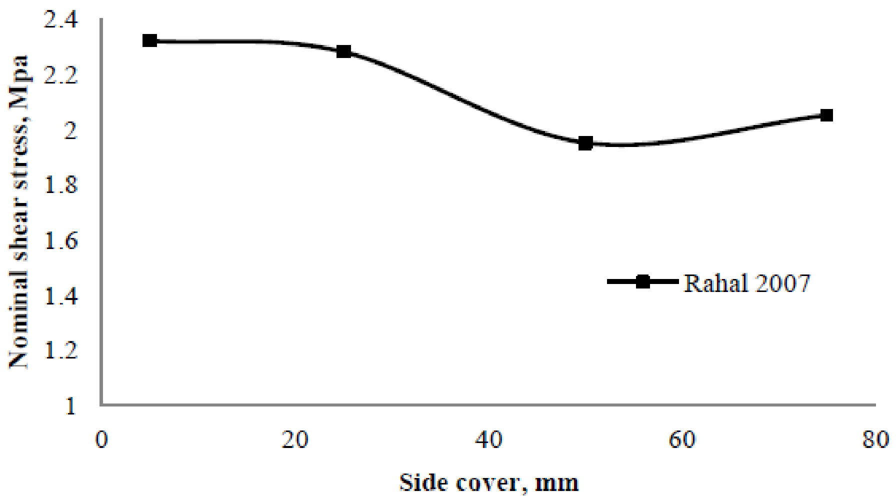
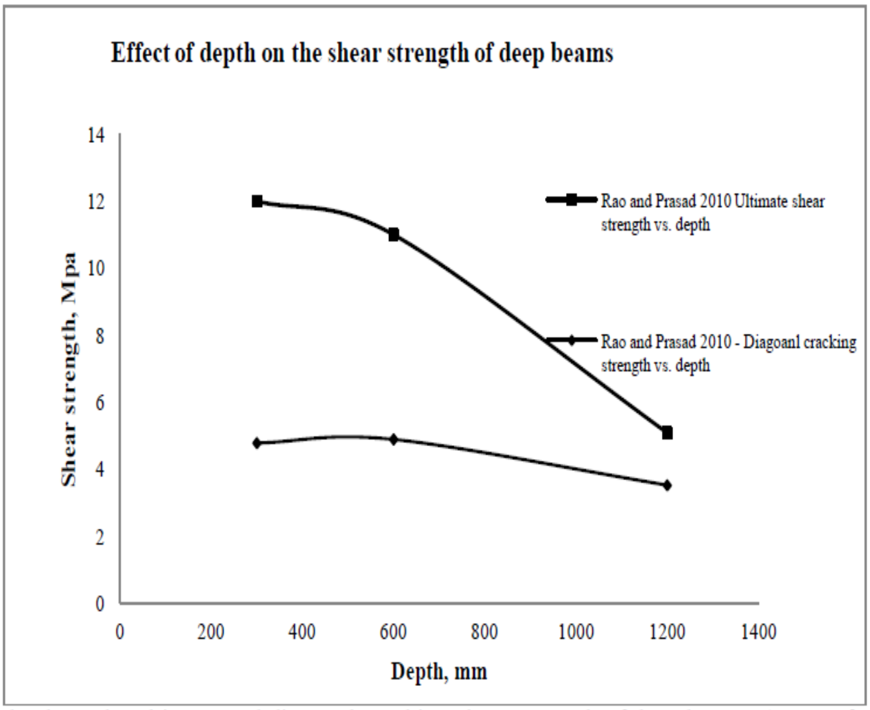


Figure 7 effect of side cover on the shear strength of the beam (Rahal, 2007)

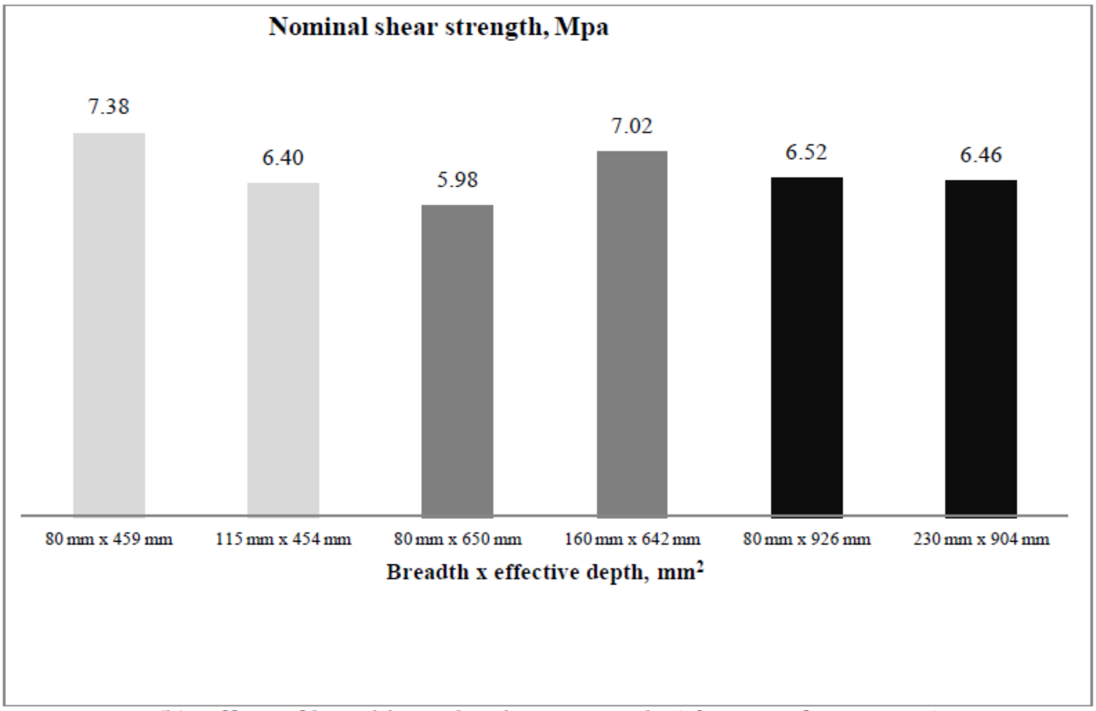
10.7. Size Effect in RC Deep Beams

Primary cause for the size effect is inappropriate adoption of the shear transfer concept subsequently; secondary cause is depends on geometry of the strut and the spacing and diameter of the web reinforcement *(Tan and Cheng 2006)*. Strut geometry and boundary conditions was postulated as influencing factors *(Zhang and Tan 2007)* Effect of breadth and depth on the shear strength is shown in Figs. 8(a) and (b). It is evident from Fig.8 (a) and (b) that beam width has no influence on the shear strength of deep beams *(Zhang and Tan 2007)* on the other hand member depth increases shear strength decreases *(Rao and Prasad, 2010)*. Ultimate load is size dependent whereas; diagonal cracking load is size independent.

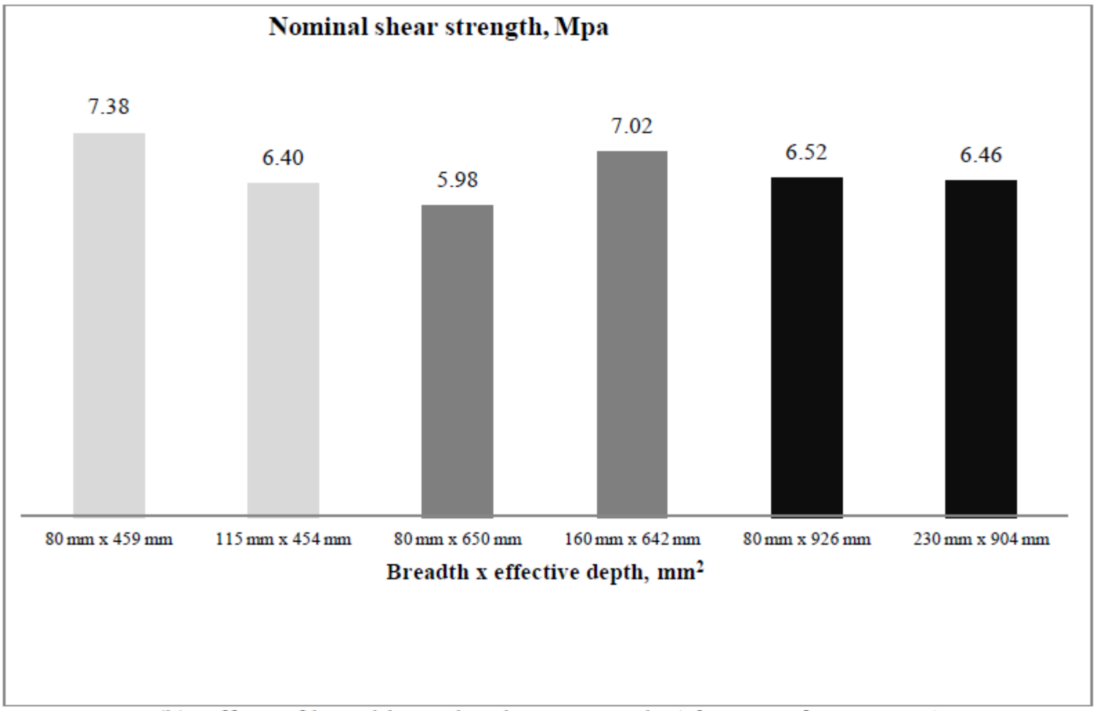
The conventional definition for shear stress Vu/bd is not appropriate because of arch action. This concept was borrowed from steel I beams with uniform shear stress distribution. Uncracked concrete depth resist the shear stress on the other hand shear transfer in the cracked potion is negligible. Randomness of material strength, interface shear transfer and unintended out of plane deflection are some of reasons stated for size effect (*Tan and Cheng 2006)*. Incorporating size-effect, models are proposed *(Rao and Sundaresan 2012, Zhang and Tan 2007, Tang et al. 2004, Rao and Sundaresan 2014 and Rao and Injaganeri 2011).*



(a) Effect of depth on the ultimate and diagonal cracking shear strength of deep beams *(Rao and Prasad 2010)*



