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Behavioral Study of Shear and Flexural Strength of Reinforced Concrete Beams with Interfaces of Concrete Casted Under Cyclic Loading

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Abstract

Reinforced concrete beams are designed primarily for resisting the shear and flexural stresses that are exhibits on the beam sections. These two parameters are influenced by different factors. Delay of concrete casting forms an interface between harden and fresh concretes. Interface is a surface between two sections of concrete that are not placing monolithically. This interface may affect the structural capacity of reinforced concrete members. Especially shear strength of the members at the shear plane is highly influenced by this interface. Many researches were conducted on different factors that affect the shear and flexural capacity of reinforced concrete beams varying different parameters. In this research paper, an experimental study was executed to investigate the effect of interfaces on the behavior of the shear and flexural capacity of reinforced concrete beams. Eleven beam specimens were examined through experiment. Main variables in the research were interface location (Half, one third, quarter, and one fifth) and interface configuration (vertical and inclined) for both shear and flexural beams. The test results indicate that considerable reduction in the shear capacity and relatively small reduction in flexural capacity of reinforced concrete beams due to the interfaces weakness at the joint.

Keywords: Shear Strength; Flexural Strength; Concrete interfaces; Reinforced Concrete Beams.

1. Introduction

In the design of Reinforced Concrete (RC) beams, shear and flexural strengths were predominantly considered to avoid the failure of the members.

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Shear failure in reinforced concrete beams is one of the most undesirable modes of failure due to its rapid progression. This sudden type of failure made it necessary to explore more effective ways to design the beams for shear. It is well recognized that Reinforced Concrete (RC) beams should be designed to preclude shear failure, which is more critical than flexural failure [1, 2]. And also in the design of Reinforced Concrete (RC) beams, flexure is usually considered first, leading to the size of the section and the arrangement of reinforcement to provide the necessary resistance for moments [14].

Nowadays, a construction industry is growing rapidly throughout the world. The structural capacity of those constructions must be adequate to withstand any internal and external actions. The structural members must have adequate strength, give adequate services for any hazardous loading conditions and, should have to sustain in any accidental loading conditions. The quality of materials used in the construction project must be kept in suitable environment. But many construction faults were made on the construction sites due to many factors such as the shortage of budgets, materials, equipment's, and labor sources for the construction projects. Some portion of structural members may delay for a long time without casting the concrete in proper way. Delay of casting concrete occurred in many reasons such as: insufficient amount of fresh concrete supplied to placing the structure continuously, or sudden breaking down of some machines (mixer or pump or vibrator….etc.), or the large amount of concrete required to placing some large structural members such slabs or foundations so that their placing cannot complete at one day, or when weather conditions do not allow casting operations to continue at the same time [8, 6]. This affects the overall strength of the reinforced concrete members, because of the formation of interface on the member. Reported that, in case of delaying in the time period for casting, there is a significant effect on the mechanical properties of concrete [15]. Shear and flexural capacities are major influencing parameters due to delay of casting the concrete in reinforced concrete members [11].

The motivation of this study was to investigate the effect of interfaces on the behavior of shear and flexural strength of reinforced concrete beams varying the interface location and configuration of casting. Generally this research paper has focused on the experimental study to investigate the effects of interfaces on overall structural behavior of sear and flexural capacity of reinforced concrete beams under monotonic loading. Varying the interface location at different locations and interface configuration (vertical and diagonal) on the beam span, the shear and flexural behavior of reinforced concrete beams has been carried out using intensive experimental study.

2. Materials and Methods

2.1. Experimental program

The experimental study has been completed at the Southern Nations, Nationalities and People Regional state (S/N/N/P/R) Construction Bureau, Construction Materials Laboratory Hawassa, to study the effect of interfaces on the behavior of shear and flexural strength of reinforced concrete beams under monotonic loading. The main variables used in this study were the interface location and interface configuration. A 1m long beam was selected for the experimental program and both shear-critical and flexure critical beam specimens were prepared by providing an appropriate design for flexural and shear reinforcement's in the beams.

2.1.1. Specimens

Table 1: Test Specimens Notations.

S.N	Casting age	Ratio of length of late casting span to total span	Name of flexural beam specimens	Name of shear beam specimens
1	3 days gap	½ 1/3 1/3 ¼ ¼ 1/5	$FB\text{-}V_{1/2}$ $FB\text{-}V_{1/3}$ $FB\text{-}V_{1/4}$	$SB\text{-}I_{1/3}$ $SB\text{-}V_{1/3}$ $SB\text{-}I_{1/4}$ $SB\text{-}V_{1/4}$ $SB\text{-}I_{1/5}$ $SB\text{-}V_{1/5}$
2	Control beam casted at the same time	Monolithic	CFB	CSB

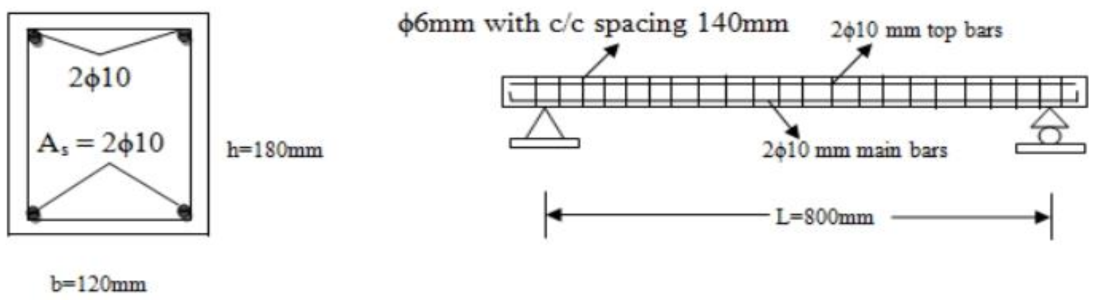

Figure 3: Detail of cross section of the flexural beam specimens.

