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Improving the concrete sections after removing intermediate support of RC continuous non-prismatic beam

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ABSTRACT

An experimental study was conducted to investigate the performance of the 2-span continuous reinforced concrete beams of different section depth after removing the middle support by adding steel fibers or steel plates. The beams were loaded monotonically with two-point loads. One continuous beam and six simply supported beams of non-prismatic section were tested using two different content of steel fibers and three different locations of steel plates welded to the reinforcement. The test results reveal that using inclined steel plates at the region of changing of cross section thickness at the middle support increase the load capacity of the beam significantly up to 75% of the continuous beam capacity, and a significant warning before failure is shown. Adding steel fibers to the concrete has less influence on the capacity of the beam. The failure mode of the beams with no middle support is the same, but with different values of deflection. The inclined steel plate again is the most effective way to decrease the deflection because of the increased stiffness of the cross section. To achieve the same capacity of the continuous beam after removing the middle support, it is recommended to use horizontal steel plates welded to the reinforcement at the region of the middle support extended within one fourth the length of each span of different thickness to avoid the stress concentration resulted from the large deflection at that region.

Keywords: Continuous Beam, Non-prismatic, Steel plate, Strengthening, Middle support

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1. Introduction

Continuous beams are statically indeterminate structure with two spans or more. They are used in bridges and building structures for their advantages in providing more strength and serviceability due to the increase in the applied vertical loads and the decrease in maximum positive moment and maximum deflection as compared to simply supported beams. In addition, continuous beams help in reducing the thickness of the supported slab or deck [1]. The spans in a continuous beam can be different in length, thickness, or both, which causes a varying stiffness and internal forces in each span. In a non-prismatic beam, when there is a change in thickness, it is necessary to add an intermediate support to avoid the large deflection where the moment of inertia of the section is variable.

There are available theoretical and experimental studies on the investigation of the behaviour of the reinforced concrete continuous beams with constant thickness reinforced with steel or different type of fiber bars in addition to strengthening the continuous beams externally by using FRP sheets [2-9]. Some research work has carried out on non-prismatic symmetric simply supported beams [10-11].

In engineering design, the economy in time and cost is essential. The objective of this study is to investigate experimentally the performance of a continuous reinforced concrete beam having two different section thickness by replacing the intermediate support with an internal strengthening to provide larger span.

2. Experimental program

The experimental work involves fabricating; casting, and testing one continuous RC beam and six simply supported RC beams of rectangular section with two different cross-sectional area, 100 mm wide by 100 mm deep (section 1) and 100 mm wide by 200 mm deep (Section 2). The total length is 2000 mm. The span length is 1000 mm. Figure 1 illustrates the geometry and reinforcement details for the 2-span continuous RC beam. All beams had clear concrete cover of 20 mm, the bottom reinforcement for the section with the smaller thickness $3\phi6$, and $3\phi8$ for the other section. The top reinforcement was $2\phi4$ along the beam length to support the stirrups on addition to $2\phi8$ reinforcing bars to resist the negative moment at the intermediate support of the continuous specimen only. Closed stirrups $\phi6$ placed at spacing equal to 50 mm for section 1 and 80 mm for section 2 to achieve the required shear strength. The design of the specimens complies with the ACI-318 [12] recommendation. The intermediate support was removed for the rest of specimens; one of the specimens had no internal strengthening, amount of steel fiber (0.5% and 1.0%) was added to the concrete for two of specimens. For the remaining three specimens, two steel plates of (60x50x25mm) in the span with smaller thickness and (60x150x25mm) in the other span were welded to the reinforcement. Two adjacent steel plates at the middle of the beam at the face where the section thickness varied, two steel plates were placed vertically at a distance 20 cm right and left of the intermediate face and two inclined plates with 45 degree were placed at a distance 10 cm right and left of the intermediate face.