(b) Effect of breadth on the shear strength *(Zhang and Tan 2007)*



(b) Effect of breadth on the shear strength *(Zhang and Tan 2007)*

Figure 8 Effect of size on shear strength of deep beams

10.8. Normal Strain Profile and Shear Strain Distribution of Deep Beams

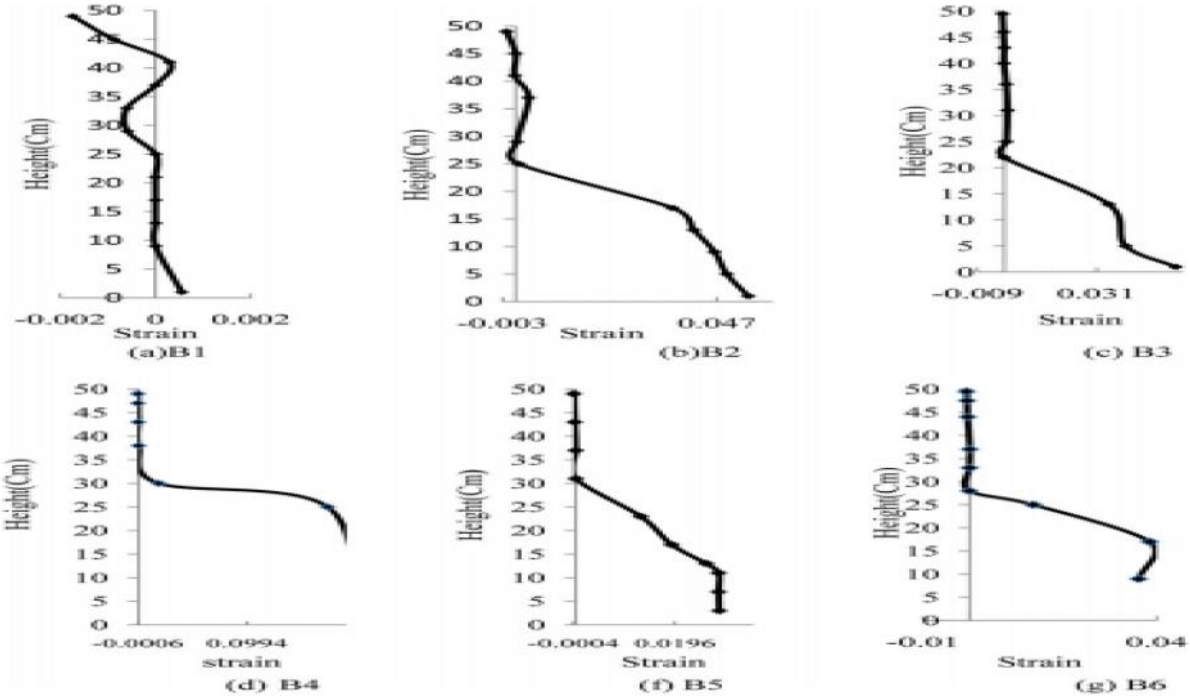


Figure 9 Normal strain profiles of reinforced concrete deep beam (Mohammadhassani et al.2012)

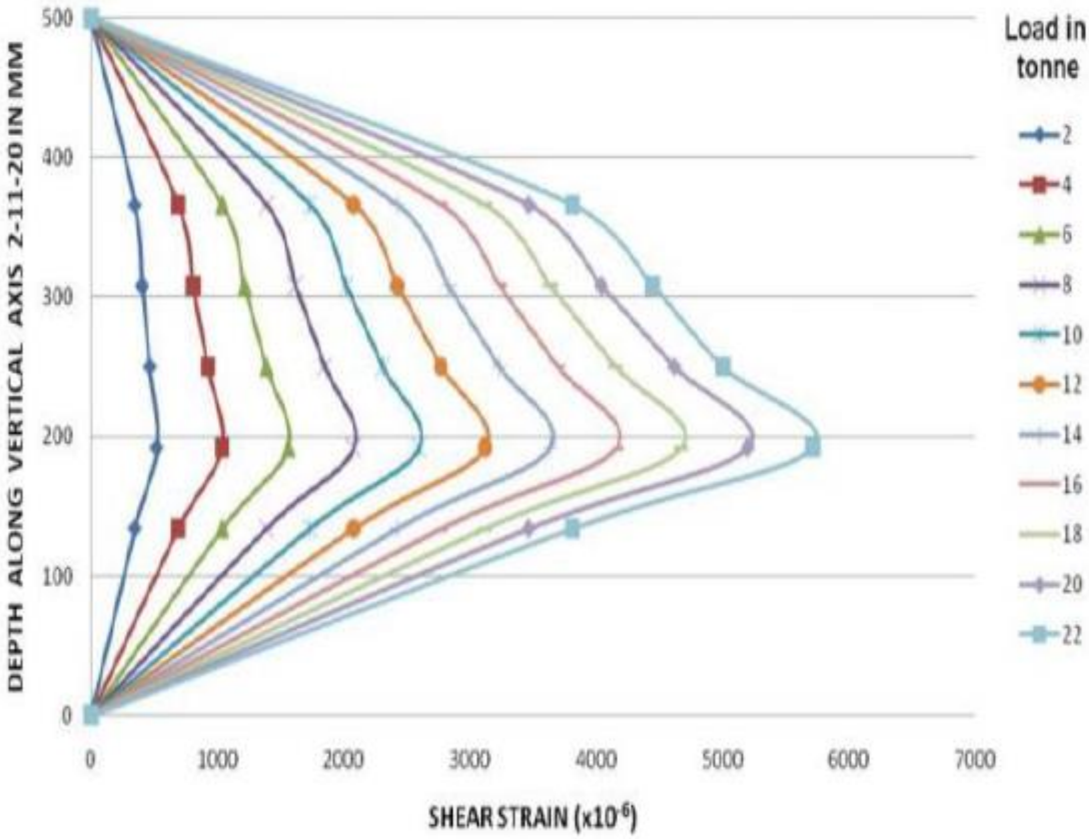
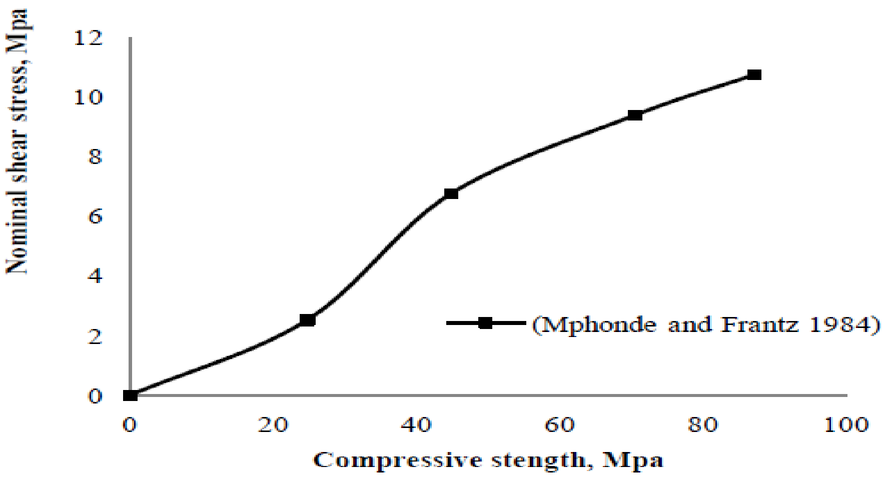


Figure 10 Shear strain vs depth vs load in tonne

Deep beams have more than one neutral axis *(Mohammad et al. 2011)*. Normal strain profiles of beams with different tension reinforcement ratios are shown in Fig.9 To equilibrate the tie forces the neutral axis is closer to the extreme compression fiber. Deep beams exhibit lower strain in the extreme compression fiber. Maximum compressive strain of high strength concrete deep beams is 0.002 *(Mohammadhassani et al. 2012)*. Shear strain distribution along the depth at different load stages level is shown in Fig.10 .Deep beams exhibit D shape shear strain profile *(Patel and Pandya 2010).* increased, shear failure mode was mixed with flexure and with high effective span-to-depth ratio flexure failure mode was predominant *(Tan et al. 1995).* When the a/d ratio tended to 2.0 change in mode of failure from shear compression to shear tension *(Shin et al. 1999).*

10.9. Effect of compressive strength of concrete



Compressive strength of concrete has a predominant role in structural strength of deep beams.

Figure 11 *Influence of compressive strength of concrete on nominal shear strength*

As show in Fig.11 compressive strength of concrete increases the nominal shear stress *(Mphonde and Frantz, 1984).* Compression softening effect (Vecchio et al. 1993) is nothing but cracked reinforced concrete in compression exhibits lower strength and stiffness than uniaxially compressed concrete. This effect influences the element strength, ductility and load-deformation curve. Parameter influencing the compression softening effect was degree of cracking that is measured by principal tensile strain. The load path, crack orientation relative to the reinforcement, crack rotation and type of reinforcing bar had no effect on the softening effect under monotonic loadings. The strength prediction of element might be overestimated if so-called compression softening effect was neglected or underestimated. Besides, the strength reduction coefficient for the main strut was found to decrease with the angle of inclination of the strut (Matamoros and Wong 2003).

10.10. Effect of Tension Reinforcement

Increase in the reinforcement ratio results in increase in ultimate load (Fig. (12), energy absorption index, number of cracks but then, decrease in ductility , length and width of the crack. Beams with high tension reinforcement ratio endure the load beyond the elastic stage with less deflection. There is no strut formation if the percentage of tension reinforcement is less than that of the code provision. On the other hand compression strut fails when the tension capacity is high (Mohammadhassani et al. 2012).

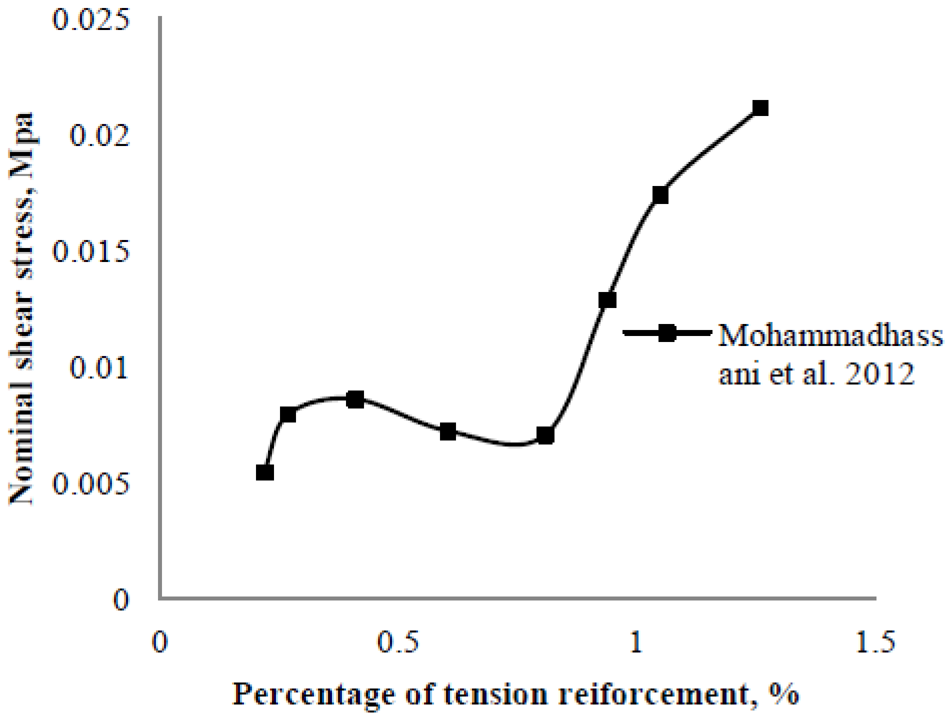


Figure 12 *effluence of percentage tension reinforcement*

10.11. Effect of web opening

Of the two shapes of web opening, the circular type is found to be more effective in transmitting the load and the diagonal cracking is well-defined. This type therefore may be recommended for provision in the design. Maximum crack width at failure will be greater when the opening centre is located at the centre of the shear zone than at any other position. So location of the opening centre at this point is undoubtedly the maximum damaging situation in the web region. The opening should not be brought too close to the vertical edge and inner and outer soffits of the beam either, because at higher loads secondary cracks might appear and cause failure ofthe beam. The strength of the beam increases when the opening is located away from what can be called the loaded quadrant to the unloaded quadrant and vice-versa (Ray and Reddy, 1979; Ray, 1980; 1982) (see Section 3.8).