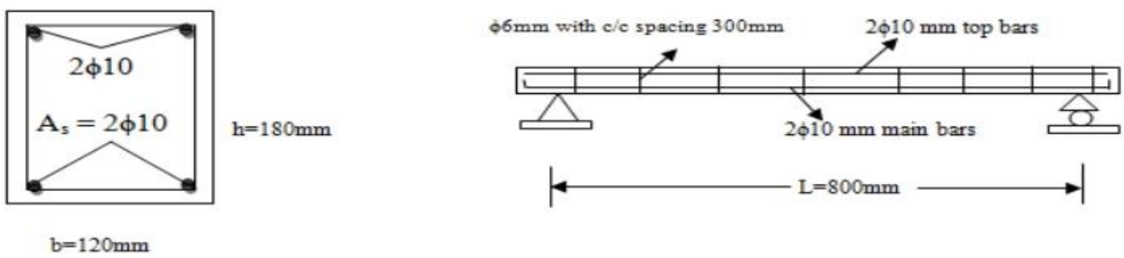

Figure 4: Detail of cross section of the shear beam specimens.

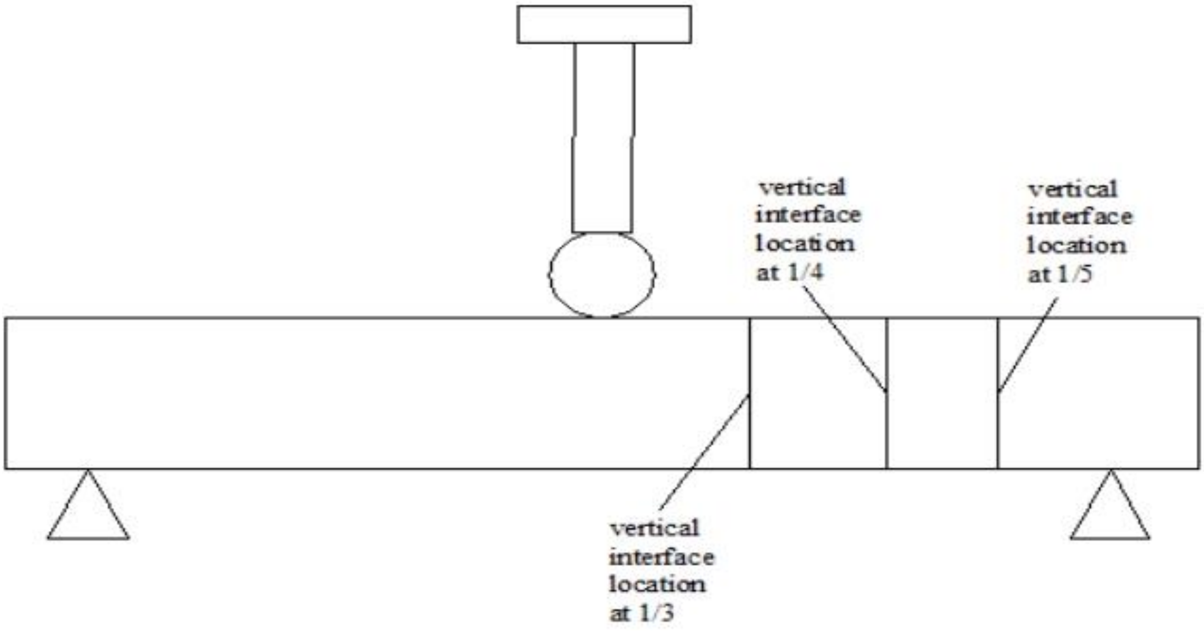

Figure 5: vertical interface locations for shear critical beam.

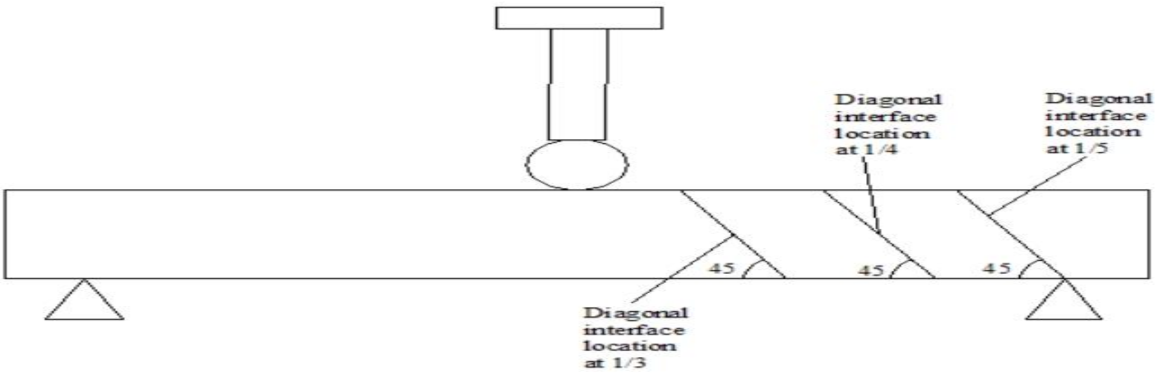

Figure 6: Diagonal interface locations for shear critical beam.

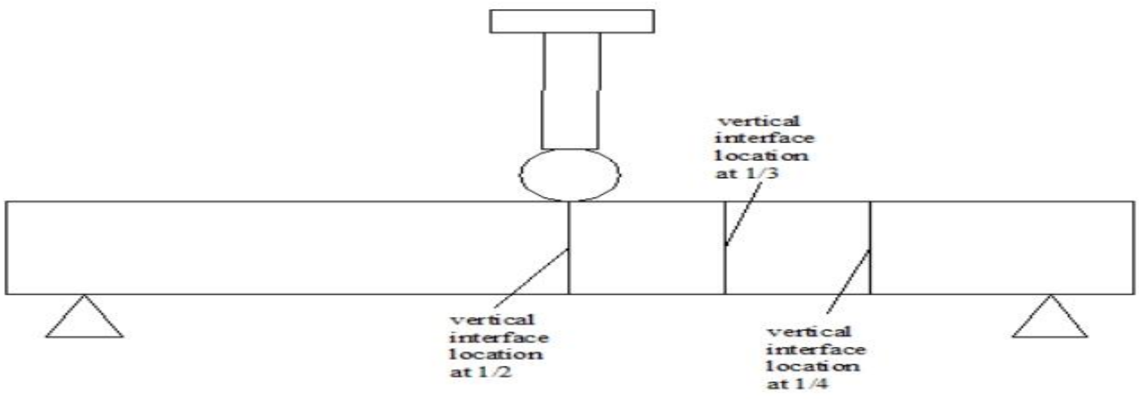

Figure7: vertical interface locations for flexure critical beam.

