The Seybold REPORT

ISSN 1533-9211

DOI: 10.5281/zenodo.8351042

EXPERIMENTAL STUDY OF COMPRESSION REINFORCEMENT ON DOUBLY REINFORCED BEAM

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Abstract

Reinforced concrete (RC) is one of the most widely used building materials in the world. Civil engineering structures mostly utilize components constructed of RC in a variety of shapes and sizes. Reinforcing steel and concrete work together resist compression and tension, (tension and compression) respectively, in reinforced concrete; the reinforcing bar, however, also resists shear, tensile, and compressive stresses. Cross-sectional area of plain cement concrete is taken into account while performing analysis by any software; however reinforcement bar area is not taken into account. The aim of the study is to check behaviour of change in vary compression and tension reinforcement of the doubly reinforced beam from minimum to maximum as suggested in per IS456:2000 from minimum to maximum. Towards that experimentation designed with the experimental program consists of testing of 90 beams with varying depth and tension reinforcement with compression reinforcement (Model size 150mmX200mmX1500mm, 150mmX300mmX1500mm, 150X400X1500mm). The study focused on refers to effect of variation in compression reinforcement.

Keywords: Reinforced Concrete, Deflection, Indeterminate Structure, Compression Reinforcement, Tension Reinforcement.

1. INTRODUCTION

Concrete has a minimal tensile strength and very strong compressive strength. Therefore, steel reinforcement is used on the tensile side of concrete known as singly reinforced beam. Therefore, singly reinforced beams are good in both compression and tension because they are strengthened on the tensile face. These beams do; however, each have a specific width, depth, and grade of concrete and steel that determines their unique limiting moments of resistance. When a section is used as a singly reinforced section and is bent at a moment greater than its limiting moment of resistance, a problem occurs. There are two ways to solve the problem such problems. Firstly, we can increase the depth of the beam, which may not be feasible in many situations. In such cases, it is possible to increase both the compressive and tensile forces of the beam by providing steel reinforcement in compression face and additional reinforcement in tension face of the beam without increasing the depth known as doubly reinforced beams.

Concrete has a very high compressive strength but relatively little tensile strength. As a result, the singly reinforced beam, which is the tensile side of concrete, uses steel reinforcement. Because they are strengthened on the tensile face, singly reinforced beams are good in both compression and tension. However, the precise width, depth, and steel and concrete grades used in each of these beams defines their own limiting moments of resistance. An issue arises when a section is bent at a moment larger than its limiting moment of resistance while being used as a single reinforced section. The problem can be resolved in two different ways. First, we can increase the beam's depth, which might not always be possible. By adding steel reinforcement to the compression face and extra reinforcement to the tension face of the beam in such situations—a process known as doubly reinforcing beams—the compressive and tensile forces of the beam can be increased.

When a beam's cross-section is constrained due to architectural or other concerns, the doubly reinforced concrete beam design is necessary. Because of this, the concrete is unable to generate the compression force necessary to withstand the current bending moment. In such a case, steel bars are added to the beam's compression zone to improve it at compression. Therefore, a beam reinforced on both the faces i.e., with tension steel and compression steel is called a doubly reinforced concrete beam. For the same cross-section, steel grade, and concrete, the moment of resistance (MR) of a doubly reinforced concrete beam is higher than that of a singly reinforced concrete beam. However, since the strength approach of design, which takes into consideration the complete strength-potential of concrete in the compression zone, has become more widely used, the use of compression reinforcement has significantly dropped. Compression reinforcement can, however, be utilized for purposes other than strength, such as reducing long-term beam deflection, accounting for minimum-moment loads, and maintaining stirrup positions. In structural analysis, especially in indeterminate structures, (S K Kulkarni et al 2014) it becomes essential to know material and geometrical properties of members. The codal provisions recommend elastic properties of concrete and steel and these are fairly accurate enough. Another method of determining modulus of elasticity of concrete is by flexural test of a beam specimen. The modulus of elasticity most commonly used for concrete is secant modulus. The modulus of elasticity of steel is obtained by performing a tension test of steel bar. Two important stiffness properties such as AE and EI play important role in analysis of high rise RCC building idealized as plane frame. The shear behavior of doubly reinforced concrete beams, (Ionut Ovidiu Toma et al 2007) with or without steel fibers, affected by distributed cracks. For this purpose, monotonic loading tests were carried out on a series of eight RC beams. Prior to testing, the surface of the beams was inspected the presence of distributed cracks. The crack density parameter introduced in the earlier research work was used to mathematically quantify the influence of the distributed cracks on the shear carrying capacity of the beams. The beams exhibited a mixed mode of failure between both diagonal tension and diagonal compression failures. A companion paper was also published (Khuntia & Ghosh b) emphasizing the applicability of the proposed stiffness expressions for all levels of applied loading, both service and ultimate loads. The parameters of interest were reinforcement ratio, concrete compressive strength, magnitude of axial load and the eccentricity ratio. The authors investigated effective parameters and the results were compared with the available experimental data. The parameters considered were bar size and the effective concrete area surrounding the reinforcement. In addition to these parameters, the additional parameter considered in the present study is variation in compression reinforcement.