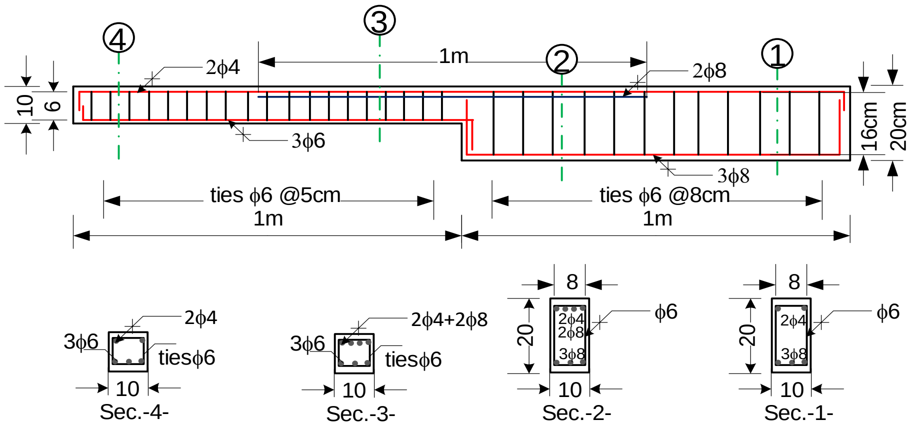


Figure 1. Dimensions and reinforcement details of the continuous beam

2.1. Materials

2.1.1 Concrete

The concrete mixture was designed according to ASTM [13] to gain a cylinder strength of 35 MPa. Three cylinders of 150x300mm dimension were used to obtain the concrete compressive strength after 7 days and 28 days. The density of the concrete was 2390 kg/m ^{3}. The mixture design proportions, and the determined compressive strength are given in Table 1.

2.1. 2 Reinforcement

The properties of the reinforcing steel bars used for the flexural and shear reinforcement are given in Table 2.

2.1.3 Steel fibers

Steel fibers were added to the concrete for two specimens with (5% and 1%) content in the middle third of the beam length, In Table 3, the properties of the steel fibers are given.

2.1.4 Steel plates

The steel plates were used for three beams in three different ways to investigate the improvement in strength of the beams in case of using the plates. The properties details of the plates are given in Table 4.

Table 1. Concrete mix and compressive strength

Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water (kg/m^3)	Superplasticizer (litter/ m^3)	$f'c_{(7days)}$ (MPa)	$f'c_{(28days)}$ (MPa)	Slump (cm)
475	720	960	190	4	25	32	19

Table 2. Steel reinforcement properties

Sample No.	Nominal Diameter (mm)	Elongation %	Yield Strength fy (MPa)	Ultimate Strength Fu (MPa)
ASTM A 615 [14]		9%	400	600
1	8	9.86%	525	825
	Nominal Diameter, mm	Reduction in area %, min	Yield Strength Min. fy (MPa)	Ultimate Strength Min. Fu (MPa)
ASTM A 82 – 02 [15]		25%	485	550
2	6	41%	635	905

Table 3. Mechanical properties of steel fibers*

Commercial name	Configuration	Property	Specifications
Dramix ZC 50/0.5	Hooked Ends 	Density	7860 kg/m3
		Ultimate strength	1130 MPa
		Modulus of elasticity	200x103 MPa
		Strain at proportion limit	5650 x10-6
		Poisson's ratio	0.28
		Average length	50 mm
		Nominal diameter	0.5 mm
		Aspect ratio (Lf/Df)	100

*Supplied by the manufacture

Table 4. Steel plate properties

Sample	Yield Tensile Stress (MPa)	Ultimate Tensile Stress (MPa)	Elongation in 50 mm%, (min)
Steel Plate	325	451	28

ASTM A36 [16] Specification

Grade A36	Elongation % (min)		Tensile Strength MPa	Min. Yield Stress, MPa
	in 50 mm	in 200 mm		
	23	20	400-550	250

2.2 Beams assembly

After removing the intermediate support from the continuous beam, the beams became simply supported and the intermediate third of the beam was strengthen in different ways to investigate the performance of beams. In Table 5, the beams descriptions are listed and Figure 2 illustrates the geometry and reinforcement details for the six beams.