2.2. Materials

2.2.1. Concrete

The mix proportion of concrete was targeted to get normal strength concrete with suitable proportion of weight of the aggregates (cement: sand: course aggregate, 1:2:3) see table 4. In the mix proportions of concrete, ordinary Portland cement was used and the water cement ratio was 0.52. Workability of the concrete using slump test was found 55mm [14, 5].

A 150mm cubes specimens were prepared and tested using a compression testing machine shown in Figure 14 below. The maximum load achieved was used to calculate the ultimate stress of each cube. Concrete compressive strength test results for different ages are listed in the following table (Table 2).

Table 2: Compressive strength of concrete for different days.

S No.	Duration (days)	Sample name	Sample weight(kg)	Applied load(KN)	Compressive strength(MPa)	Mean(MPa) $\frac{(S1+S2)}{2}$
1	3	1	7.65	509.85	22.66	23.86
2		2	7.85	563.85	25.06	
3	14	1	7.53	534.58	23.76	24.64
4		2	7.93	574.24	25.52	
5	28	1	7.70	566.73	25.19	26.58
6		2	7.98	629.51	27.98	

Table 3: Concrete mix proportion.

Cement type	Ordinary Portland cement
Maximum aggregate size	20 mm
water content	187.2 kg/m^3
Cement content	360 kg/m^3
Fine aggregate content	750 kg/m^3
Course aggregate content	1088 kg/m^3
Water-cement ratio	0.52
Workability (slump)	55mm
Average compressive strength	26.58

Figure 8: Setup of compression test machine and workability (slump test).

2.2.2. Reinforcement bars

The reinforcement bars used for this research were 6mm plane bar and 10mm deformed bars which are free from any harmful defects. All the shear reinforcement (stirrups) in beams was 6mm and 10mm bars were used as a main reinforcement in the beams. As can be see here it was not tested the tension test for reinforcing steel due to the problem of availability of test machine. Rather, the property of these reinforcing bars was obtained from the manufacturer's manual. The tensile strength of reinforcements tested by ECAE testing laboratory for 6mm and 10mm used steel were 421MPa and 798MPa respectively.

2.3. Instrumentations

The beams were setups on the magnetic steel rod with a roller supports. A concentrated load was applied on the slender steel rod transverse to the longitudinal axis of the beam using a loading piston (shown in Figure 9) of maximum capacity 90KN.

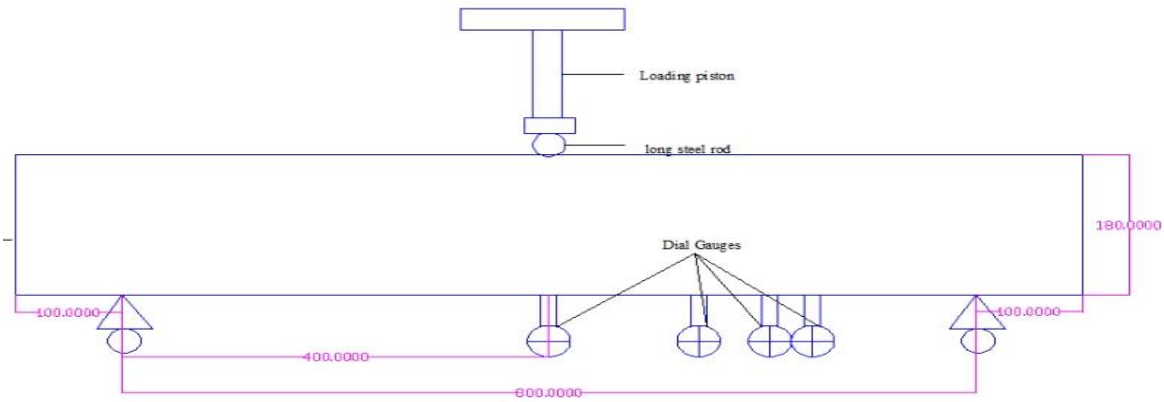

Figure 9: Model for test setup.

All beams were fully instrumented to measure the applied loads on the beams and the deflections. In brief, the instrumentation consisted of a load cell which measures the applied load (shown in Fig 10), deflection measurement tool dial gauge (shown in Fig 10) for the mid span and other critical-points.

Figure 10: Flexural testing machine a) Full setup b) Loading piston c) Digital load reading cell d) Dial Gauges.

3. Results and discussions

3.1. Shear-Critical Beam Specimens

As it was mentioned earlier, the load was applied monotonically in the interval of 5KN on the beam by using a loading piston on a long transverse steel rod up to failure. The deflection also measured by a manual displacement reading machine (Dial Gauges) with an accuracy of 0.01mm placing on the proposed positions.

A one-third span vertical interface shear critical beam (SB-V1/3) also failed by diagonal tension failure modes, because the test specimens were designed to fail in shear, the ultimate shear strength of the beam specimens was governed by web reinforcement provided. The primary crack started at the interface of the concrete (see Figure 11), but the crack didn’t continue with the proposed line of interfaces, rather it follows the diagonal tension crack direction. Finally the opening of this diagonal tension crack becomes excessive, and then the beam failed.

Figure 11: mode of One-third spanned vertical interface shear beam (SB-V1/3).

The same behavior was observed for quarter span vertical interface shear beam (SB-V1/4), the primary shear cracks initiated at the interface (see figure 12). Gradually this crack directed to the loading point. An increase in applied load opens the primary crack excessively. Finally the beam reaches its ultimate carrying capacity, the concrete on the top of loading point and bottom of the interfaces crashed out.

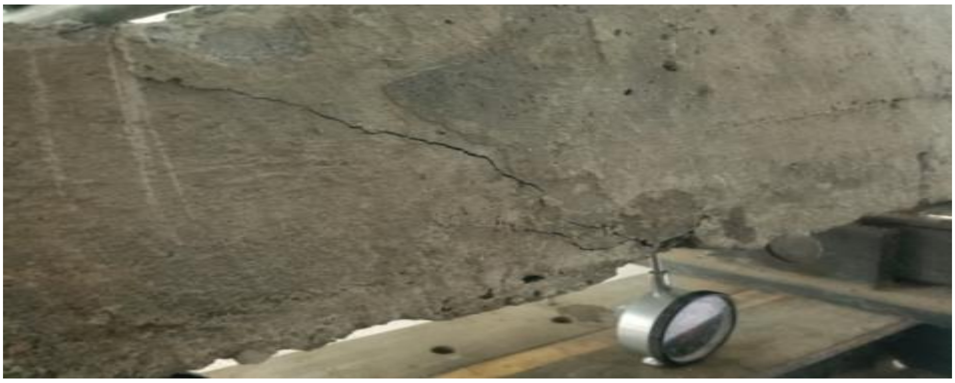

Figure 12: mode of Quarter spanned vertical interface shear beam (SB-V1/4).