The minimum compression steel in doubly reinforced beams is not specified in IS 456:2000. However, the creep and shrinkage of concrete may require hangers and other bars that provided up to 0.2% of the total area of the cross section. In light of this, these bars are not regarded as compression reinforcement. Therefore, in order for the doubly reinforced beam to handle the additional loads in addition to resisting the effects of concrete creep and shrinkage, the minimum amount of steel used as compression reinforcement should be at least 0.4% of the area of concrete in compression or 0.2% of the entire cross-sectional area of the beam. According to IS 456 clause number 26.5.1.2, the maximum amount of compression steel cannot be more than 4% of the entire area of the beam's cross-section.

As stipulated in clause 26.5.1.1(a) and (b) (IS 456: 2000), the minimum amount of tensile reinforcement shall be at least (0.85 bd/fy) and the maximum area of tension reinforcement shall not exceed (0.04 bD). The singly reinforced beams shall have Ast normally not exceeding 75 to 80% of Ast, lim so that xu remains less than xu, max with a view to ensuring ductile failure. Nonetheless, the presence of compression steel in the case of doubly reinforced beams ensures the ductile failure. Thus, the depth of the neutral axis may be taken as xu, max if the beam is over-reinforced. Accordingly, the A_{st1} part of the tension steel can go up to A_{st}, lim and the additional tension steel A_{st2} is provided for the additional moment Mu - Mu, limit. The quantities of A_{st1} and A_{st2} together form the total $A_{st,}$ which shall not exceed 0.04 bD.

2. EXPERIMENTAL PROGRAM

In this section combinations of compression and tension reinforcement with varying cross section of beam is being provided. Also, sections consist of experimental set up arrangement. Beam deflection is recorded after experimentation work.

This section provides information about combinations of compression and tension reinforcement with different beam cross sections. Additionally, experimental setup arrangements described in brief. After doing the experiment, the beam deflection is recorded.

2.1 Material Properties

After carefully considering the literature suggestions and conducting an analysis, following material properties were considered for the study as shown in table 1.

Table 1: Materials Specification

Materials	Specifications
Cement	
Grade of Cement	OPC, 53 Grade, Birla Super
Specific gravity of cement	3.15
Fineness of Cement	4.28% (IS 4031 Part 2)
Consistency of Cement	39% (IS 4031 Part 4)
Coarse Aggregates (CA)	
Specific Gravity	2.74
Size of Aggregate	20mm
Fine Aggregates (FA)	
Specific Gravity	2.58
Bulk Density	1620 kg/m3
Consumable Water	
pH	7.0-8.0

2.2 Design Mix

M20 grade of concrete was designed having following properties as shown in table 2.

Table 2: Design Mix for M20 grade of Concrete.