Again, for openings located completely outside the shear region, the beam with a web opening may be assumed to be a solid web beam. The location of the web opening is therefore a major factor influencing the strength of the beam. It is interesting from the load-deflection characteristics that the flexibility of the beam decreases as the location of the opening is moved away from the support to the interior of the beam. This is contrary to the usual expectation. However, it should be remembered that the deflection in deep beams are substantially influenced by shear and, as such, location of the opening in the region of high shear and intercepting the critical path is understandable. The openings should invariably be provided with some loop reinforcement in their periphery to avoid possible stress concentration.

11. Analysis of deep beam

1. ELASTIC SOLUTION

Elastic solutions of reinforced concrete deep beams provide a good description of the behavior before cracking.

2. INELASTIC SOLUTION

After cracking, a major redistribution of stresses occurs and hence the beam capacity must be predicted by inelastic analysis.

Numerous classical mathematical procedure of approximation has been developed for the analysis. The methods of approximation used to solve governing differential equation can be grouped into three approaches

1. Direct Approach,
2. Weighted Residual Method
3. Finite Strip Method

11.1. Finite strip method

For a structure with constant cross section and end boundary conditions that do not change transversely, stress analysis can be performed using finite strips. The finite strip method over finite element method includes reduced computer resources and significant reduction in the time taken to model the problem. It is regarded as a special form of displacement formulation of the finite element procedure, in that it employs the minimum total potential energy therein to develop the relationship between unknown nodal displacement parameters and the applied loading. A computer program has been prepared in FORTRAN77 based on direct stiffness approach in order to design deep beams. It is clear that a computer program is necessary for solution of governing differential equation

The results are validated with manual calculations. Such program helps when several numbers of deep beams have to be designed in order to avoid laborious works of manual calculations.

12. Mode of Failure

The strength of deep beams is usually controlled by shear rather than flexure, provided a normal amount of longitudinal reinforcement is used. The shear action in the beam web leads to compression in a diagonal direction and tension in a direction perpendicular to that.

Beams is used for testing that properties is given below –

Table 1
HSSCC mix design.

Characteristic cube strength	75 MPa
Aggregate	Crushed granite and natural sand
Cement	Ordinary Portland cement
Slump of concrete	More than 650 mm
Coarse aggregate	553 kg/m^3
Fine aggregate	887 kg/m^3
Water-cement ratio	0.27
Water-binder ratio	0.25
Super plasticizer	46.0 kg/m^3
Silica fume–cement ratio	0.1

Table 2
Specifications of tested HSSCC deep beams.

Beams	f'_c (Mpa)	ρ (%)	Horizontal stirrup	Vertical stirrup	Tensile bar
B1	91.5	0.219	∅9@15 cm c/c	∅9@10 cm c/c	3∅9
B2	91.5	0.269	∅9@15 cm c/c	∅9@10 cm c/c	3∅10
B3	91.1	0.410	∅9@15 cm c/c	∅9@10 cm c/c	2∅10 + 2∅12
B4	93.7	0.604	∅9@9.5 cm c/c	∅9@10 cm c/c	2∅10 + 2∅16
B5	79.1	0.809	∅10@8 cm c/c	∅10@10 cm c/c	2∅10 + 3∅16
B6	87.5	0.938	∅10@8 cm c/c	∅10@10 cm c/c	1∅9 + 4∅16

Table 3
Bar specifications.

Bar diameter (mm)	f_y (Mpa)	f_u (Mpa)
Φ_9	353.1	446
Φ_{10}	614.4	666
Φ_{12}	621.6	678
Φ_{16}	566.3	656

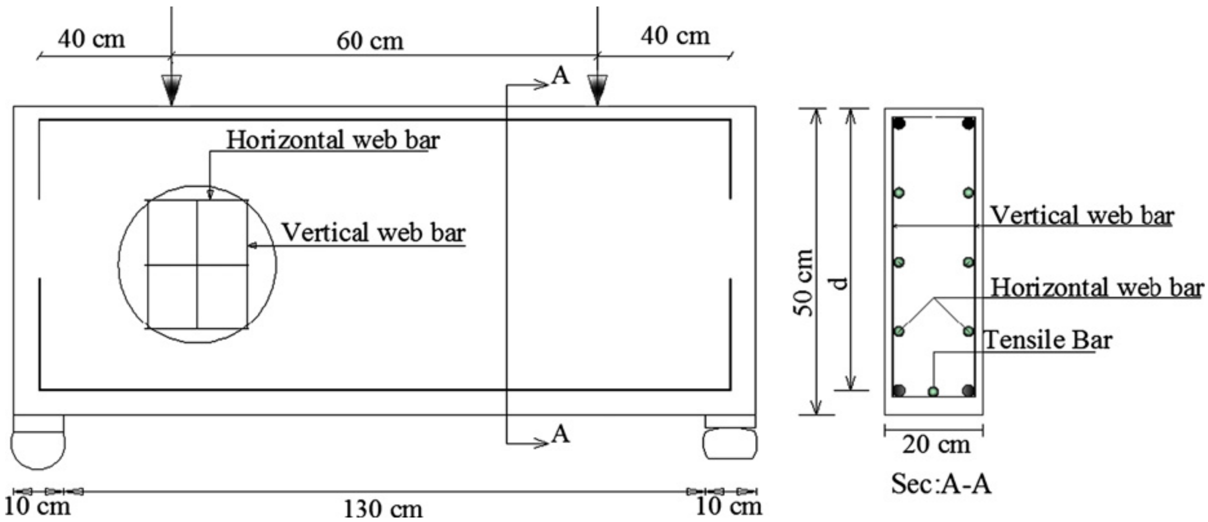


Figure 13 detail of tested beam

12.1 Failure modes of deep beam can be divided in following main categories

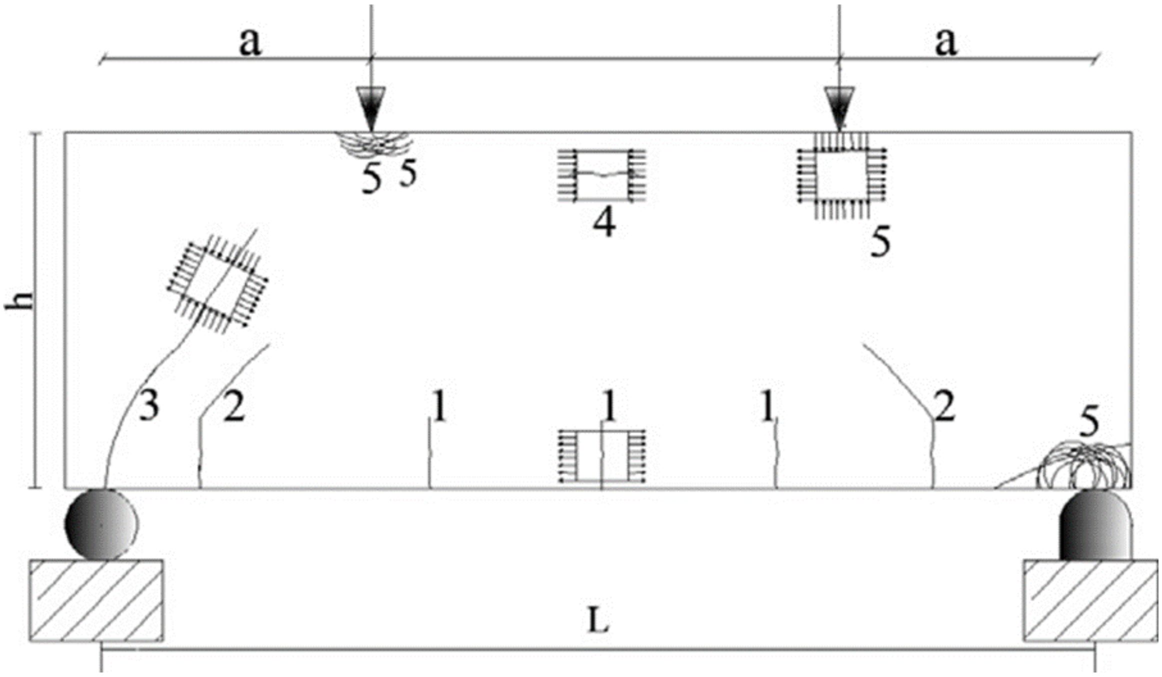


Figure 14 A Typical crack pattern of deep beams with two point loading

Fig. 14 shows the failure pattern of deep beams under study. The length and depth of beams considered for test are 130 cm and 50 cm respectively. Flexural failure is observed in pure bending zone. At compression strut trajectory the failure is pure shear by diagonal cracking. The area between compression strut and mid-span contains combined flexural and shear failure. Failure due to compression is observed at extreme compression fiber of mid-span.

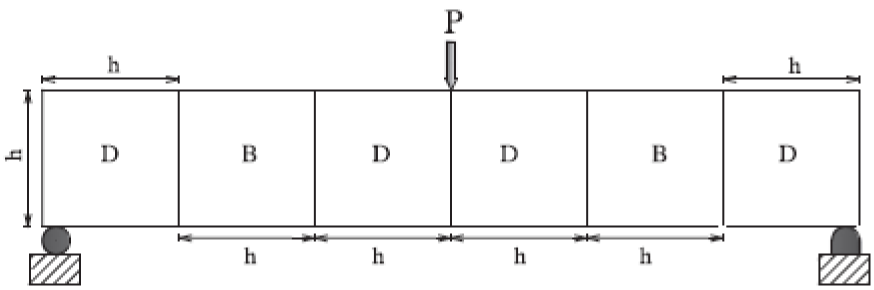


Fig. B-region and D-region.