For the one-fifth span vertical interface shear critical beam (SB-V1/5) as shown in figure 13 the primary crack starts near to support, which is at the interface location. This shear crack becomes wide and excessively opened and finally the beam to fail in diagonal tension failure which is the crack directed from support to the mid span or the loading point.

Figure 13: Failure mode of One-fifth spanned vertical interface shear beam (SB-V1/5).

3.1.1. Load-Deflection curves for vertical interface beam specimens

Figure 14 shows the load versus deflection behaviors of all vertical interface shear critical beam specimens. All the beams at the beginning of the curves moves in similar trend up to the failure load. But the control shear beam (CSB) gives the highest load carrying capacity to its failure [3, 10, 9 and 7]. The remaining beam specimens showed that an immediate change of the paths of the curve within relatively lower load as compared to CSB. SB-V1/5 gives the lowest load carrying capacity.

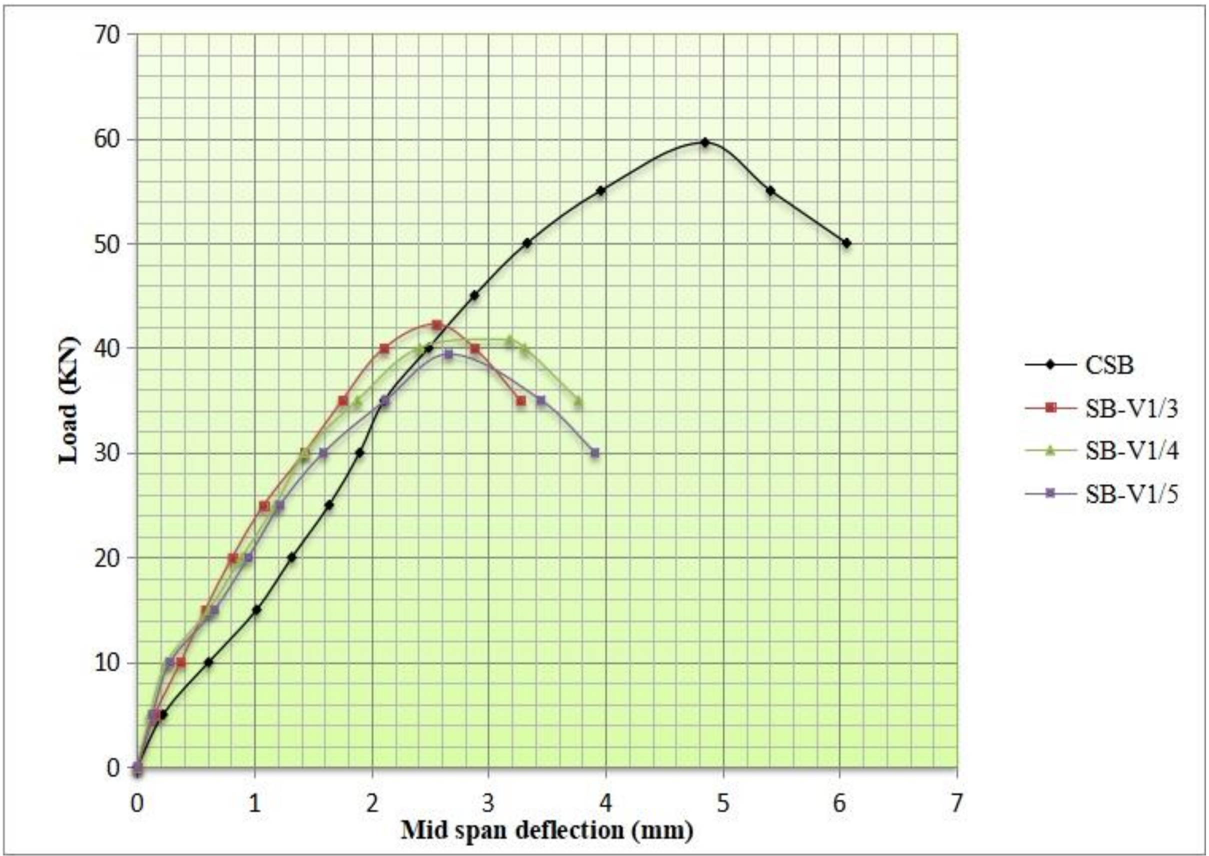

Figure 14: Load versus deflection curves for vertically casted shear beams.

The stiffness of the beams specimens with interfaces has shown closely similar behaviors with each other. Due to the size effect of the beam specimens, there were no significant changes in stiffness, because the distances between the locations of interfaces with each others are small. The beam length was limited with 1m total length and a clear span of 0.8m. So for this case the interface locations didn't shows significant effects on the beam stiffness. Quantitatively, the control shear critical beam (CSB) has been resulted a capacity of 59.59KN. But for a one-third span casted shear beam (SB-V1/3), the failure load was found 42.28KN which indicates 29.05% reduction in load carrying capacity with respect to CSB. For the quarter span vertical interface shear critical beam (SB-V1/4), the failure load resulted 40.8KN which showed 31.53% decreases in load carrying capacity as compared with the control beam. The final specimen for the vertical interface shear critical beam was a one-fifth span (SB-V1/5). This specimen also showed a decrease in load carrying capacity up to 33.88% with the control one. Figure 15 shows the variation of load carrying capacity of the proposed vertical interface shear beams.