	Compressive Strength in MPa
	20
W/C	0.60
Cement, kg/m^3	319.3
Fine Aggregate, kg/m^3	711.58
Coarse Aggregate, kg/m^3	1182.01
Water, litres	191.58

2.3 Specimen Details

Total 90 beams were tested for deflection by using Universal Testing machine of 400KN capacity. A doubly reinforced beam is designed as per IS 13920-2016. A minimum width of the beam kept is 150mm. As per IS code depth should not be more than one fourth of clear span accordingly, depth of beam used is 200mm, 300mm, 400mm and length of beam is kept constant as1500mm.

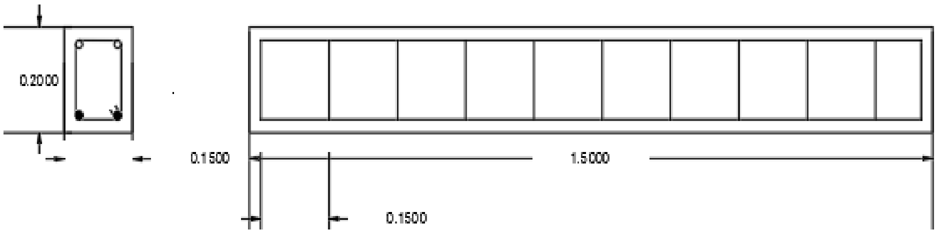


Fig. 1: Sectional View of concrete beam (all dimensions are in meter).

By considering various parameters number of combinations are done by varying tension and compression reinforcement as mentioned in the table 3, table4, and table 5.

Table 3: Combination of compression and tension reinforcement of 150mmx200mm c/s.

Model	Tension Reinforcement	Compression Reinforcement	Beam No.	Compression Steel	Tension Steel
Model I	Maximum	Maximum	A1	2 bars of 10mm Ø	2 bars of 10mm Ø
		Minimum	A2	2 bars of 8 mm Ø	2 bars of 10mm Ø
Model II	Moderate	Maximum	A3	2 bars of 10mm Ø	3 bars of 8 mm Ø
		Moderate	A5	3 bars of 8 mm Ø	3 bars of 8 mm Ø
		Minimum	A4	2 bars of 8 mm Ø	3 bars of 8 mm Ø
Model III	Minimum	Minimum	A6	2 bars of 8 mm Ø	2 bars of 8 mm Ø

In Table 3, three beam models of size 150mmX200mmX1500mm are prepared and by keeping tension reinforcement constant and variations are done in compression reinforcement from minimum to maximum. Similarly for model II, tension reinforcement is kept constant and variations are done in compression reinforcement from minimum to maximum. Similar variations are done for model III.

DOI: 10.5281/zenodo.8351042

Table 4: Combination of compression and tension reinforcement of 150mmx300mm c/s

Model	Tension Reinforcement	Compression Reinforcement	Beam No.	Compression Steel	Tension Steel
Model II	Maximum	Maximum	B9	3 bars of 10 mm Ø	3 bars of 10 mm Ø
		Moderate	B6	2 bars of 10mm Ø	3 bars of 10 mm Ø
		Moderate	B8	3 bars of 8 mm Ø	3 bars of 10 mm Ø
		Minimum	B7	2 bars of 8 mm Ø	3 bars of 10 mm Ø
Model I	Moderate	Maximum	B5	3 bars of 10 mm Ø	2 bars of 12mm Ø
		Moderate	B1	2 bars of 12mm Ø	2 bars of 12mm Ø
		Moderate	B2	2 bars of 10mm Ø	2 bars of 12mm Ø
		Moderate	B4	3 bars of 8 mm Ø	2 bars of 12mm Ø
		Minimum	B3	2 bars of 8 mm Ø	2 bars of 12mm Ø
Model III	Minimum	Maximum	B12	4 bars of 8 mm Ø	4 bars of 8 mm Ø
		Moderate	B11	3 bars of 8 mm Ø	4 bars of 8 mm Ø
		Minimum	B10	2 bars of 8 mm Ø	4 bars of 8 mm Ø

In Table 4, three beam models of size 150mmX300mmX1500mm are prepared and by keeping tension reinforcement constant and variations are done in compression reinforcement from minimum to maximum. Similar variations are done for model II and model III.

