

Experimental Investigation on the Flexural Behavior of the Steel-Concrete Composite Beams

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Abstract-The Principle behind the composite construction is to make two materials to combine together in resisting the external load. An experimental investigation was carried out on 8 simply supported beam specimens to understand the flexural performance. Two beams were control beams and the remaining six beams were composite beams. Six composite beams were provided with different configuration of the shear transfer mechanism. The cross section of the beams were kept such that, span to depth ratio varied from 6 to 9 and shear span to depth ratio varied from 2.5 to 3. The grade of concrete was M30 and the grade of steel was kept Fe415. Composite action is predominant over the fundamental mechanism of load slip, load transfer and shear transfer. Sound bond between the two materials under flexure-shear is to be achieved during the design and construction of composite structures. The connection between the steel and the concrete section of this work was established using T-shear connectors. T-shear connectors were used in three different configurations. The beam specimens were tested by subjecting them to two point loading. The cracking load, load-deflection behavior, ultimate load and failure pattern of the beam specimens were studied. The experimental results indicate that, the load carrying capacity of the composite beams were increased by 38.09% to 214.28%. The experimental results have also indicated that, the span to depth ratio and shear span to depth ratio have an influence on the increase in the load carrying capacity of the composite beams. The mid-span deflection at ultimate load for the composite beams were reduced by 50% when compared to control beams. It was observed that, the steel-concrete composite beams failed due to shear-compression failure in the shear span.

Key Words: Composite beams, shear connector, Cracking load load-deflection, ultimate load etc.

1. INTRODUCTION:

A composite section is one which contains two or more materials connected together to act as a single component. The composite sections aims at utilizing the properties of both the materials used in the composite section in an effective manner. The most commonly used composite section in structures is the steel-concrete composite section [10]. In steel-concrete composite section, steel is used in the tension zone and concrete is used in the compression zone. Hence, the steel-concrete composite sections is a solution for the problem of low tensile strength of concrete and web buckling of steel in compression.

The use of composite sections in civil engineering structures is gaining much importance nowadays owing to their advantages over conventional steel and concrete sections [9]. Steel-concrete composite construction, particularly for multi-storey steel frames, have achieved a high market share in several countries, mainly due to reduction in cross sectional dimensions, savings in conventional steel reinforcement, rapid construction and many other advantages [6]. In addition, the composite sections have shown promising performance in terms of safety and serviceability conditions [10].

The connection between the steel and concrete section is an important aspect which influences the structural behavior of the composite section. The connection is necessary to make steel and concrete sections act as a single composite unit and to induce composite action [6]. The mechanical devices called shear connectors are used to establish the connection between steel and concrete.

1.1 Scope of the present work

The scope of the present work is to study and compare the flexural behavior of the steel-concrete composite beams cast as reinforced rectangular concrete sections into steel channels with control beams having same span and dimensions. The steel-concrete composite beams were provided with T-shear connector to establish the

connection between steel and concrete. The T-shear connector was used in three different configurations in the study. The first cracking load, ultimate load, deflection at ultimate load, failure patterns and load-deflection behavior of both control beams and composite beams were studied. The beams were cast using M30 grade concrete and Fe 415 steel. The beam specimens were tested as simply supported beams subjected to two point loading.

1.2 Objectives

1. To arrive at the mix proportion for M30 grade of concrete as per IS:10262-2009
2. To study the load-deflection behavior of the conventional RC and composite beam specimens
3. To compare the first cracking load, ultimate load and deflection at ultimate load
4. To study the failure pattern of the composite beam specimens

2 MATERIALS AND MIX PROPORTIONS

Ordinary Portland cement of 43 grade conforming to IS:1269-1987 was used. Locally available manufactured sand free from silt, organic matter and passing through 4.75mm sieve conforming to zone II of IS:383-1970 was used as Fine aggregate. The tests on fine aggregate was conducted to determine the specific gravity and fineness modulus. Locally available crushed granite aggregate passing through 20mm sieve and retaining on 4.75mm sieve was used as Coarse aggregate. The aggregate was conforming to IS:383-1970. The tests on coarse aggregate was conducted in accordance with IS:2386-1963 to determine specific gravity and fineness modulus. The results are presented in Table-1.