Table 4: Variations in load carrying capacity of vertical interface shear beams

Beam specimens	Failure load (KN)	Variation (%)
CSB	59.59	0
SB-V1/3	42.28	29
SB-V1/4	40.8	31.53
SB-V1/5	39.4	33.88

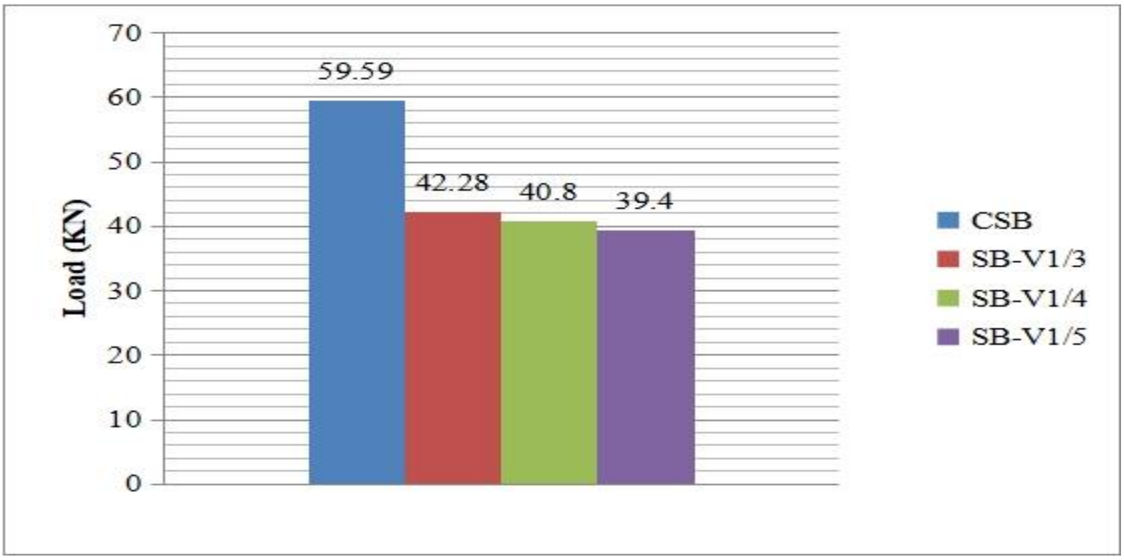

Figure 15: Variation of load carrying capacity for vertical interface shear beams.

As stated by the overall capacity of reinforced concrete structures significantly reduced due to the presence of interface. Results in the current study confirm the report of A.R [14].

Further, the deflection was measured at the interface location in addition to the mid span (see appendices B). Due to the size effect and the location of the interfaces, the measured deflections resulted small in all cases. But the deflection of the specimens increases when we move the interfaces from the support to the mid span. For the beam specimens SB-I 1/3, SB-I 1/4 and SB-I 1/5 the resulted deflections were 3.69mm, 3.21mm and 3.01mm respectively.

3.1.2. Failure mode of diagonal interface beam specimens

Unlike the vertical interface shear beam, all the beams with diagonal interfaces were exhibits similar failure modes. The primary shear crack initiated from the interfaces. Figure 23 shows the patterns of the crack is along the casting configuration. As stated by [15] Diagonal tension failure governs the current specimens, the propagation of cracks follows the formed interfaces which are weaken joint. This indicates that a significant effect is observed on the presence of interfaces in reinforced concrete beam.

The load carrying capacities of all the three diagonal interface beam specimens for resulted 51.87KN, 48.21KN and 44.84KN respectively. The results indicated that a decreases in the load capacity of 12.95%, 19.09% and 24.75% as compared with the control beam. But when we compare the results with vertical interface beams, it gives better shear capacity.

a) b) c) d)

Figure 23: Crack pattern of diagonally casted shear beams; a) CSB b) SB-I1/3 c) SB-I1/4 d) SB-I1/5.

3.1.3. Load-Deflection curves for diagonal interface beam specimens

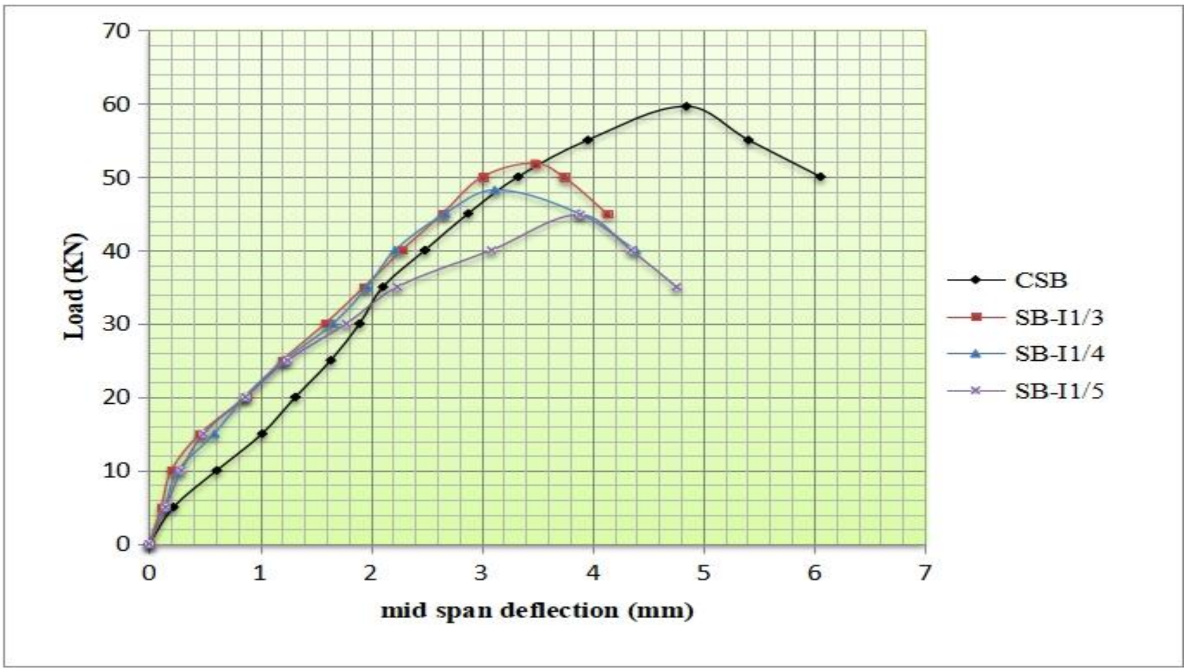

Figure 16: Load versus mid span deflection curves for diagonally casted shear beams

The above curves in figure 16 shows the load versus deflection diagram of the proposed beam specimens. It can be seen that the control beam specimens (CSB) totally dominated on load carrying capacity as compared with other beam specimens. All the beams were exhibits nonlinear load deflection after the first crack appeared. At the beginning, all the beams shows the same trends like the control beam, but after a certain interval of time, all the specimens loses their stiffness and change their direction of the pattern within smaller failure load. The beams with diagonal interfaces have shown smaller stiffness relative to the vertical interface. SB-I1/5 shows relatively lowest load capacity and highest mid span deflection as compared with SB-I1/3 and SB-I1/4. There is a proportional reduction of load carrying capacity of the proposed specimens (see figure 25).