Table 5: Combination of compression and tension reinforcement of 150x400 c/s

Model	Tension Reinforcement	Compression Reinforcement	Beam No.	Compression Steel	Tension Steel
Model II	Maximum	Maximum	C9	3 bars of 10 mm Ø	3 bars of 10 mm Ø
		Moderate	C6	2 bars of 10mm Ø	3 bars of 10 mm Ø
		Moderate	C8	3 bars of 8 mm Ø	3 bars of 10 mm Ø
		Minimum	C7	2 bars of 8 mm Ø	3 bars of 10 mm Ø
Model I	Moderate	Maximum	C5	3 bars of 10 mm Ø	2 bars of 12mm Ø
		Moderate	C1	2 bars of 12mm Ø	2 bars of 12mm Ø
		Moderate	C2	2 bars of 10mm Ø	2 bars of 12mm Ø
		Moderate	C4	3 bars of 8 mm Ø	2 bars of 12mm Ø
		Minimum	C3	2 bars of 8 mm Ø	2 bars of 12mm Ø
Model III	Minimum	Maximum	C12	4 bars of 8 mm Ø	4 bars of 8 mm Ø
		Moderate	C11	3 bars of 8 mm Ø	4 bars of 8 mm Ø
		Minimum	C10	2 bars of 8 mm Ø	4 bars of 8 mm Ø

In Table 5, three beam models of size 150mmX400mmX1500mm are prepared and by keeping tension reinforcement constant and variations are done in compression reinforcement from minimum to maximum. Similar variations are done for model II and model III.

2.4 Actual Beam Specimen Model

Fig. 2: Actual beam model.

Total 90 beams were casted on site by varying cross section of beam and also, tension and compression reinforcement was considered from minimum to maximum range as mentioned in above table1, table2 and table 3. The width of beam used was 150mm and depth of beam used was 200mm, 300mm and 400mm. The length of beam was kept constant i.e., 1500mm.

2.5 Experimental Set up

A Universal testing machine (UTM) of 400kN capacity is used to test 90 beams and deflection was measured. UTM can be used to test a wide variety of materials like concrete, steel, cables, springs, steel wires and chains, slings, links, rope, winches, steel ropes, etc.

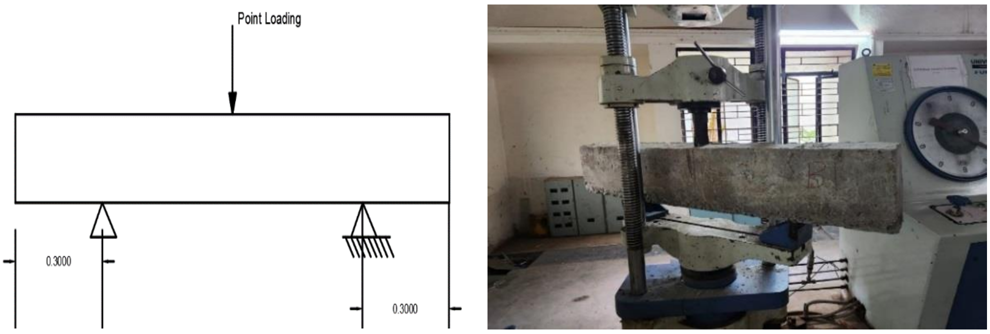


Fig. 3: Test Setup.

2.6 Testing of Beams

A universal testing machine (UTM), of 400kN capacity was used and compressive strength of doubly reinforced beam. The results include the maximum load the specimen can withstand before failure, the deformation or strain at the point of failure, and the modulus of elasticity of the material. Flexural cracks initially developed on the bottom of the beams as the specimens were loaded. The beams exhibited linear behavior up until cracks were noticed at the concrete cover in the middle of the beam, which was subjected to the greatest amount of pure bending. Peak load appeared when the wider flexural fissures and concrete cover in the compression zone began to crumble.

Fig. 4: Failure and cracking pattern of beams.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In this section, the test conducted on beams were used to calculate actual strength. This section presents general behavior, mode of failure.