Potable water free from injurious salts was used for both mixing and curing. Fe415 grade steel was used for all the beams as conventional reinforcement and mild steel plates of 5mm thickness were used to form channel sections used for composite beams. Also, 5mm plates were used to fabricate shear connectors.

Table-1:Material Characterization

SI NO	Test	Results
Cement		
1	Specific gravity	3.15
Fine aggregate		
2	Specific gravity	2.54
3	Fineness modulus	2.52
Coarse Aggregate		

4	Specific gravity	2.67
5	Water absorption	1.50
6	Impact test	Impact value=29%
7	Crushing test	Crushing value=22.40%
8	Los Angeles abrasion test	% wear=26.36
9	Bulk density test	1549 Kg/m ³
10	Fineness modulus	6.04

Based on the properties of the materials obtained and the specifications as per IS:10262-2009 the mix proportion for M30 grade of concrete was obtained as 1:2.013:3.247 with a W/C ratio of 0.55. The obtained mix proportion is shown in Table-2.

Table-2:Mix proportion for M30 concrete

Cement (Kg/m ³)	Fine Aggregate (Kg/m ³)	Coarse Aggregate (Kg/m ³)	Water (Kg/m ³)
348.33	681.66	1146.80	191.58

3 EXPERIMENTAL WORK

The experimental work carried out in this research work involves, evaluation of material properties, fabrication of reinforcement cages as per the requirement, fabrication of shear connectors and welding them to the channel sections, casting of beam specimens and the companion cubes for compressive strength determination and testing of the beam specimens.

3.1 Nomenclature of beam specimens

The beam specimens were named systematically for their identification as follows, B/6/2.5/1, means, beam name/span to depth ratio/ shear-span to depth ratio/Type of shear connector. The first letter 'B' indicates beam, second number '6' indicates span to depth ratio, third number '2.5' indicates shear-span to depth ratio and the last number '1' indicates Type of shear connector. Since, the control beams didn't had any shear connector, number '0' was used to identify the shear connector type, which indicates that, no shear connector was used.

3.2 Shear connector

The size of the shear connector used for beams with varied span to depth ratio and shear-span to depth ratio were kept different. The shear connector used for beams with span to depth ratio of 6 and shear-span to depth ratio of 2.5 were named after letter 'a' and the shear connector used for beams with span to depth ratio of 9 and shear-span to depth ratio of 3 were named after letter 'b'.

Type 1 shear connector: In this type, the T-shear connector was provided in between the stirrup rings. The shear connector spacing was kept same as the spacing for stirrup rings. Depending on the c/s of the beam, the size of the shear connector is varied. The typical cross-section and the longitudinal section of Type 1 shear connector is shown in Fig-1-3.

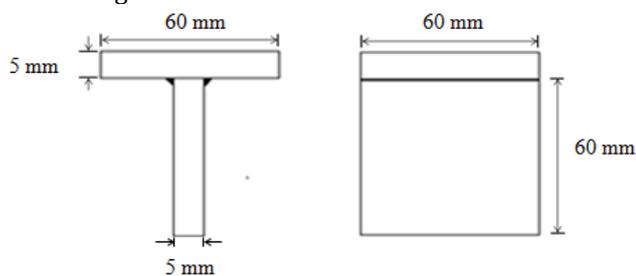


Fig-1: C/S and L/S of Type 1a shear connector

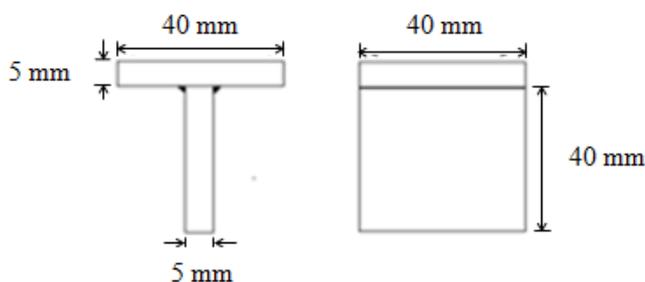


Fig-2: C/S and L/S of Type 1b shear connector



Fig-3: Type 1a shear connector welded to channel section

Type 2 shear connector: In this type, the T-shear connector was provided in such a way that, the stirrups were inserted into the holes provided in the shear connector. The shear connector spacing was kept same as the spacing for stirrup rings. The typical cross-section (C/S) and the longitudinal section (L/S) of Type 2 shear connector is shown in Fig-4-6.