Figure 15 B-region and D-region

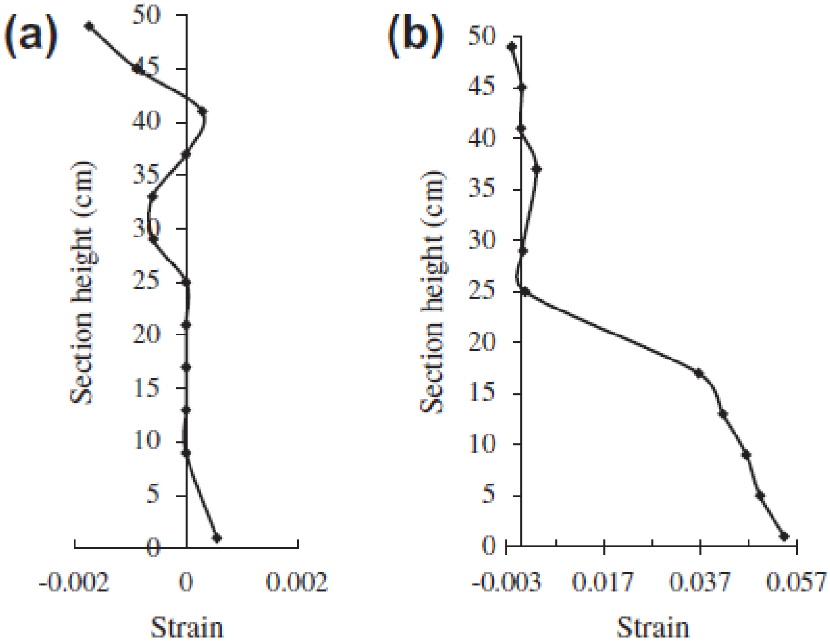


Fig. : . Strain distribution of beams: (a) B1 and (b) B2 at ultimate state.

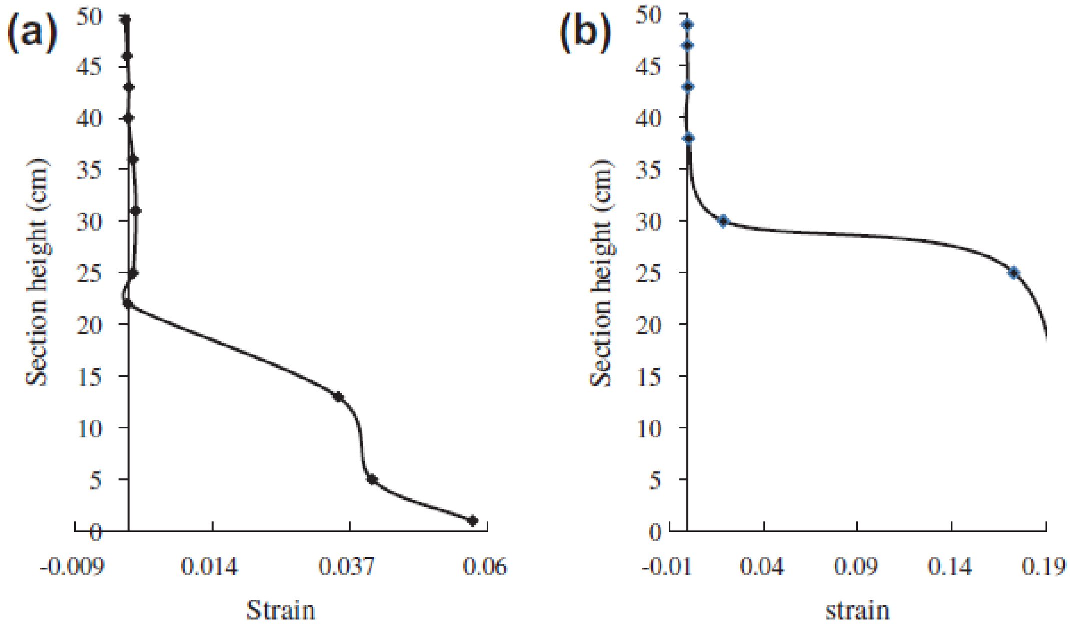


Fig. Strain distribution of beams: (a) B3 and (b) B4 at ultimate state.

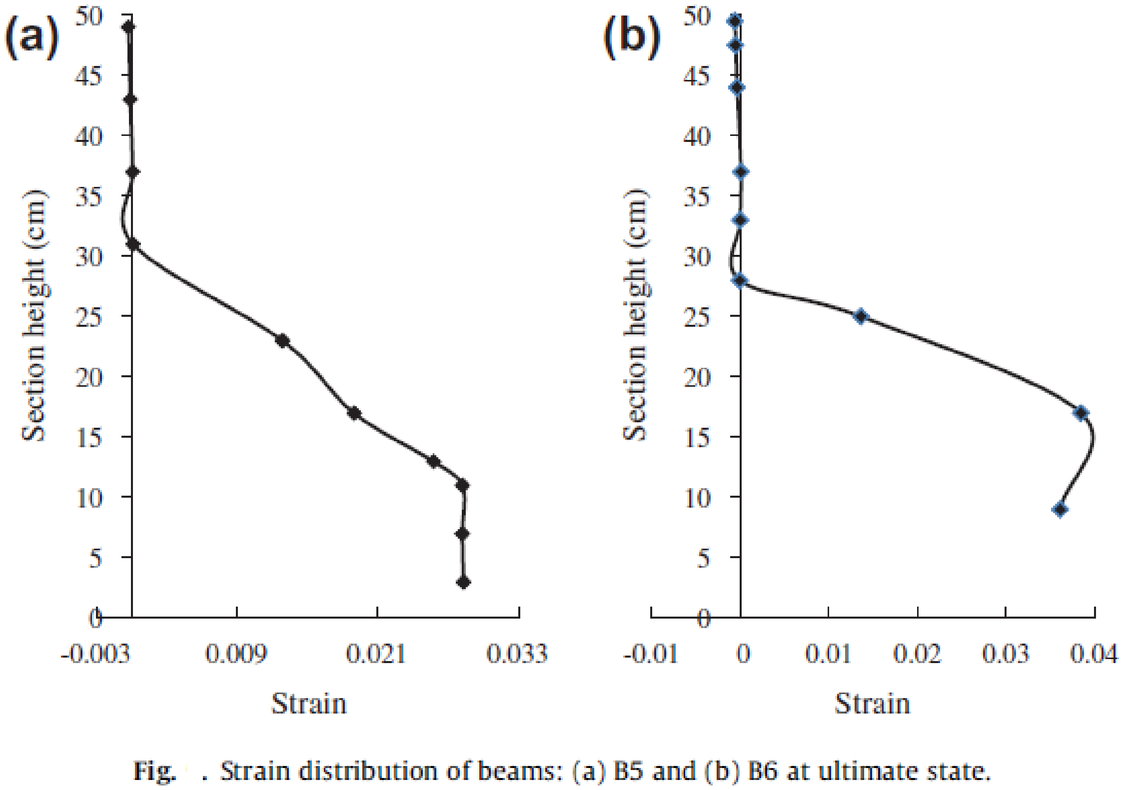


Figure 16 Strain distribution at ultimate state

Failure15 in B and D regions of deep beams Based on the structural behavior the failure modes of deep beams can be classified into two regions B and D. The B region follows Bernoulli theory in which the strain distribution is linear. In D region or Discontinuity region the strain distribution is non linear. D-regions include the area where concentrated load is applied or abrupt change in geometry occurs. According to St. Venant's principle the D-region is equal to one section depth on either side of discontinuity. Fig.16 shows B and D regions of deep beams.

12.1.1. Flexural failure mode in deep beams

Above Fig. 14 shows cracks at mid span. These are pure flexural cracks are labelled as crack type 1. These cracks appear when the tension stress exceeds tensile strength of concrete. The cracks are vertical due to the effect of horizontal tension stress in pure bending zone. The appearance of these cracks is due to inherent shortage of concrete in tension. The type 1 crack is not critical except in the case where tensile bar percentage is less than the minimum percentage suggested by codes. In case of beam B1 the used tensile bar percentage is less than ACI building code 318-83. The code states that the main steel percentage ρ shall not be less than $\rho_{min} = 200/f_y$. Thus, beam B1 failed by widening of flexural cracks as shown in Fig. 17.The failure type of this beam is flexural failure due to vertical cracks at bottom, crushing at the top and also formation of diagonal tension cracks at the end of flexural cracks. More than 50% of cracks formed are flexural/vertical cracks.

Flexural cracks at mid-span region were always vertical and within the range of 25–42% of failure load. The heights of flexural cracks were ranged between 0.24 and 0.6 of section height.

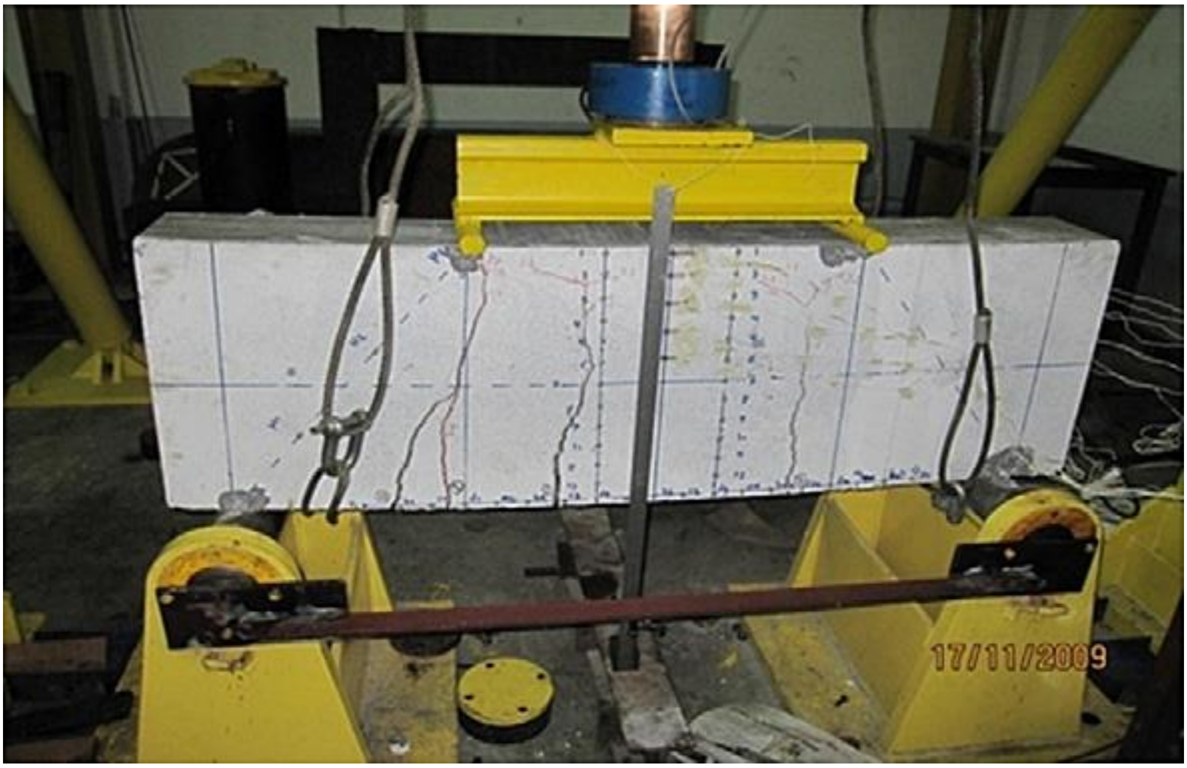


Figure 17 Crack pattern for beam B1

12.1.2. Shear failure mode in deep beams

Shear compression failure where R.C. beam fails due to the development of diagonal crack into the compressive zone and reduces the area of resisting region excessively and beam crushes once generated compressive stress exceeds compressive strength of concrete.