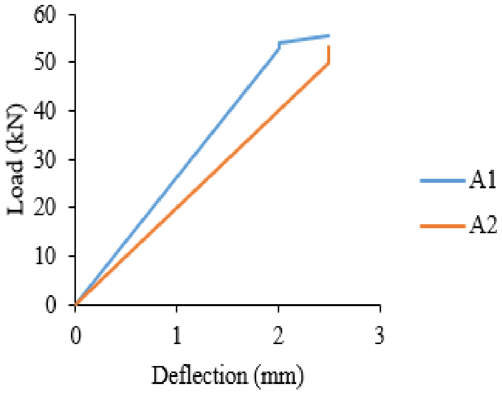
In this part, the real strength was determined using the results of the beam test. The overall behaviour and mode of failure are presented in this section.

3.1 Experimental Results

The deflection of the beam was recorded with reference to the compression and tension steel as mentioned in table 3, table 4, table 5, for first crack and failure load as shown in table 6, table 7, and table 8.

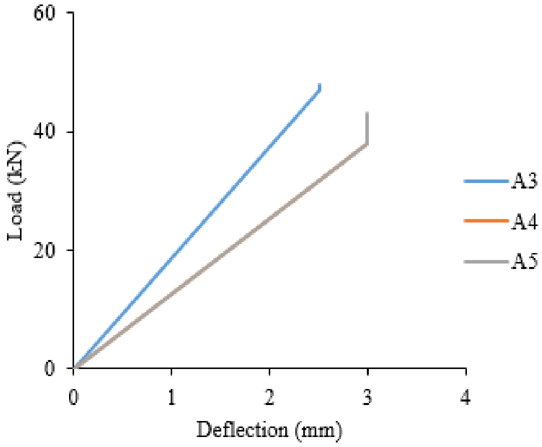
Table 6: Load and Deflection at first crack and failure load of 150mmx200mm c/s beam.

Model	Beam No.	Load at first Crack (kN)	Deflection at first Crack (mm)	Average Deflection at first Crack (mm)	Failure Load (kN)	Deflection at failure Load (mm)	Average Deflection at failure Load (mm)
Model I	A1	49	0.5	0.5	54	2	2.17
		51	0.5		53	2	
		49.5	0.5		55.5	2.5	
	A2	42	0.5	0.5	50	2.5	2.5
		46	0.5		53.5	2.5	
		41	0.5		50	2.5	
Model II	A3	39	0.5	0.5	47	2.5	2.5
		37	0.5		48	2.5	
		39	0.5		48	2.5	
	A5	35	0.5	0.5	43	3	3
		35	0.5		39	3	
		31	0.5		38	3	
	A4	35	0.5	0.5	41	3	3
		32	0.5		38	3	
		33.5	0.5		42	3	
Model III	A6	29	1	1	34	4	4
		31.5	1		31	4	
		28	1		33	4	



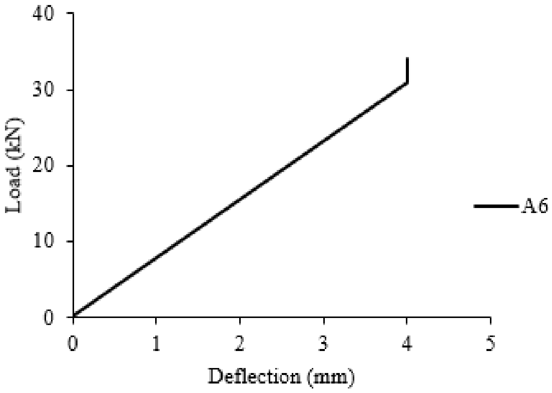
Beam No.	Percentage of Steel	
	Compression steel	Tension steel
A1	0.69	0.69
A2	0.45	0.69

Fig. 5: Graph of Load vs deflection for model I from table 6.



Beam No.	Percentage of Steel	
	Compression steel	Tension steel
A3	0.69	0.67
A5	0.67	0.67
A4	0.45	0.67

Fig. 6: Graph of Load vs deflection for model II from table 6.