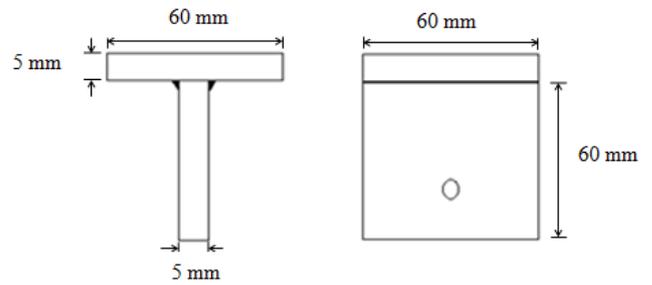


Fig-4: C/S and L/S of Type 2a shear connector

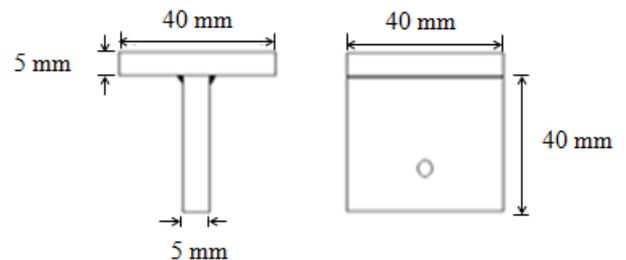


Fig-5: C/S and L/S of Type 2b shear connector



Fig-6: Type 2a Type 2b shear connector with stirrups welded to channel section

Type 3 shear connector: In this type, the T-shear connector was provided throughout the length of the beam continuously except for a length of 20mm at either end to account for the cover. Typical cross section (C/S) and longitudinal section (L/S) of Type 3 shear connector is shown in Fig-7-8.

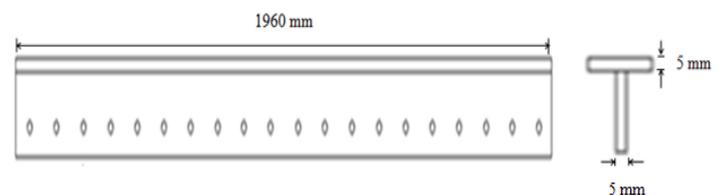


Fig-7: C/S and L/S of Type 3 shear connector



Fig-8: Type 3a shear connector with stirrups welded to channel section

The typical C/S of control beam and Composite beam is shown in Fig-8 and Fig-9.

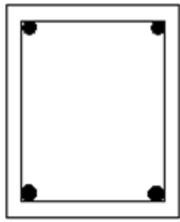


Fig-8: C/S of control Beam

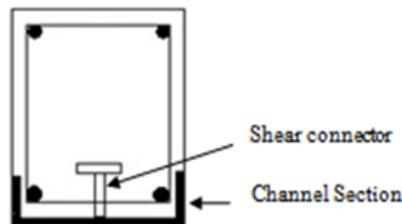


Fig-9: C/S of Composite beam

3.3 Casting of Specimens

The beam specimens were cast using the channel sections of required depth which were placed back to back and were connected by bolts which can be adjusted for the required width. The channel sections were cleaned and oiled before concreting for easy demoulding. Then the reinforcement cages for conventional RC beams and channel sections welded with T-shear connectors along with reinforcement cages for composite beams were placed into the beam moulds and were given a cover of 20mm as per IS:456-2000 guide lines. Then the fresh, workable concrete was placed in layers and compacted by using needle vibrator. Three cubes were also cast simultaneously for determination of the characteristic compressive strength of concrete. The beam specimens and cubes were then demoulded after 24 hours and then they were cured for 28 days before they were tested. Fig-10-14 demonstrates the various stages of casting.