In deep beams, significant part of load is transferred to support directly through compression struts formed between load and support points. This mechanism of transferring load leads to the type of failure that is most common in deep beams. The deep beams fail by widening of diagonal shear cracks and crushing of concrete. These cracks are schematically shown in Fig.14 as type 3. As shown in Figs.18,19& 20 the failure of beams B2, B3 and B4 is initiated by diagonal cracks which appear along compression strut trajectories from support to load points. These types of cracks appear only between load and support points. It has an angle of Ɵ=Tan¯ (d/a), where d is effective depth and is shear span .In all cases of tested beams the load corresponding to inclined cracks is in close proximity. Appearance of these cracks is independent of tensile bar or web bar percentages. It depends on concrete compressive strength.

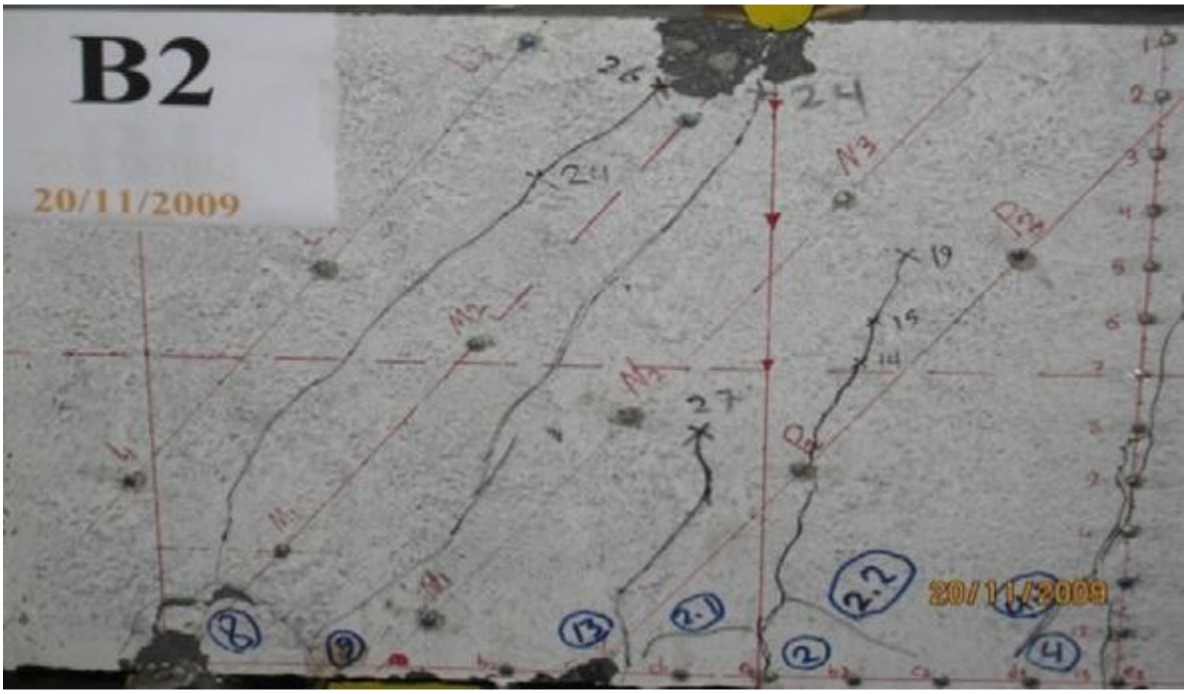


Figure 18 crack pattern for B2

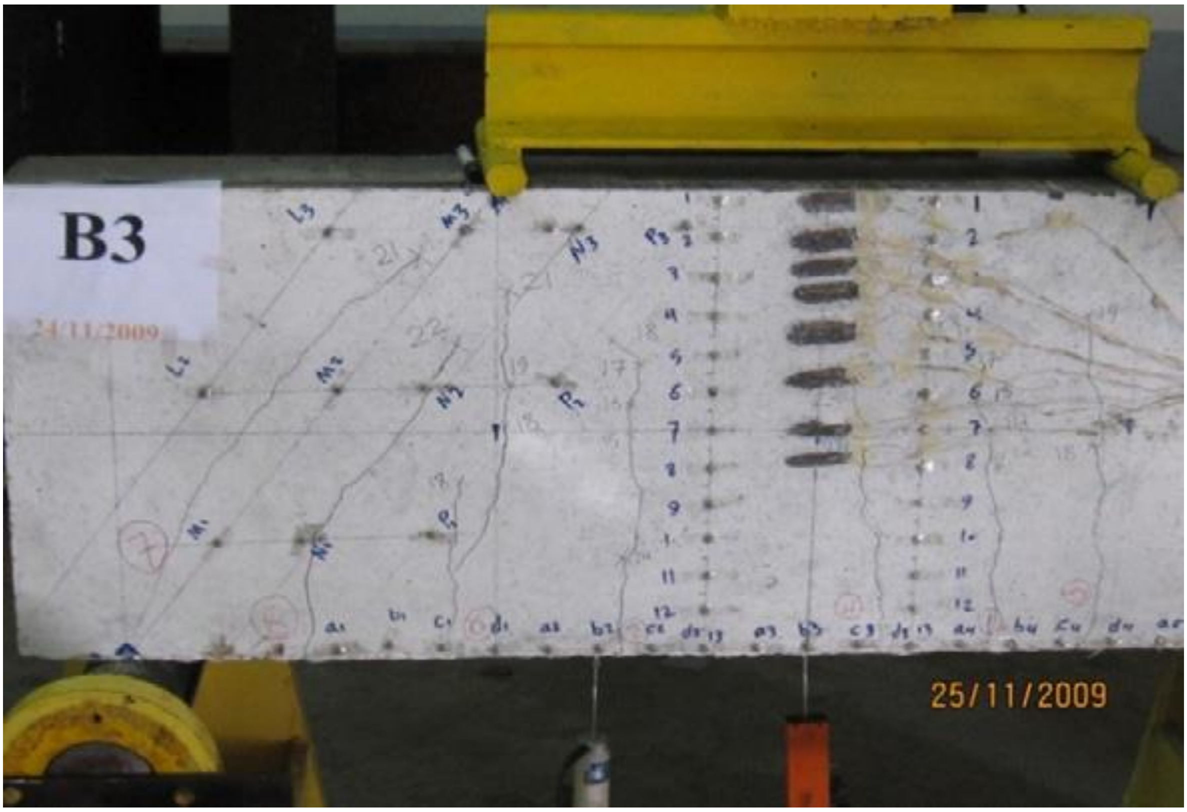


Figure 19 crack pattern for B3

Figure 20 crack pattern for B4

12.1.3. ***combined flexural and shear failure in deep beams***

Type 2 in Fig 14 cracks are the combined flexural and shear cracks. It can be observed from Fig.21 a that upon increasing the load, inclined cracks appear at the end of vertical cracks. These cracks are directed towards the load points. These cracks seldom appear as failure crack at ultimate load. The failure of beam B5 is shown in Fig.21 It shows that diagonal crack appears perpendicular to the strut compression trajectory which causes failing of support. Diagonal cracks rarely develop within the exterior shear span, only beam B5 shows two diagonal cracks in this region. After emergence of these cracks at support, the beam abruptly fails in shear. Combined shear and flexural cracks appear within 25% of pure bending zone from load point to center of beam.

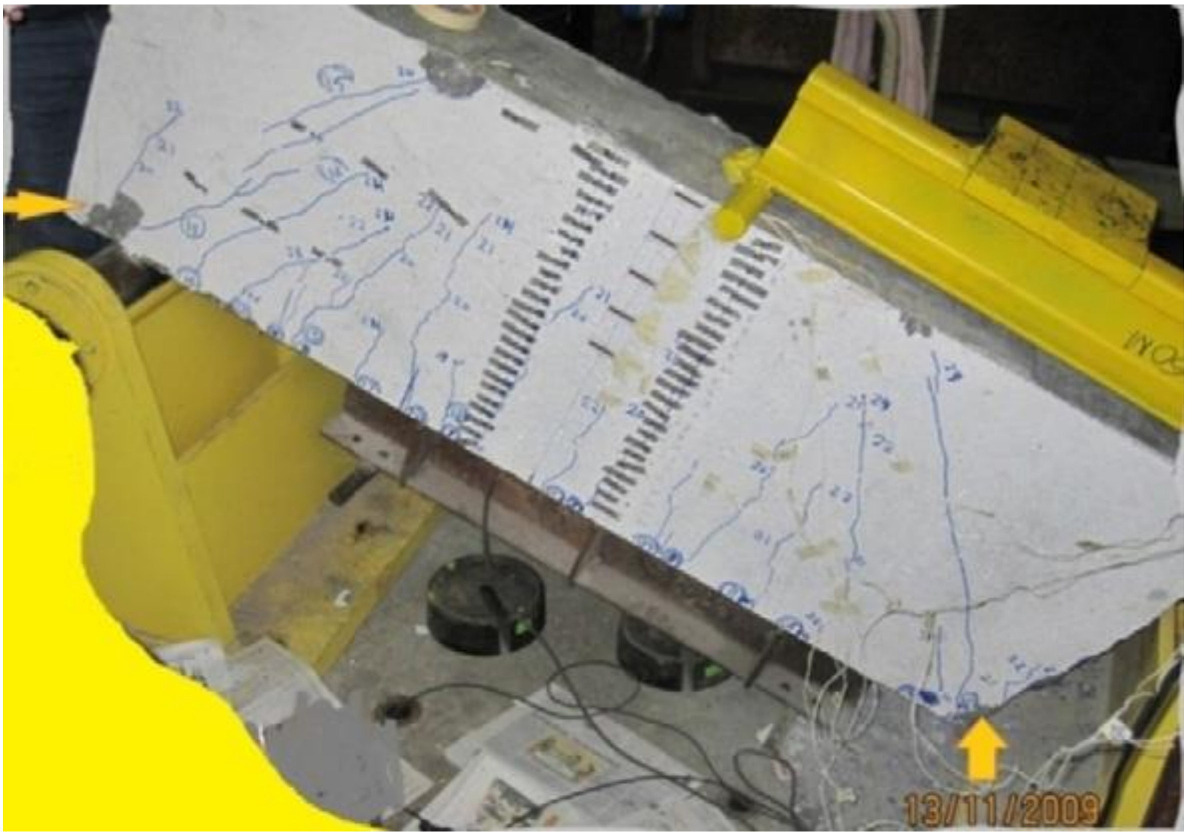


Figure 21 Crack pattern for beam B5

12.1.4. Local failure of deep beams

Failure due to crushing of concrete over supports or under concentrated load points due to insufficient resistance is called the local failure. Anchorage failure results from insufficient anchorage length or splitting of concrete above the upright bend of the tensile steel.