Table 5: Variations in load carrying capacity of diagonal interface shear beams

Beam specimens	**Failure load (KN)**	**Variation (%)**
CSB	59.59	0
SB-I1/3	51.87	12.95
SB-I1/4	48.21	19.1
SB-I1/5	44.84	24.75

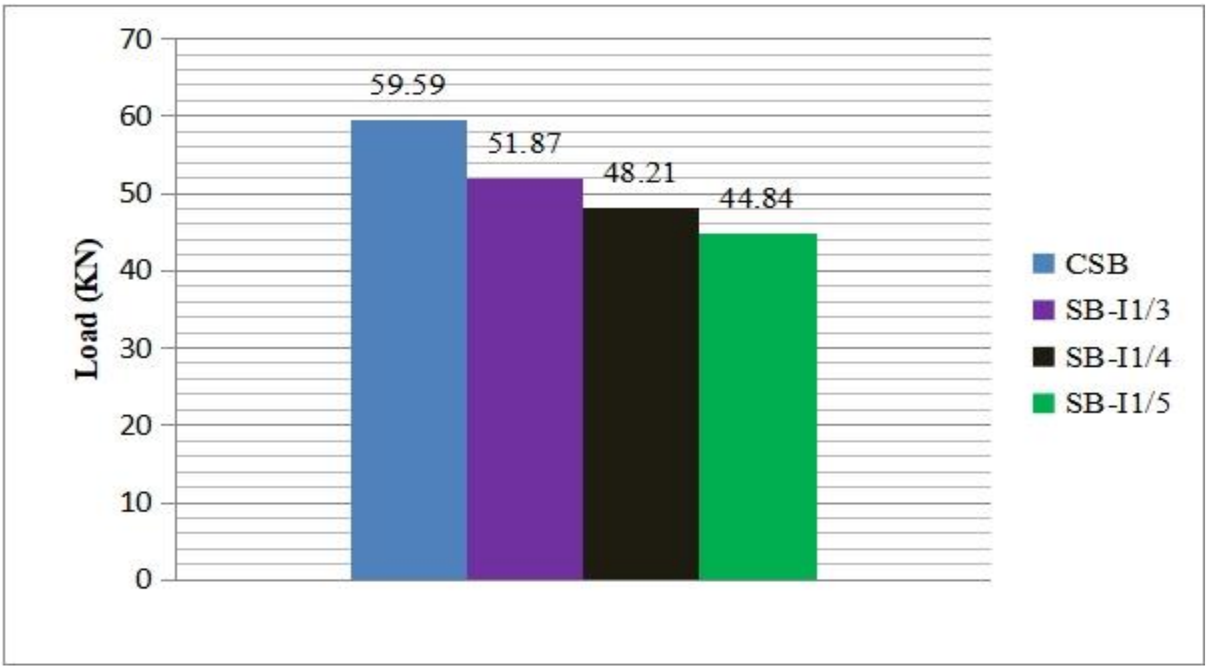

Figure 17: Variation of load carrying capacity for diagonal interface shear beams.

3.2. Flexural Beam Specimens

3.2.1. Failure mode of vertical interface flexural beam specimens

In flexural beam specimens casted monolithically (CFB) figure 18, small flexural cracks first appeared on the bottom of beam section along the concentrated loads, where the flexural stress is highest and shear stress is zero. Because the test specimen was designed to fail in flexure, the ultimate flexural strength of the beam specimen was governed by the yielding of tensile reinforcement in the bottom region and crashing of concrete in the compression zone. Therefore, as loading increased, those small flexural cracks opened excessively, finally the beam failed reaching its ultimate capacity.

Figure 18: Flexural cracks for control flexural beam (CFB) specimen.

Other interface locations flexure-critical beam specimen's exhibits similar failure behaviors with CFB. But, the Control Beam Specimen (CFB) has given a highest load carrying capacity as compared with the others.

A half span interface location flexural beam specimen (FB-V1/2) shows the same behavior as the control beam, at the mid span of the beam a branch of small flexural cracks was observed. But in addition to these flexural cracks, there was a crashing of concrete at the interface location; it is because of weakening of the joint at the interface. Then the flexural crack goes wider and wider, finally the beam failed. The load carrying capacity of this beam has a slight difference with the control beam, the load versus deflection behavior for all beams discussed later.

A one third flexural beam specimen (FB-V1/3) also shows the same behavior as the former half flexure, crushing of concrete at the interface location of beam specimens was observed. Relatively slight reduction of load carrying capacity was registered in this specimen.

For quarter span casted flexural beam (FB-V1/4) figure 19, small flexural cracks initiated at the mid span of the beam. Unlike the other flexural beam specimens, a sudden propagation of diagonal crack was observed starting from the interface formed. This crack becomes wider and the beam goes up to maximum carrying capacity, finally the beam failed. In this beam, it was found that the load was decreased dramatically and failed with small amount of loads. As can be seen in the figure the failure mode was not flexural failure rather its failure was shear-flexural failure, such kind of uncertainty occurred in this specimen only.

Figure 19: Failure of Quarter flexural beam (FB-V1/4) specimen.

3.2.2. Load-Deflection curves for vertical interface beam specimens

The following figure shows the load-deflection behaviors of flexural beam specimens.