Fig-10: Reinforcement cage for composite beam with Type 1 shear connector ready for casting



Fig-11: Reinforcement cage for composite beam with Type 2 shear connector ready for casting



Fig-12: Reinforcement cage for composite beam with Type 3 shear connector ready for casting



Fig-13: Moulds with reinforcement cages ready for casting



Fig-14: Beam specimen after casting

3.4 Testing

After the curing period of 28 days, beam specimens were kept for 24 hours in a dry state and then they were cleaned to remove grit and dirt. Then the beam specimens were whitewashed to facilitate easy detection of cracks. The beam specimens were tested in a reaction frame of 1000 kN capacity and hydraulic jack of 500 kN capacity subjected to two point loading. The beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5 were tested at the load increment of 4kN and beams having a span to depth ratio of 9 and shear-span to depth ratio of 3 were tested at the load increment of 2kN. The load increment was increased after the first crack load. The deflection of the beam specimens was noted down for every increment in the load till the failure. The first crack load, deflection at first crack load, ultimate load and deflection at ultimate load were noted down and the crack pattern was marked on the beam. The companion cubes were also tested simultaneously in compressive testing machine (CTM) to evaluate the compressive strength of concrete on the same day of testing of beams. The loading arrangement is shown in Fig-15 and the failure specimen is shown in Fig-16.



Fig-15: Beam specimen under testing



Fig-16: Typical failure pattern of composite beam specimen

4 RESULTS

Table-3: Beam specimen details and test results Test results

Name	Type of beam	Type of Shear connector	C/S (mm)	Reinforcement %	Stirrups 2L- ϕ @	P_{cr} kN	Δ_{cr} mm	P_u kN	Δ_u mm	Mean 28 days compressive strength of Concrete N/mm ²	Mode of failure
B/6/2.5/0	Control	-	150x300	1.0	100mm c/c	40	2.49	210	39.50	39.355	Flexure
B/6/2.5/1a	Composite	Type 1	150x300	1.0	100mm c/c	124	3.37	320	16.65	38.94	Shear-compression
B/6/2.5/2a	Composite	Type 2	150x300	1.0	100mm c/c	136	3.68	396	19.12	39.09	Shear-compression
B/6/2.5/3a	Composite	Type 3	150x300	1.0	100mm c/c	120	5.83	290	15.34	40.69	Shear-compression
B/9/3/0	Control	-	100x200	1.28	100mm c/c	18	7.48	70	44.45	38.51	Flexure
B/9/3/1b	Composite	Type 1	100x200	1.28	100mm c/c	60	5.07	200	21.84	37.93	Shear-compression
B/9/3/2b	Composite	Type 2	100x200	1.28	100mm c/c	70	4.46	220	22.60	39.38	Compression
B/9/3/3b	Composite	Type 3	100x200	1.28	100mm c/c	54	4.39	142	19.10	39.35	Shear-compression

Note: P_{cr} -1st cracking load in kN

Δ_{cr} -Deflection at 1st crack in mm

P_u -Ultimate load in kN

Δ_u -Deflection at ultimate load in mm

4.1 Cracking load

Cracking load is a very important stage in the load-deflection behavior of flexural members. Generally, load-deflection behavior will be linear up to cracking load. The cracking load depends upon the tensile strength of concrete and the geometry of the specimen.

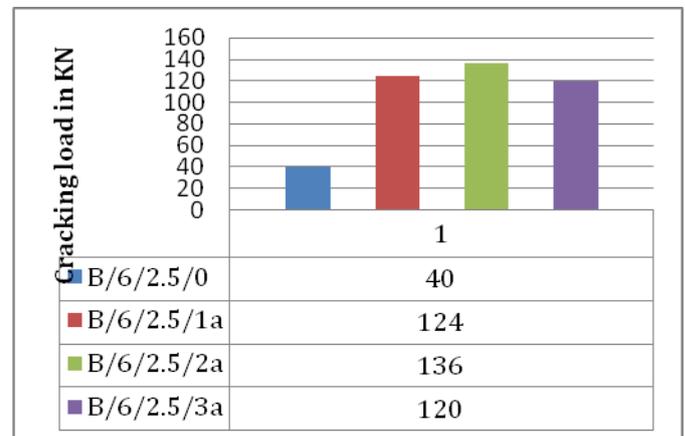


Fig-17: Cracking load for beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5