Beam No.	Percentage of Steel	
	Compression steel	Tension steel
A6	0.45	0.45

Fig. 7: Graph of Load vs deflection for model III from table 6.

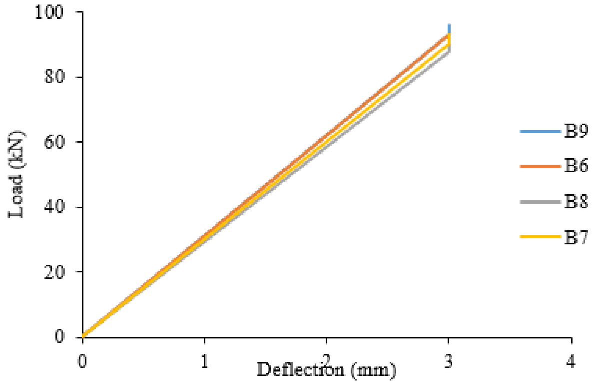
ISSN 1533-9211

DOI: 10.5281/zenodo.8351042

Fig. 5, Fig 6 and Fig. 7 represents deflections of the beam for the failure load as mentioned in table 6. Compression reinforcement varies in each case as mentioned in table 3.

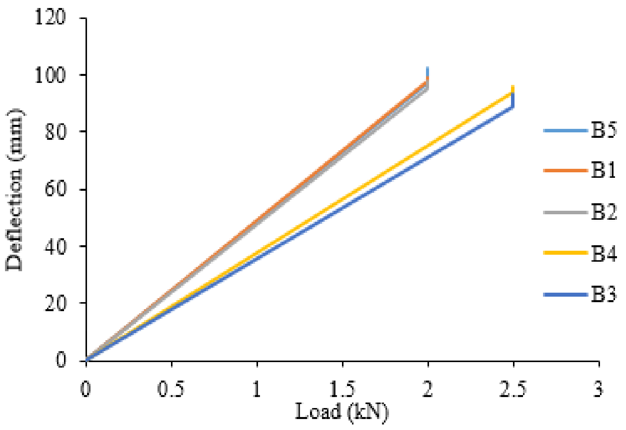
Table 7: Load and Deflection at first crack and failure load of 150mmx300mm c/s beam.

Model	Beam No.	Load at first Crack (kN)	Deflection at first Crack (mm)	Average Deflection at first Crack (mm)	Failure Load (kN)	Deflection at failure Load (mm)	Average Deflection at failure Load (mm)
Model II	B9	87	0.5	0.5	95	3	3
		88	0.5		96	3	
		82	0.5		93	3	
	B6	81	0.5	0.5	93	3	3
		82	0.5		93	3	
		86	0.5		93	3	
	B8	80	0.5	0.5	93	3	3
		77	0.5		88	3	
		83	0.5		88	3	
	B7	83	0.5	0.5	90	3	3
		81	0.5		93	3	
		81	0.5		92	3	
Model I	B5	85	0.5	0.5	99	2	2
		89	0.5		102	2	
		83	0.5		97	2	
	B1	80	0.5	0.5	99	2	2
		79.5	0.5		98	2	
		78	0.5		99	2	
	B2	82	0.5	0.5	97	2	2
		84	0.5		95	2	
		79	0.5		98	2	
	B4	81	0.5	0.5	94	2.5	2.5
		83	0.5		94	2.5	
		83	0.5		96	2.5	
	B3	79	0.5	0.5	93	2.5	2.5
		77.5	0.5		91	2.5	
		76	0.5		89	2.5	
Model III	B12	73	1	1	83	3.5	3.5
		74	1		79.5	3.5	
		71	1		82	3.5	
	B11	70	1	1	78	3.5	3.5
		70	1		76	3.5	
		67	1		77	3.5	
	B10	70	1	1	76	3.5	3.5
		68	1		75	3.5	
		71.5	1		82	3.5	