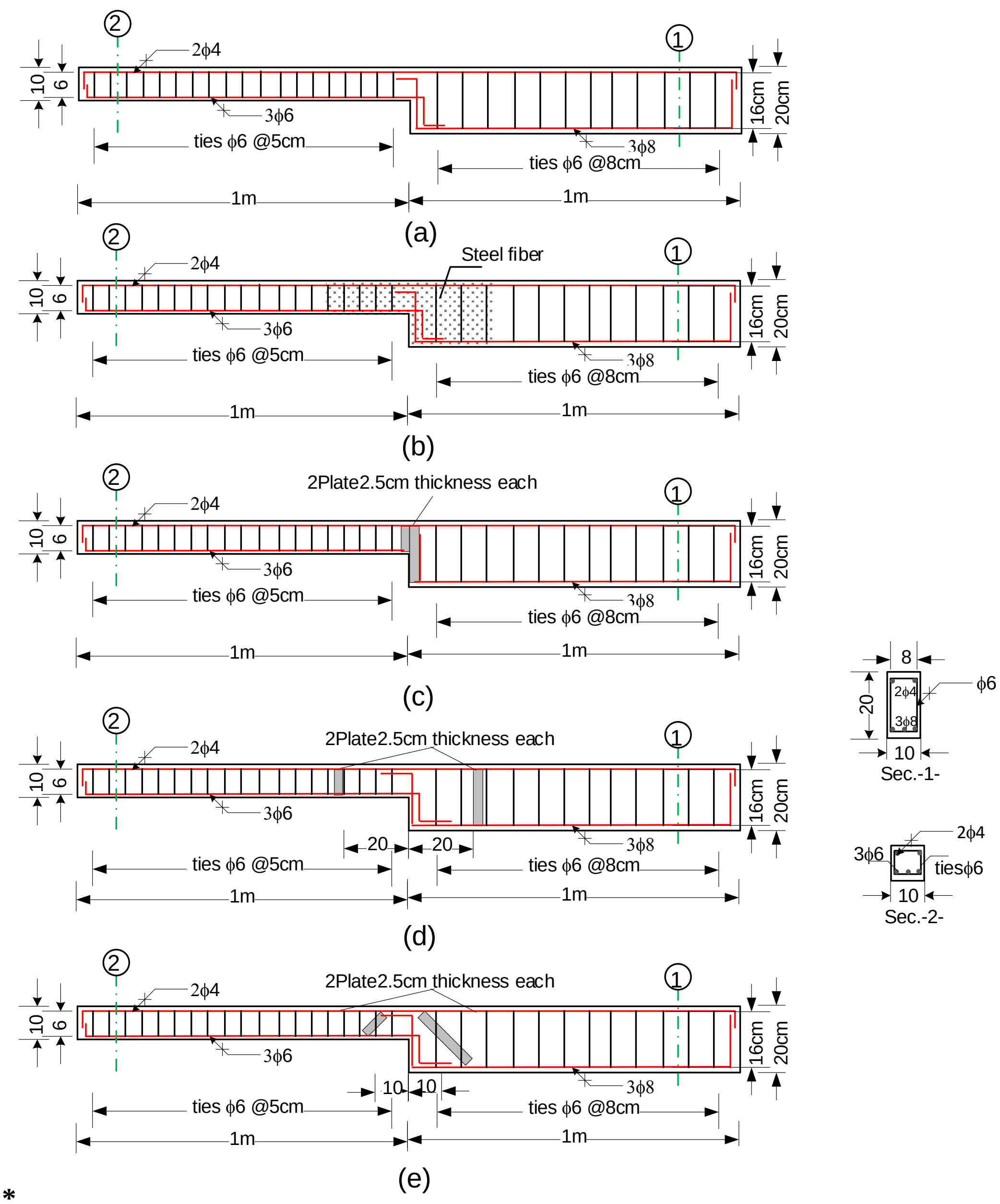


Figure 2. Dimensions and reinforcement details of the simply supported beams
(all dimension is in cm)

a) without strengthening b) strengthened with steel fiber c, d, and e) strengthened with steel plates

Table 5. Beam specimens' descriptions

Beam	Description
BC	Continuous Beam
BSN	Simply supported beam
BSF0.5	Simply supported beam 0.5% steel fiber
BSF1	Simply supported beam 1% steel fiber
BSPA	Simply supported beam with two adjacent steel plate
BSPF	Simply supported beam with two adjacent steel plate
BSPI	Simply supported beam with two inclined steel plate

2.3 Test setup

The beams were tested using hydraulic universal testing machine (MFL system) under concentrated loading subjected to steel beam which is simply supported that the loading is transferred to the specimens by two point load applied at the distance equals half the supported length of each span. The deflection was measured by means of (0.01mm) accuracy and (30mm) capacity dial gauges placed at the half-length of each span. For each loading value, the deflection was recorded until reaching the maximum capacity of the beam. Figure 3 shows the beam test setup and Figure 4 shows a scheme of the tested beams in addition to the theoretical reactions and bending moment calculated by statical analysis.