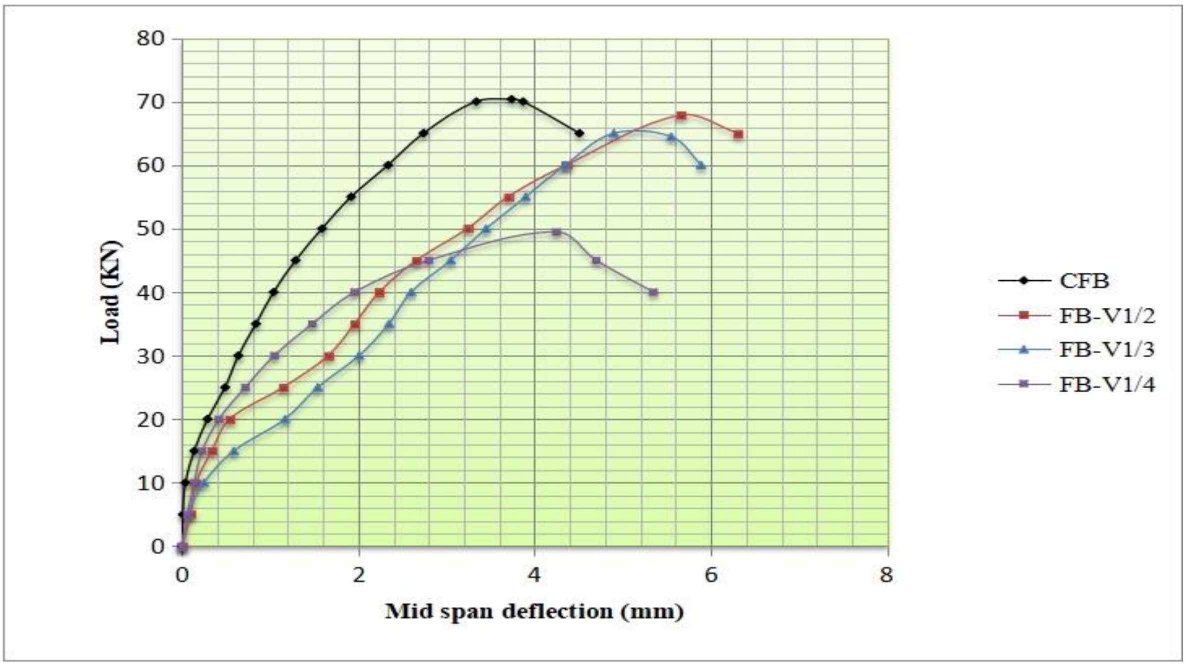

Figure 20: Load versus deflection curve for flexural beams.

In the above curve (see Figure 20), the load versus mid span deflections curves of all the flexural beam specimens were plotted in combined. In the first stage "At-flexural-cracking stage", all the beams behaved similarly and approximately linearly. Beam stiffness at this stage was almost identical, representing the behavior of the un-cracked beam with the gross moment of inertia of the concrete cross section. After cracking, all the beams were experienced a nonlinear load-deflection behavior. The trends of the curves were slightly similar, and the load carrying capacity of the other beams decreases slightly when the interface location moves from mid span to the support. Fully casted flexural beam or control flexural beam (CFB) shows a highest load carrying capacity and it was stiffest as compared with the others. The stiffness of the beams with interface noticeably decreases as we seen in the above graph. This shows that the presence of interfaces weaken the stiffness of the beams and increase its ability to exhibit the deformations under application of loads. Unlike the others beams, quarter span flexural beams shows a greater reduction of load reductions as compared to control beam. Erratic result and failure mode was appeared in FB-V1/4 (figure 20). This beam showed shear-flexure failure rather than flexural failure. The crack also initiated at the interface location. This was uncertainty observed during the experiment. As can be seen in the graph, the maximum load for control beam (CFB) was found 70.36KN with a mid-span deflection of approximately 4.51mm. For a half span casting beam specimen, the load was 67.86KN, which is decreases by 3.55% in load carrying capacity. A one-third span casted beam specimen (FB-V1/3), the maximum load was found 64.48KN. When we compare this with the control beam (fully casted beam) there is a decrease in load carrying capacity with approximately 8.35%.

Finally, quarter span casted beam specimen (FB-V1/4), the failure load was found 49.49KN, and the mid span deflection for this beam read 5.35mm. A dramatic decreases of load observed in this beam, which was reduced 29.66% with the control beam.

The following table shows the variation of reduction in load carrying capacity of the proposed beam specimens in percentages (%). It is clearly observed that the capacity of beams decreases when the location of the interface is near to the support.

Table 6: Variations in load carrying capacity of flexural beams.

Beam specimens	**Failure load (KN)**	**Variation (In %)**
CFB	70.36	0
FB-V1/2	67.86	3.55
FB-V1/3	64.48	8.35
FB-V1/4	49.49	29.66

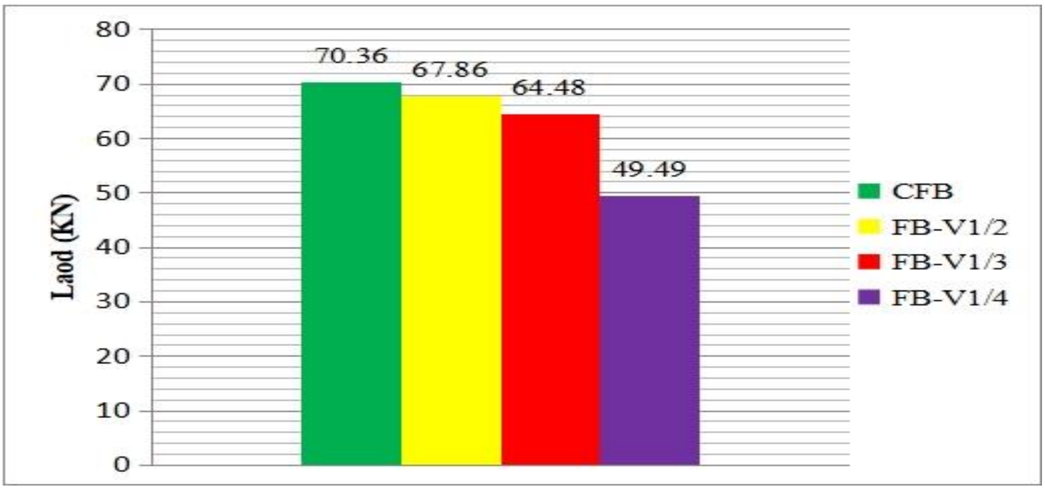

Figure 21: Load variations for flexural beam specimens.

The Chart shown in figure 21 indicated that a slight decreases in load carrying capacity when the interface moves from the mid span to the support location. But, only FB-V1/4 gives an erratic result in this case. This may be due to uncertainty occurred by experimental studies. Generally, it can be seen that, the presence of interfaces on the flexural beam specimens has insignificant effects on the structural capacity of the proposed specimens.

In addition to the mid span, it was tried to measure the deflection in the proposed interface location. The following graphs show the relative load versus deflection curves at one third and quarter span of the beams. As can be seen in the graph 30, the control beam gives better stiffness with a lower deflection as compared to the interface location (one-third span). This indicates that the presence of interface affects the stiffness and overall capacity of the structural members.