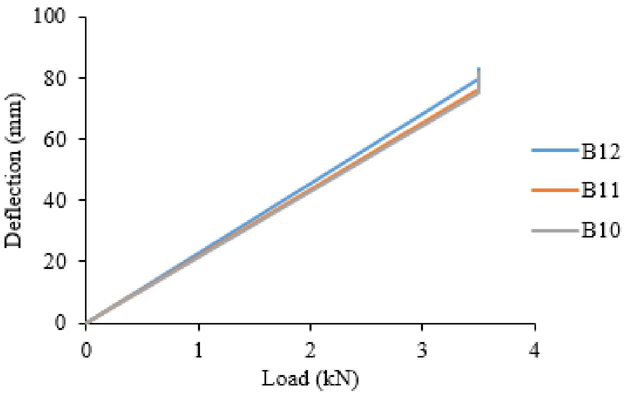
Beam No.	Percentage of Steel	
	Compression steel	Tension steel
B9	0.63	0.63
B6	0.42	0.63
B8	0.4	0.63
B7	0.27	0.63

Fig. 8: Graph of Load vs deflection for model II from table 7.



Beam No.	Percentage of Steel	
	Compression steel	Tension steel
B5	0.63	0.6
B1	0.6	0.6
B2	0.42	0.6
B4	0.4	0.6
B3	0.27	0.6

Fig. 9: Graph of Load vs deflection for model I from table 7.



Beam No.	Percentage of Steel	
	Compression steel	Tension steel
B12	0.54	0.54
B11	0.4	0.54
B10	0.27	0.54

Fig. 10: Graph of Load vs deflection for model III from table 7.

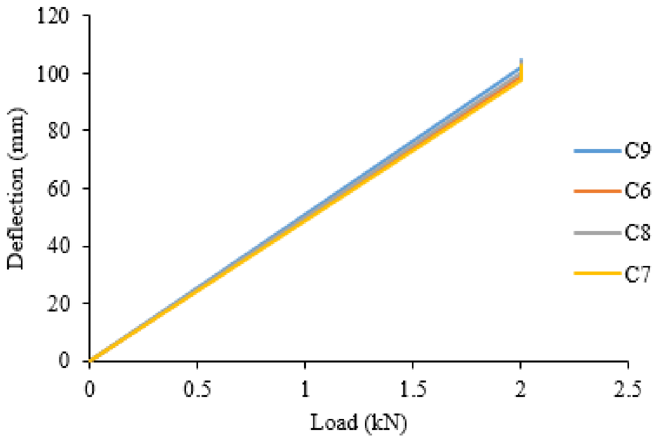
Fig. 8, Fig. 9 and Fig. 10 represents deflections of the beam for the failure load as mentioned in table 7. Compression reinforcement varies in each case as mentioned in table 4.

Table 8 Load and Deflection at first crack and failure load of 150mmx300mm c/s beam.

Model	Beam No.	Load at first Crack (kN)	Deflection at first Crack (mm)	Average Deflection at first Crack (mm)	Failure Load (kN)	Deflection at failure Load (mm)	Average Deflection at failure Load (mm)
Model II	C9	88	0.5	0.5	105	2	2
		89	0.5		104.5	2	
		86	0.5		102	2	
	C6	93	0.5	0.5	102	2	2
		95	0.5		101	2	
		94	0.5		99	2	
	C8	89	0.5	0.5	101	2	2
		91	0.5		104	2	
		89	0.5		100	2	
	C7	90	0.5	0.5	98	2	2
		89	0.5		98	2	
		89	0.5		103	2	
Model I	C5	100	0.5	0.5	115	1.5	1.5
		95.5	0.5		104	1.5	
		98	0.5		109	1.5	
	C1	101	0.5	0.5	119	1.5	1.5
		99	0.5		121	1.5	
		106	0.5		115	1.5	
	C2	98	0.5	0.5	111	1.5	1.5
		101	0.5		115	1.5	
		96	0.5		112	1.5	
	C4	97	0.5	0.5	109	1.5	1.5
		96	0.5		109	1.5	
		96	0.5		107	1.5	
	C3	97	0.5	0.5	104	2	2
		97	0.5		103	2	
		99	0.5		108	2	
Model III	C12	79	1	1	90	3	3
		81	1		86	3	
		80	1		87	3	
	C11	79	1	1	87	3	3
		78	1		88	3	
		78	1		85	3	
	C10	76	1	1	83	3	3
		77	1		90	3	
		79	1		87	3	