Fig-17 shows the cracking load for beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5. From the chart, it can be observed that, the cracking load for all composite beams was recorded much more than the cracking load for control beam. The composite beams has shown increase in the cracking load by 3 times more than the cracking load for control beam. B/6/2.5/2a beam had shown maximum cracking load compared to all other beams. The increase in cracking load for composite beams in comparison with control beam is expressed in percentage was found as 210%,240% and 200% respectively for B/6/2.5/1a,B/6/2.5/2a and B/6/2.5/3a beams.

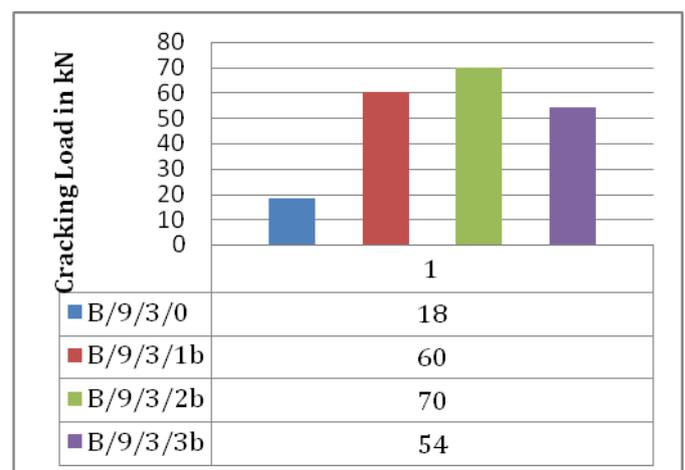


Fig-18: Cracking load for beams having a span to depth ratio of 9 and shear-span to depth ratio of 3

Fig-18 shows the cracking load for beams having a span to depth ratio of 9 and shear-span to depth ratio of 3. From the chart, it can be observed that, the cracking load for all

composite beams was recorded very much more than the cracking load for control beam. The composite beams had shown increase in the cracking load 3 times more than the cracking load for control beam. B/9/3/2b beam had shown maximum cracking load compared to all other beams. The increase in cracking load for composite beams was found as 233.33%, 288.88% and 200% respectively for B/9/3/1b, B/9/3/2b and B/9/3/3b beams.

From Fig-17 and Fig-18, it can be observed that, composite beams in both groups had shown increased cracking load compared to control beams. Composite beam provided with Type 2 shear connector had shown a maximum increase in cracking load. The maximum increase in cracking load was observed for beam B/9/3/2b and was found as 288.88%.

4.2 Ultimate load

The load at which the beam is unable to carry any further load is termed as ultimate load. The ultimate load is concerned with the strength or load carrying capacity aspect of the structural behavior of the beams.

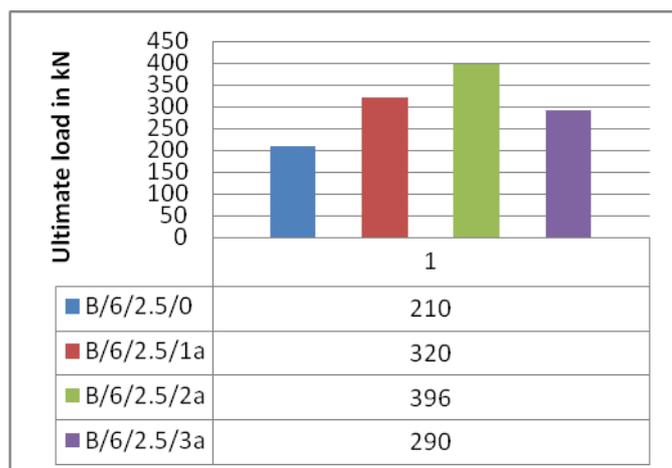


Fig-19: Ultimate load for beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5

Fig-19 shows the ultimate load for beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5. From the chart, it can be observed that, the ultimate load for all composite beams was recorded more than the ultimate load for control beam. The composite beams have shown increased ultimate load by 2 times more than the ultimate load for control beam. B/6/2.5/2a beam had shown maximum ultimate load compared to other composite beams. The minimum increase in ultimate load was observed for B/6/2.5/3b beam. The increase in ultimate load for composite beams compared to control beam expressed as a percentage was found as 45.45%, 80% and 31.81% respectively for B/6/2.5/1a, B/6/2.5/2a and B/6/2.5/3a beams.