Fig. 14 also shows local failure at support and load points. This failure is denoted as type 5. It is due to high compressive stress occurring in the area around load and support. Failure of beam

B6 happened at by widening of two diagonal cracks and crushing of concrete at support point as shown in Figs.19&20. This type of failure is also observed in beams B3 and B4. To overcome this failure mode the high compressive stress should be distributed over an area using bearing plates at support and load points. This failure is recognized as a premature failure which is not desirable. It occurs when the stress exceeds the allowable compression stress of concrete. The crushing of concrete by settling of support or load points causes high redistribution of internal forces.

12.1.5. Compression failure of deep beams

The other possible failure mode in deep beams is explosion of concrete in compression zone. It happens when the strain in compression zone exceeds the ultimate strain. This type of failure is labelled by type 5 in Fig. 14. This failure pattern is rare because concrete in compression may not reach the ultimate strain due to the beam height. In all tested HSSCC deep beams, the highest strain in extreme compression fiber was recorded as 0.002. Occurrence of this phenomenon is in accordance with the plasticity theory which assumes the yielding of all steel reinforcement before compression failure. In this case the failure capacity of tensile reinforcement is higher compared with compression area.

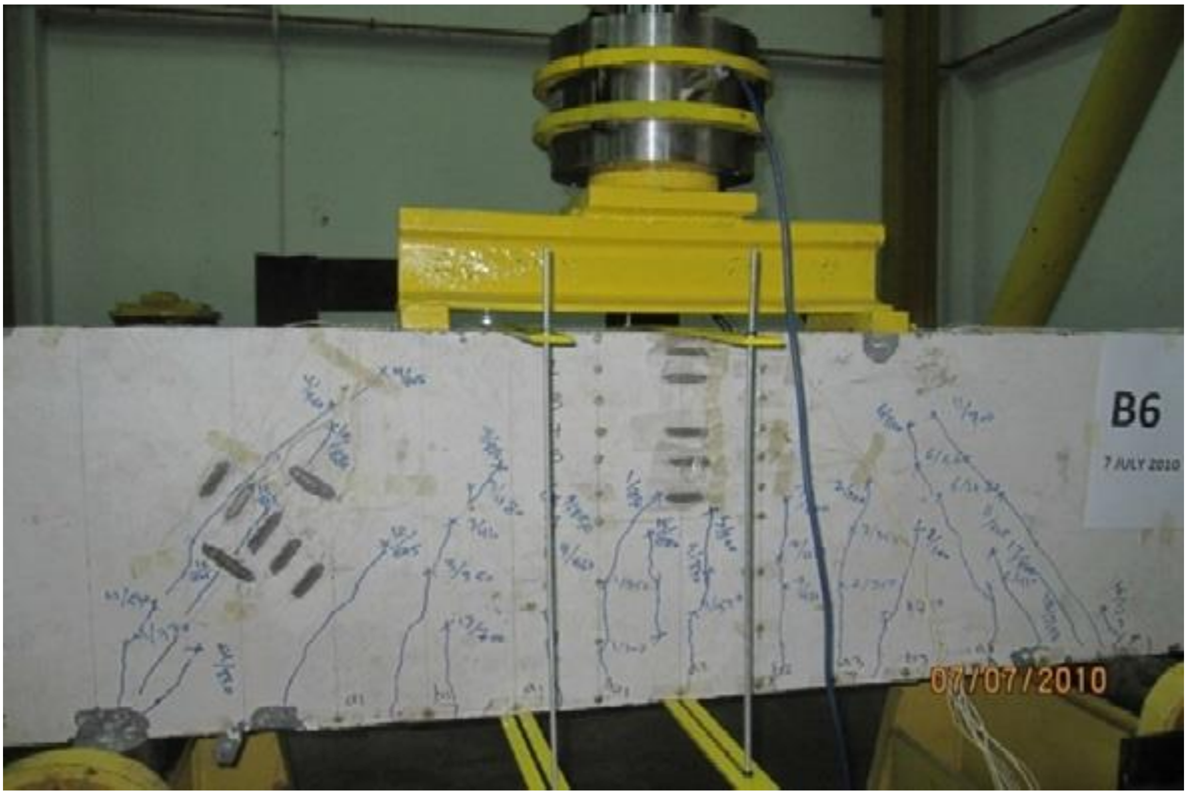


Figure 22 crack pattern B6

13. Comparison of different country codes as per crack pattern developed

13.1. As per IS 456-2000

The beam was designed by IS-456-2000 code provisions having dimensions L=700 mm, D=400 mm. B=150 mm and the two point loading were applied to the given beam Two point loads of 50 KN were applied on the beam. The initial cracking was observed at 200 KN load at point of support of bearing at top and the maximum cracking pattern was observed in the middle and diagonal portion of the beam after 250 KN. After that application of loading was stopped at 335KN. The cracking pattern of the deep beam was observed is as shown in Fig.23

Figure 23 As per IS 456 crack pattern

13.2. As per ACI-318 (Strut and Tie method)

The beam was designed by Appendix A of ACI-318 (STRUT AND TIE METHOD) having dimensions L=700 mm, D=400 mm. B=150 mm and the two point loading was applied to the given beam. Two point loads of 50 KN were applied on the beam. The initial cracking was observed at 230 KN at the point of support of bearing, and the cracking pattern was observed in the middle and diagonal portion of the beam at 300 KN. After that application of loading was stopped at 430 KN where maximum crack pattern was observed. The cracking pattern of the deep beam was observed is as shown in Fig.24.

Figure 24 As per ACI 318 crack pattern

13.3. As per New Zealand code

The beam was designed by NEWZEALAND CODE having dimensions L=700 mm, D=400 mm. B=150 mm and the two point loading were applied to the given beam. Two point loads of 50 KN were applied on the beam. The initial cracking was observed at 180 KN at the point of support of bearing, and the cracking pattern was observed in the middle and diagonal portion of the beam at 300 KN. After that application of loading was stopped at 440KN where maximum crack pattern was observed. The cracking pattern of the deep beam was observed is as shown in Fig. 25.

Figure 25 As per New Zealand code crack pattern

13.4. As per Canadian code

The beam was designed by CANADIAN CODE having dimensions L=700 mm, D=400 mm. B=150 mm and the two point loading was applied to the given beam. Two point loads of 50 KN were applied on the beam. The initial cracking was observed at 170 KN at the point of support of bearing, and the cracking pattern was observed in the middle and diagonal portion of the beam at 300 KN. After that application of loading was stopped at 360 KN where maximum crack pattern was observed. The cracking pattern of the deep beam was observed is as shown in Fig.26.

Figure 26 *As per Canadian code crack pattern*

13.5. As per Ciria Guide-2

The dimensions of the deep beam designed by CIRIA GUIDE-2 was L=700 mm, D=400 mm. B=150 mm and the two point loading is applied to the given beam. Two point loads of 50 KN were applied on the beam. The initial cracking was observed at 180 KN load at point of support of bearing at top, and the cracking pattern was observed in the middle and diagonal portion of the beam aftert250 KN. After that application of loading was stopped where the maximum cracks were observed at 315 KN. The cracking pattern of the deep beam was observed is as shown in Fig.27

Figure 27 As per Ciria Guide-2 crack pattern

13.6. Comparison of various parameter as per different country codes

The below 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.**

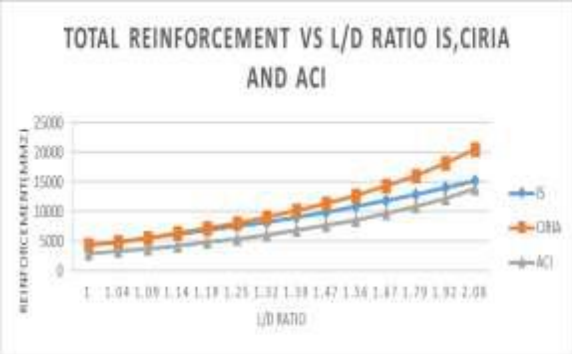
1. Moment and Shear constant for a 5m deep beam

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 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.

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.

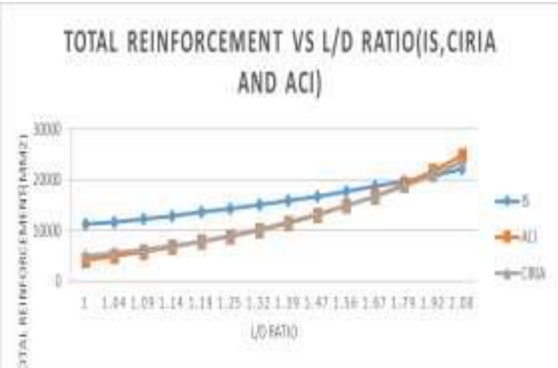
The plot of ACI and IS shows consistent and similar behavior whereas the CIRIA plot gives higher values of steel at higher values of moment.