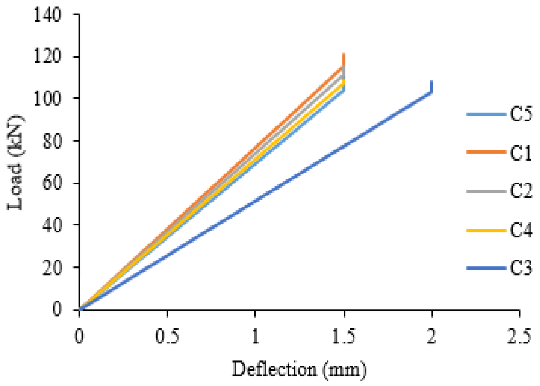
ISSN 1533-9211

DOI: 10.5281/zenodo.8351042



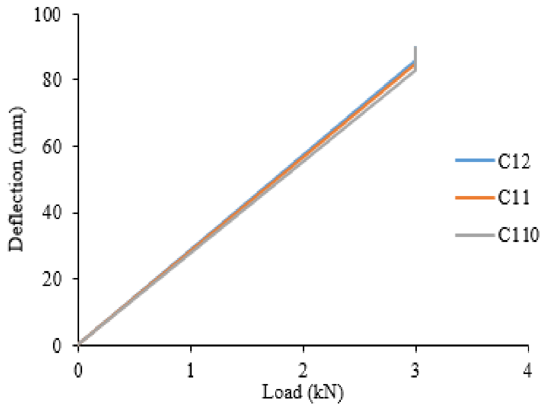
Beam No.	Percentage of Steel	
	Compression steel	Tension steel
C9	0.45	0.45
C6	0.299	0.45
C8	0.287	0.45
C7	0.19	0.45

Fig. 11: Graph of Load vs deflection for model II from table 8.



Beam No.	Percentage of Steel	
	Compression steel	Tension steel
C5	0.45	0.43
C1	0.43	0.43
C2	0.299	0.43
C4	0.287	0.43
C3	0.19	0.43

Fig. 12: Graph of Load vs deflection for model I from table 8.



Beam No.	Percentage of Steel	
	Compression steel	Tension steel
C12	0.38	0.38
C11	0.287	0.38
C10	0.19	0.38

Fig. 13: Graph of Load vs deflection for model III from table 8.

DOI: 10.5281/zenodo.8351042

Fig. 11, fig 12 and fig. 13 represents deflections of the beam for the failure load as mentioned in table 8. Compression reinforcement varies in each case as mentioned in table 5.

4. CONCLUSION

In the longitudinal direction, beams experience normal stresses that range from maximum tension at one surface to zero at the beam's midplane to maximum compression at the opposing surface. When the length-to-height ratio of the beam is high, shear stresses are also created, but they are frequently insignificant in contrast to the normal stresses. With the right tension reinforcement, flexural cracks can be controlled. Compression reinforcing enhances both the curvature and the resisting moments of concrete sections. Due to tensile stress acting on the mass concrete structure, this microcrack has the potential to cause conventional mass concrete to break. From the experimental study it was observed that, cracks were observed at the central portion of the beam while testing and less the cross section of the beam, more was the deflection.

Normal stresses on beams in the longitudinal direction range from the highest tension at one surface to the midplane of the beam being zero to the maximum compression at the opposing surface. Shear stresses are also produced when the length-to-height ratio of the beam is high, but they are typically negligible in comparison to the normal stresses. Flexural fissures can be managed with the appropriate tension reinforcement. Both the curvature and the resisting moments of concrete sections are improved by compression reinforcing. This microcrack has the potential to result in the traditional mass concrete breaking because of the tensile stress pressing on the mass concrete structure. According to the experimental study, cracks were found in the beam's centre during testing, and the deflection increased as the cross section of the beam decreased.

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