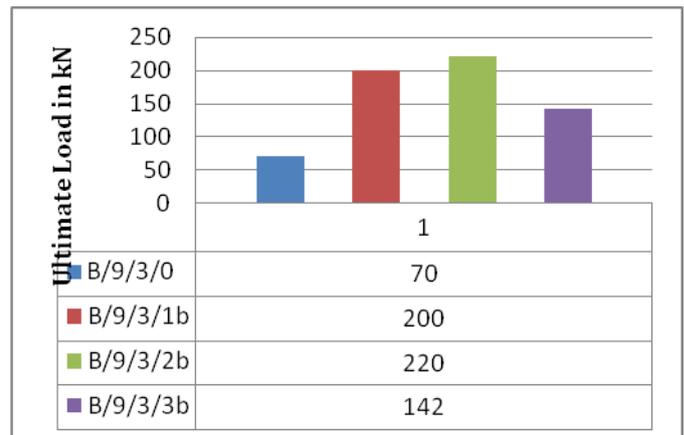


Fig-20: Ultimate load for beams having a span to depth ratio of 9 and shear-span to depth ratio of 3

Fig-20 shows the ultimate load for beams having a span to depth ratio of 9 and shear-span to depth ratio of 3. From the chart, it can be observed that, the ultimate load for all composite beams was recorded more than the ultimate load for control beam specimen. The composite beams had shown increased ultimate load by more than 3 times the ultimate load for control beam. B/9/3/2b beam had shown maximum ultimate load compared to other beams. The minimum increase in ultimate load was observed for B/9/3/3b beam. The increase in ultimate load for composite beams compared to control beam was found as 185.71%, 214.28% and 102.85% respectively for B/9/3/1b, B/9/3/2b and B/9/3/3b beams.

From Fig-19 and Fig-20, it can be observed that, composite beams in both groups had shown increased ultimate load, but beams having a span to depth ratio of 9 and shear-span to depth ratio of 3 had shown maximum increase in the ultimate load compared to beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5. Hence, it is clear that, the span to depth ratio (l/d) and shear-span to depth ratio (a/d) of beams along with composite action lead to increase in load carrying capacity. Composite beam provided with Type 2 shear connector i.e. B/9/3/2b shown maximum had shown maximum ultimate load carrying capacity compared to control beam.

4.3 Mid-span deflection at ultimate load

The deflection of the beam, corresponding to its ultimate load is termed as deflection at ultimate load. The deflection of a structural member is concerned with the serviceability aspect of the structural behavior of the beams.

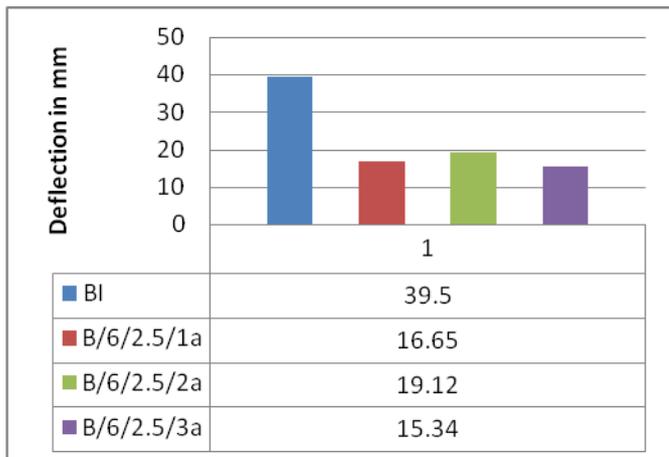


Fig-21: Mid-span deflection at ultimate load of beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5

Fig-21 shows the deflection at ultimate load of beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5. From the chart it can be observed that, maximum deflection at ultimate load was recorded for the control beam B/6/2.5/0 and the minimum value of deflection at cracking load was recorded for composite beam B/6/2.5/3a. Deflection at ultimate load for composite beams B/6/2.5/1a, B/6/2.5/2a and B/6/2.5/3a were recorded as 57.84%, 51.59% and 61.16% less than deflection at ultimate load for control beam respectively.