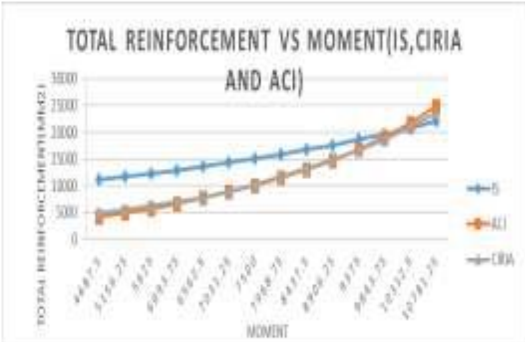

TOTAL REINFORCEMENT VS L/D RATIO IS,CIRIA AND ACI
REINFORCEMENT(MM2)
L/D RATIO
IS
CIRIA
ACI

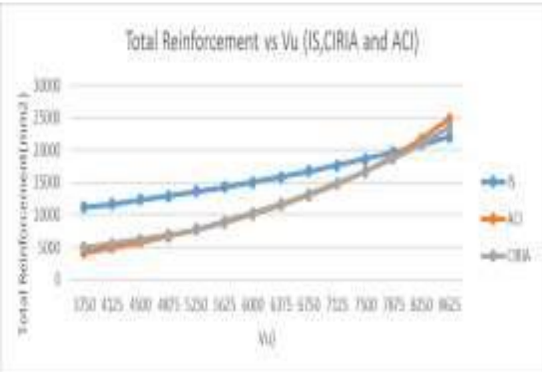

IS ,ACI,CIRIA SHEAR REINFORCEMENT VS L/D RATIO
SHEAR REINFORCEMENT(MM2)
L/D RATIO
IS
CIRIA
ACI


SHEAR REINFORCEMENT VS MU(IS,CIRIA AND ACI)
SHEAR REINFORCEMENT(MM2)
MU
CIRIA
ACI
IS


Shear Reinforcement Vs Vu(IS CIRIA and ACI)
Shear Reinforcement(mm2)
Shear
CIRIA
ACI
IS


TOTAL REINFORCEMENT VS L/D RATIO(IS,CIRIA AND ACI)
TOTAL REINFORCEMENT(MM2)
L/D RATIO
IS
ACI
CIRIA

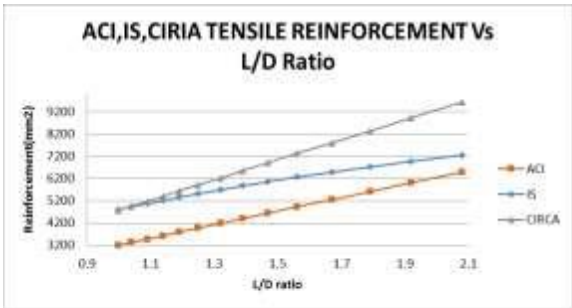

TOTAL REINFORCEMENT VS MOMENT(IS,CIRIA AND ACI)
TOTAL REINFORCEMENT(MM2)
MOMENT
IS
ACI
CIRIA

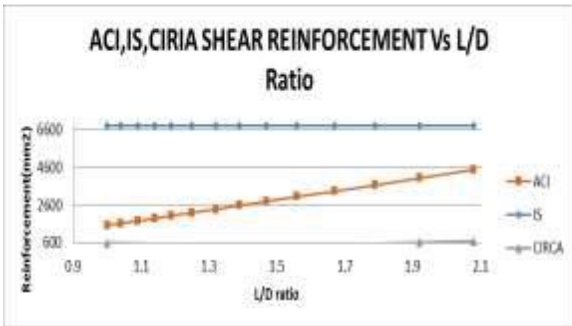

Total Reinforcement vs Vu (IS,CIRIA and ACI)
Total Reinforcement(mm2)
Vu
IS
ACI
CIRIA

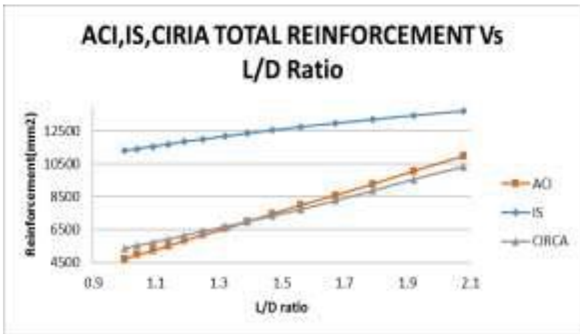

REINFORCEMENT VS VU IS,CIRIA AND ACI
REINFORCEMENT(MM2)
SHEAR
IS
CIRIA
ACI

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

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

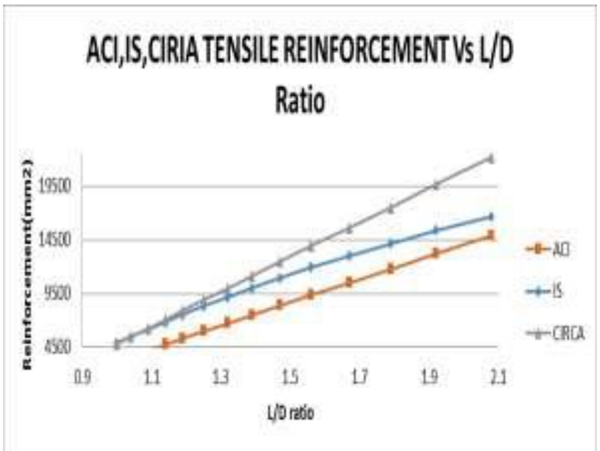


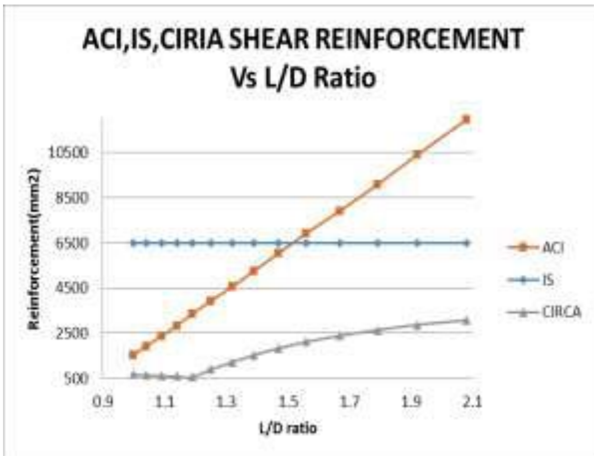


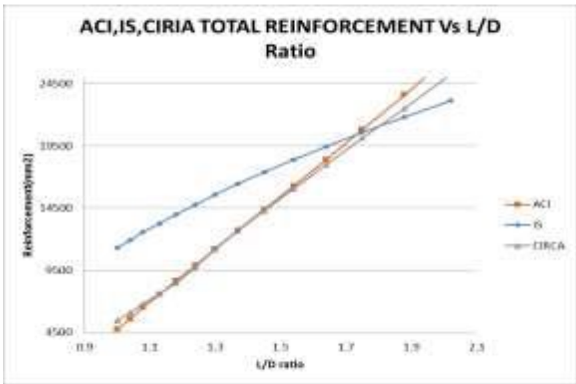


4. Moment and Shear variable for a 4.5 M deep beam:

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

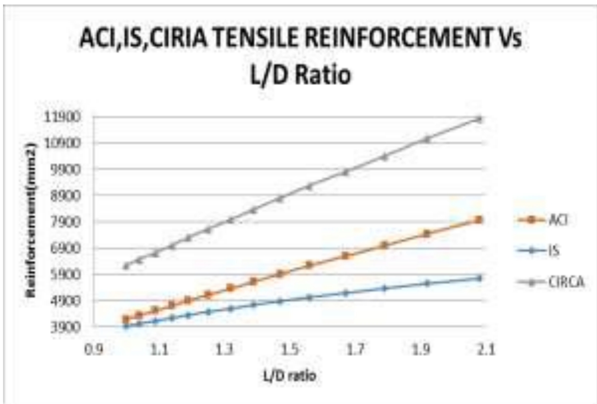


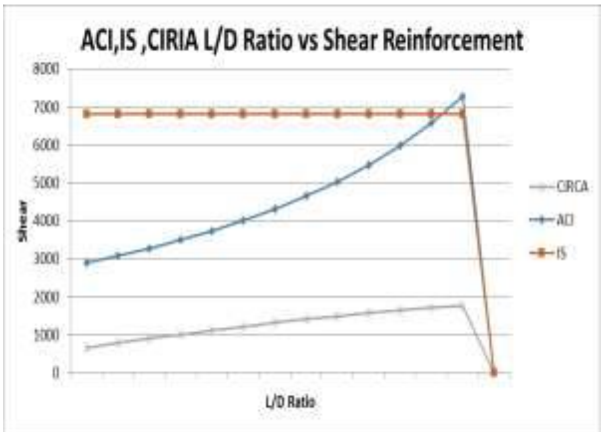




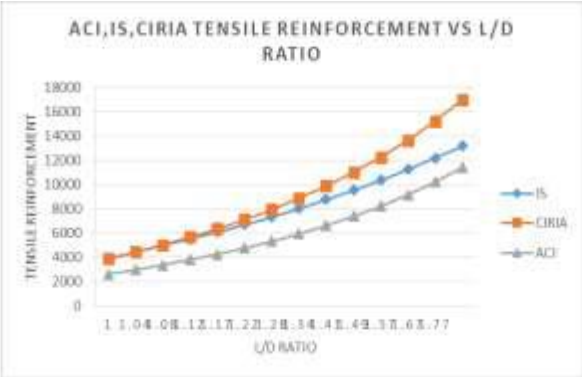
5. Moment and Shear constant for a 5.5 M deep beam**:**

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





6. Moment and Shear variable for 5.5 m deep beam:



DESIGN EXAMPLE OF DEEP BEAMS WITH DIFFERENT COUNTRY CODES

Deep beams are designed and cast for Two Point Loading and for two shear spans viz. 200 mm and 250 mm. In total eighteen deep beams were designed and cast. Point loads of 50 kN are applied on deep beams for design purpose. Dimensions of deep beams chosen for design purpose are, Length = 700 mm, Depth = 325 mm and Thickness = 150 mm. A 30 mm clear cover is provided all around the reinforcement cage. M20 grade concrete and Fe 550 steel was used for casting of deep beams with simple support condition. The Reinforcement Schedule is shown in Table

Design of deep beams is done by following codal provisions:

1. Design by using I. S. 456-2000 method
2. Design by using B. S. 8110-2005 method
3. Design by using A. C. I. 318-2005 method

The important steps used in the design of R.C. deep beams are as follow:

1. Determine whether the given beam is deep according to the definition or not.
2. Check its thickness with respect to buckling as well as its capacity to carry the major part of the shear force by the concrete itself.
3. Design for flexure.
4. Design for minimum web steel and its distribution in the beam.
5. Design for shear. If the web steel already provided is inadequate, design additional steel for shear requirements.
6. Check safety of supports and loading points for local failure.
7. If the beams are not top loaded, design the special features required for deep beam action under the special loading conditions.
8. Detail the reinforcements according to accepted practice.