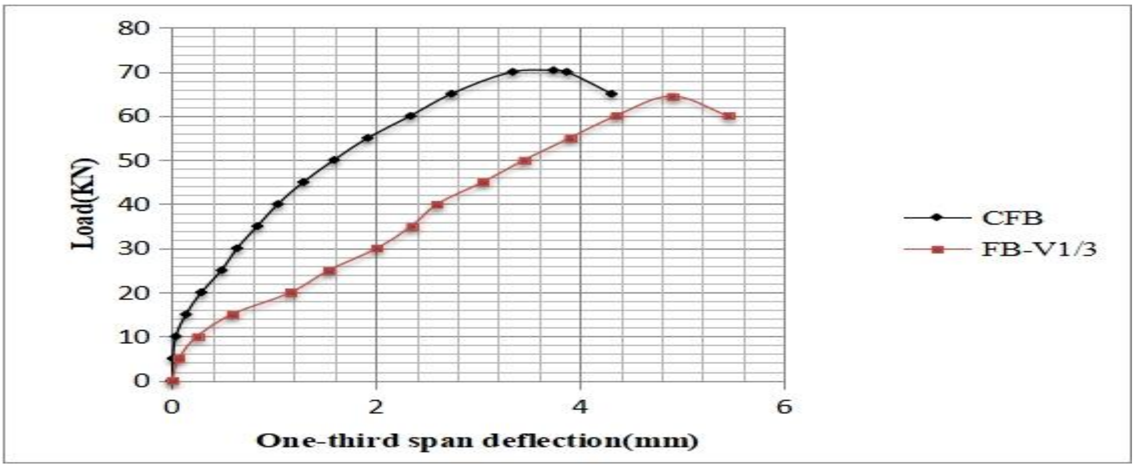

Figure 22: Relative load-deflection curves for flexural beams (CFB vs FB-V1/3).

In the figure 22 below, the graphs starts in the same trend for both specimens, but quarter span cast beam (FB-V1/4) was registered lower load capacity and relatively higher deflection than the control beam. Smaller stiffness observed on FB-V1/4 that affects the deflection of the beam.

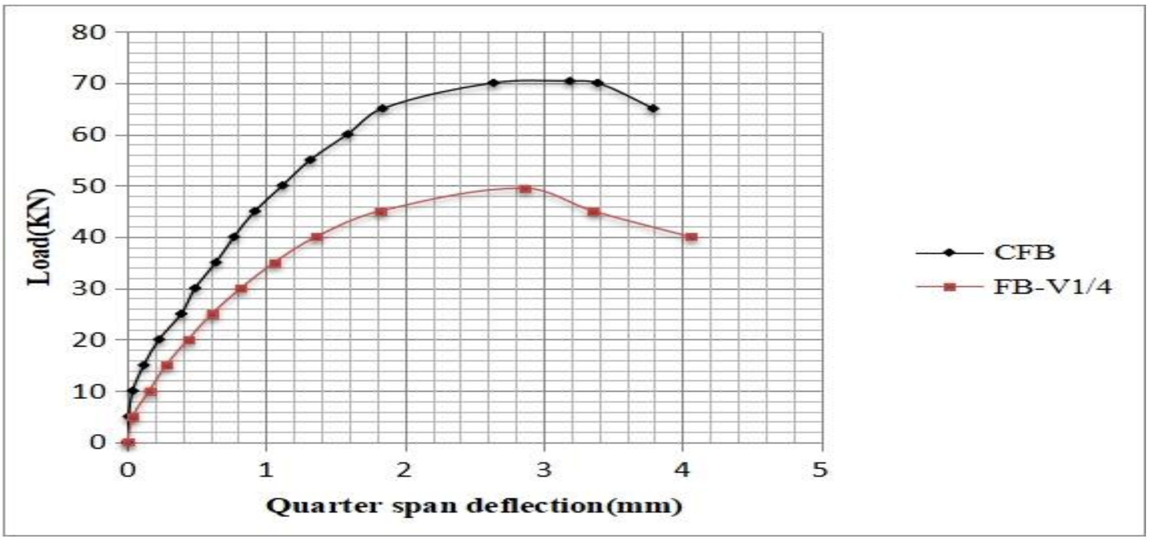

Figure 23: Relative load-deflection curves for flexural beams (CFB vs FB-V1/4).

3.3. Effects of interfaces on the overall structural capacity of reinforced concrete beams

All of the beams specimens which proposed in this study affected by the presence of interfaces on reinforced concrete beam. The effects of interfaces on the flexure-critical beams were relatively small as compared with shear critical beams. The location of the interface also slightly affects the load carrying capacity of beams. The beam which interfaces located near to the supports gives smallest load carrying capacity relative to other flexure critical, and the beam FB-V1/4 shows shear-flexure failure mode rather than flexural failure mode. This was uncertainty that the researcher observed during the experimental study.

On the other hand, for shear critical beams, it was found that a significant effects on the shear capacity of the member. The inclined/ diagonally configured beam specimens give relatively better load carrying capacity that of vertically casted beams. But in both cases, when the interface location moves from the mid span to near support, it can be observed that there are proportional reductions in load carrying capacity.

4. Conclusions

An intensive full scale experimental study has been carried out to investigate the overall behavior of shear and flexural capacity of reinforced concrete beams with interfaces. Totally eleven test specimens were prepared for testing with their classification as flexure critical and shear-critical beam specimens. After conducting the experimental program, the following conclusions were pointed out;

- The overall shear and flexural capacity of reinforced concrete beams are affected by the presence of interfaces on the beam portion due to the delay of casting concrete, which forms weak joints at the interfaces.
- When the interface location goes from mid span to the support region gives proportional reduction in load carrying capacity on shear critical beams, particularly on the diagonal interfaces shear beam specimens.
- The configuration of the interface also affects the structural capacity of the members, especially on shear capacity of the beam. Inclined/diagonal interface configuration gives better resistance capacity as compared with that of vertical interface configuration.
- Flexural beams specimens, which varies only with interface location shows that a slight reduction in load carrying capacity of the beam specimens, when the interfaces goes from the mid span to the support region.
- An inclined or diagonal interface of beam specimen’s results shows that the crack pattern follows the direction of the interfaces, whereas the crack patterns didn’t follows the direction of interfaces for the vertical interfaces beam specimens.

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