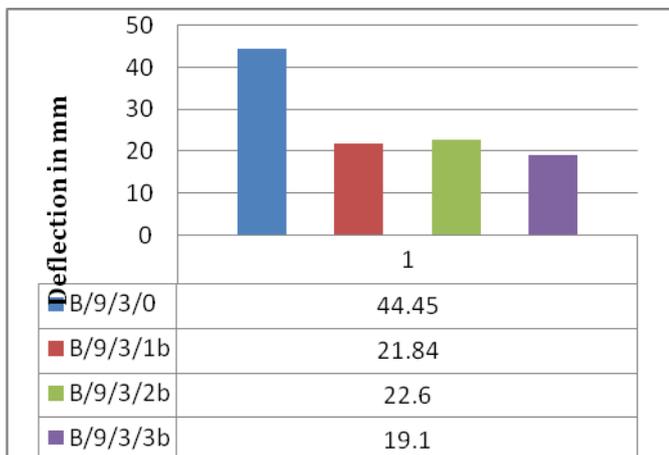


Fig-22: Mid-span deflection at ultimate load of beams having a span to depth ratio of 9 and shear-span to depth ratio of 3

Fig-22 shows the deflection at ultimate load of beams having a span to depth ratio of 9 and shear-span to depth ratio of 3. From the chart it can be observed that, maximum deflection at ultimate load was recorded for the control beam B/9/3/0 and the minimum value of deflection at ultimate load was recorded for composite beam B/9/3/3b. Deflection at ultimate load for beams B/9/3/1b, B/9/3/2b and B/9/3/3b were recorded as

50.86%, 49.15% and 57.03% less than deflection at ultimate load for control beam respectively.

From Fig-21 and Fig-22 it can be observed that, beams had shown similar variation for deflection at ultimate load. Maximum deflection at ultimate load was recorded for control beam in both groups. Minimum deflection was recorded for composite beam. The reduced deflection of composite beams under ultimate load is expressed in terms of percentage and it varied between 49.15% to 61.16%.

4.4 Load-deflection behavior

Load-deflection behavior is the principle constituent of the flexural behavior of the beams. Load-deflection curve serves as the basis for calculating many structural parameters like, energy absorption, deflection ductility etc.

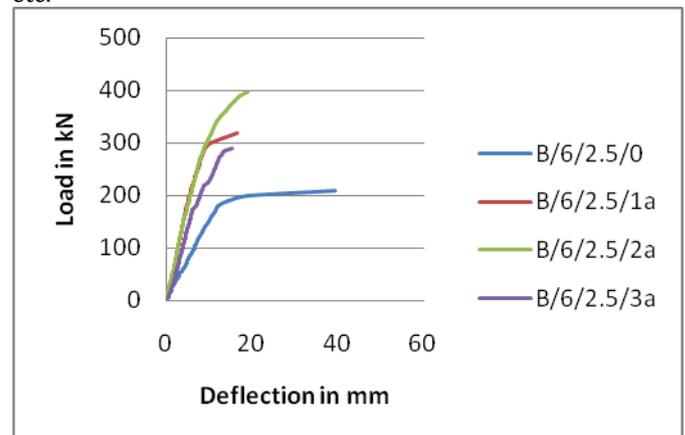


Fig-23: Load-deflection curve for beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5

Fig-23 shows the Load-Deflection curves for beams having span to depth ratio of 6 and shear-span to depth ratio of 2.5. It can be observed from the chart that, load-deflection curves showed linear variation under initial loading. The load-deflection curve for control beam is steeper than the load-deflection curves for composite beams indicating that, control beam deflected more than the composite beams under a given load. The load-deflection curves for all the beams indicates reduction in stiffness with increase in load. But, reduction in stiffness observed was more for control beam when compared to steel-concrete composite beams.