Table 1 Reinforcement Schedule

Code used for Design of Deep Beam		I. S. 456:2000		B. S. 8110-05		A. C. I. (318)-05	
Identification Mark		a-1	a-2	b-1	b-2	c-1	c-2
Total No. of samples of Deep beams		03	03	03	03	03	03
Shear Span (mm)		200	250	200	250	200	250
Shear span to depth ratio		0.62	0.77	0.62	0.77	0.62	0.77
Sr. No.	**Type of reinforcement**	**Spacing and No. of bars**					
1	Horizontal Main steel	3-8 mm Φ	1- 10 mm Φ & 2-8 mm Φ	3-8 mm Φ	1- 10 mm Φ & 2-8 mm Φ	3-8 mm Φ	1- 10 mm Φ & 2-8 mm Φ
2	Side Face Reinforcement a) Vertical Steel	5-Two legged 6 mm dia. stirrups @ 165 mm c/c	5-Two legged 6 mm dia. stirrups @ 165 mm c/c	4-Two legged 6 mm dia. stirrups @ 220 mm c/c	4-Two legged 6 mm dia. stirrups @ 220 mm c/c	6-Two legged 6 mm dia. stirrups @ 130 mm c/c	6-Two legged 6 mm dia. stirrups @ 130 mm c/c
	b) Horizontal Steel (in central zone)	3-Two legged 6 mm dia. stirrups @ 70 mm c/c	3-Two legged 6 mm dia. stirrups @ 70 mm c/c	3-Two legged 6 mm dia. stirrups @ 70 mm c/c	3-Two legged 6 mm dia. stirrups @ 70 mm c/c	2-Two legged 6 mm dia. stirrups @ 90 mm c/c	2-Two legged 6 mm dia. stirrups @ 90 mm c/c

After analysis and design was over, casting of deep beams was done. In all eighteen deep beams were cast (for 200 mm shear span and for 250 mm shear span) , nine samples each by three design methods viz. I. S. 456-2000, B. S. 8110-05 and A. C. I. -318-05. Three samples for each shear span were cast. Before actual casting, various ingredients of concrete such as cement, sand and aggregate were tested in Laboratory. Reinforcement mesh as shown in Figure, for every deep beam was kept ready according to individual designs. Formwork for casting deep beams of required dimensions as mentioned above is kept ready. For M 20 grade concreting, weigh batching is adopted. After casting curing has been done for next 28 days. The concrete cubes and steel bars are tested to assure material quality and stipulated strength. There is a controversy that the web reinforcement makes significant contribution to the maximum load carrying capacity. There are no unique guide lines for provision of web reinforcement.

Table Average Test Results

Case No.		Case 1			Case 2		
Design Method		**I.S.456**	**B.S.8110**	**ACI 318**	**I.S.456**	**B.S.8110**	**ACI 318**
Shear span (mm)		200	200	200	250	250	250
Shear span to depth ratio		0.62	0.62	0.62	0.77	0.77	0.77
Reinforcement Provided (No. of bars)	Flexural Steel Required in mm^2	126.14	146.25	126.14	157.41	157.42	157.95
	Flexural Steel						
	i) 10 mm Φ				1	1	1
	ii) 08 mm Φ	3	3	3	2	2	2
	iii) Area (mm^2)	150.73	150.73	150.73	179.02	179.02	179.02
	Shear Required (mm^2) Vertical	110.625	113.04	110.625	73.125	113.04	110.625
	Horizontal	66.375	84.78	66.375	121.875	84.78	66.375
	6 mm dia. Vertical	6	4	6	5	4	6
	Horizontal	2	3	2	3	3	2
Average Load at first crack	Total	390 kN	370 kN	430 kN	370 kN	360 kN	420 kN
	Each Point load	195 kN	195 kN	215 kN	185 kN	180 kN	210 kN
Average Failure Load	**Total**	**1000 kN**	**970 kN**	**1000 kN**	**950 kN**	**960 kN**	**970 kN**
	Each Point load	500 kN	485 kN	500 kN	475 kN	480 kN	500 kN
Average Deflection at failure	**Total**	**3.43 mm**	**3.32 mm**	**3.56 mm**	**3.49 mm**	**3.75 mm**	**3.65 mm**
	Permissible deflection	2.4 mm	2.4 mm	2.4 mm	2.4 mm	2.4 mm	2.4 mm
	Deflection at 500 kN load	2.19 mm	2.59 mm	2.19 mm	2.13 mm	2.22 mm	2.16 mm
Observed mode of failure		**ModeII3**	**Mode II3**	**Mode II3**	**Mode II3**	**Mode II3**	**Mode II3**

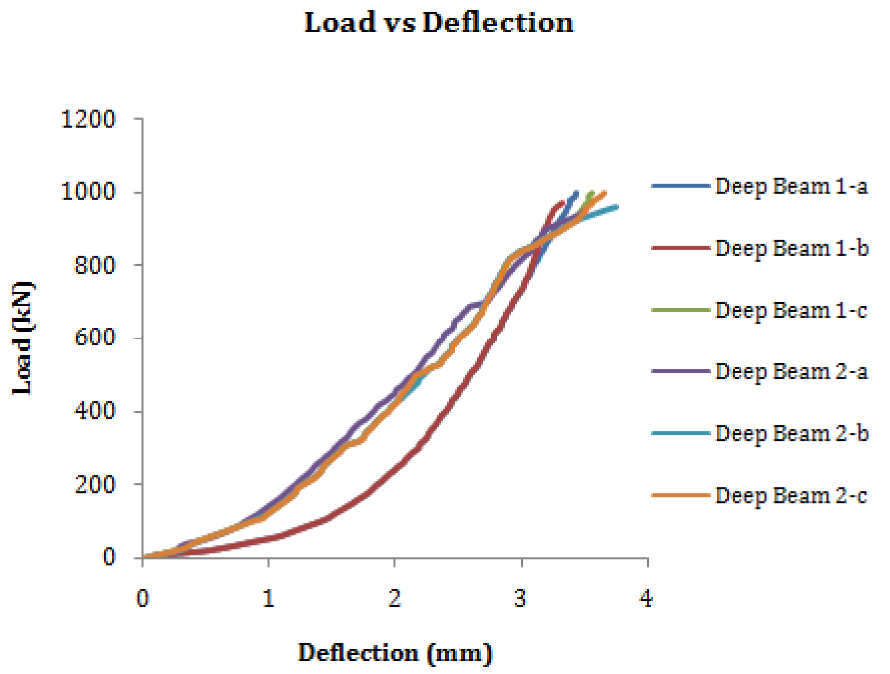


Figure 28 *Load vs Deflection*

14. Result & conclusion

1. The modes of failure in reinforced concrete deep beam are influenced by the beam size and the percentage of shear reinforcement. However, as the depth of beam and amount of web reinforcement increase the failure seems to be due to shear-compression failure.
2. Increase in shear reinforcement increases the ultimate shear strength of RC beams. However, in larger size beams, at a given shear reinforcement large size beams exhibit less strength and fail in a brittle manner.
3. As the depth of beam increases, the crack width also increases. However, with increase in amount of shear reinforcement, the crack width decreases.
4. The shear ductility of RC deep beams increases as the shear reinforcement increases. The increase is significant in beams with shear reinforcement index greater than 0.6.
5. The stress and strain distribution in deep beam is nonlinear. The number of neutral axis depth at ultimate load is one, while there are more than one neutral axes before ultimate failure.
6. The flexural crack in deep beam is not critical except in the case where tensile bar percentage is less than the minimum suggested by codes. Flexural crack in mid-span region were always vertical and within the range of 25–42% of failure load. The heights of flexural cracks were ranged between 0.24 and 0.6 of section height.
7. Shear and diagonal cracks appear between 46% and 92% of failure load. In all cases of tested beams the load corresponding to inclined cracks is in close proximity. Appearance of these cracks is independent of tensile bar or web bar percentages. It depends on concrete compressive strength.
8. Emergence of combined shear and flexural cracks at support perpendicular to compression strut trajectory causes abrupt shear failure. These cracks appear within 25% of pure bending zone from load point to centre of beam.
9. As tensile bar percentage increases the energy absorption capacity increases in all beams. The increase in tensile bar percentage also increases number of cracks having lesser crack widths.
10. For over reinforced beam with high-strength reinforcement the section may not reach its yield point thus leading to local compressive failure in concrete strut.
11. 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.

12. 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.
13. 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.
14. 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.
15. 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.
16. 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.
17. 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.
18. 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.
19. Significantly influencing parameters are shear span-to-depth ratio, horizontal web reinforcement, vertical web reinforcement, support and load bearing plates, distribution of web reinforcement along depth, compressive strength and tension reinforcement. Least influencing parameters are width of the beam, bottom cover, side cover, aggregate size and distribution of vertical stirrups in web.
20. The cracks pattern and failure mechanisms for deep beams reinforced with high strength reinforcement were similar to those deep beams with normal strength reinforcing steel. Minimum flexural steel requirement of B. S. 8110-05 as well as A. C. I.-318-05 is more than I.S. 456-2000. (The lever arm of A. C. I.-318 -05 is more by 6% that of B. S. 8110-05 & I. S. 456- 2000) The flexural steel required of all three cases is nearly same.
21. The flexural steel required by Finite strip method is approximately 10% less than all three cases. The vertical web reinforcement required by A.C.I.-318-05 code is approximately 40 % more than I. S. 456-2000 and horizontal web reinforcement required by A.C. I. -318-05 code

is approximately 40 % less than I. S. 456-2000. The strength of beams with 250 mm shear span is less than that of 200 mm shear span which means the strength of deep beam is inversely proportional to the shear span for the constant depth of the beam.

22. The average failure load of A. C. I. -318-05 code is approximately 10 % more than B. S. 8110 -05 as well as I. S. 456-2000. No separate checking for shear is specified in I. S. 456-2000. It is assumed that the arching action of the main tension steel & the web steel together with concrete will carry the shear. All deep beams had low deflection at failure as there was no flexural failure. As reported by F. K. Kong the shear strength of deep beams is 2 to 3 times greater than that given by usual equations. But in this case due to use of high strength reinforcement the shear strength of deep beam is found 6 times greater than design loads.

23. As per the code provisions of different countries it was observed that, As L/D ratio decreases there is an increase in the flexural steel of the deep beams has been observed, L/D ratio is inversely proportional to flexural steel of the beam.

24. It was observed that the vertical steel required in the deep beam as per the provisions given in APPENDIX-A OF ACI-318 (Strut and Tie method) is more by 50 % in the NEWZEALAND code, 62.5 % more in the CANADIAN, 62.5 % in the CIRIA GUIDE-2 (1977) and 50 % in the IS 456-2000 code provisions.

25. From the study of the different codes it was observed that as the L/D ratio increases the lever arm decreases.

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