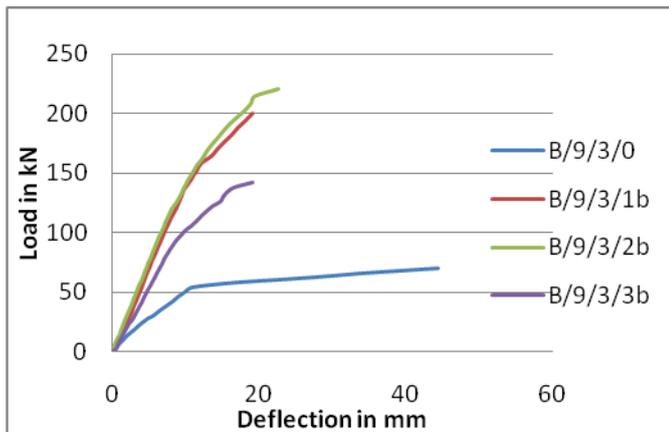


Fig-24: Load-deflection curve for beams having a span to depth ratio of 9 and shear-span to depth ratio of 3

Fig-24 shows the Load-Deflection curves for beams with span to depth ratio of 9 and shear-span to depth ratio of 3. It can be observed from the chart that, load-deflection curves showed linear variation under initial loading. The load-deflection curve for control beam is steeper than the load-deflection curves for composite beams indicating that, control beam deflected more than the composite beams under a given load. The load-deflection curves for all the beams indicates reduction in stiffness with increase in load. But, reduction in stiffness observed was more for control beam when compared to steel-concrete composite beams.

5 CONCLUSIONS

1. The material properties have significant influence on arriving at the concrete mix design of M30 grade concrete. Also trial mix preparation should be done in a meticulous manner as it played an important role in arriving at the mix proportion.
2. It is observed that, cracking load for composite beams is thrice more than the cracking load for control beams for both beams having span to depth ratio of 6 and shear-span to depth ratio of 2.5 and span to depth ratio of 9 and shear-span to depth ratio of 3.
3. It is evident from the Fig-17 and Fig-18, that, Type 2 shear connector is more efficient in increasing the cracking load.
4. The reduction in the deflection of composite beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5 is expressed as percentage of deflection in comparison with control beam was observed to be 51.59% to 61.16%.
5. The reduction in the deflection of composite beams having a span to depth ratio of 9 and shear-span to depth ratio of 3 is expressed as percentage of

deflection in comparison with control beam was observed to be 49.15% to 57.03%.

6. The increase in Ultimate load of composite beams having a span to depth ratio of 6 and shear-span to depth ratio of 2.5 is observed to be varied between 38.09% to 88.57% in comparison with the respective control beam.
7. The increase in Ultimate load of composite beams having a span to depth ratio of 9 and shear-span to depth ratio of 3 is observed to be varied between 102.85% to 214.28% in comparison with respective control beam.
8. The increased Ultimate load of composite beams with Type 2 shear connector i.e. B/6/2.5/2 and B/9/3/2 is observed to be 88.57% and 214.28% respectively in comparison with respective control beams.
9. The composite beams having a same span to depth ratio and shear-span to depth ratio recorded different percentage increase in the load carrying capacity, indicating that, shear connector arrangement also has significant influence on the load carrying capacity of the proposed composite beam specimens, since all other parameters except the shear connector arrangement was kept same.
10. The composite beam specimens have shown shear-compression mode of failure in the shear span, hence it is evident from this observation that, the load carrying capacity of the proposed composite beam specimens can be further enhanced by strengthening the beams in shear.
11. It can be concluded from the study that, the strength of the channel section can be exploited in a much better way by using the channel section in combination with high strength concrete, since the failure of the beam was accompanied by failure of the concrete in compression.
12. The strength to weight ratio of the beams could be increased significantly by using Light-weight concrete in place of normal-weight concrete.

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