Figure 3. Beam test setup

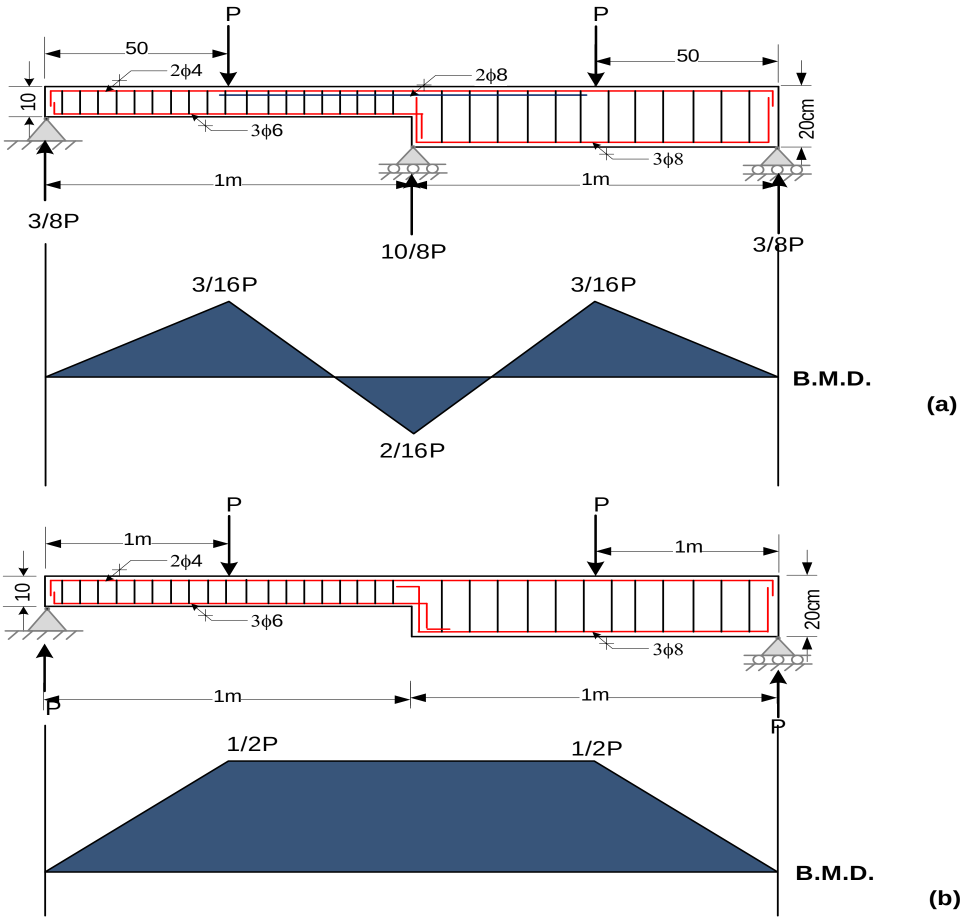


Figure 4. Scheme of loading

a) Continuous beam b) Simply supported beam

3. Results and discussion

3.1 Ultimate failure load: All beam specimens were loaded up to failure, the failure loads and cracking loads are listed in Table 6. The beams experienced different loading value due to the different support condition, concrete mix and the presence of steel plates.

The failure load of the continuous beam is 42.5kN, which is more than the failure load values of all other beams. Beam BSN has the less load resistance. With the addition of steel fibers by 0.5% and 1% content, the performance of the S.S. beam improved by 16% and 24%, respectively, but they have 48% and 56% of the BC load capacity. Concerning the beams with plates, it can be seen that the beam with inclined plates has the largest load capacity, which is 75% of the BC load capacity, while BSPF has the least failure load, which is 59% of the BC, but it is still more than BSN by 27% of its load capacity.

For the cracking load, BC resisted 74% of the ultimate load after first crack, while BSN needed less time to fail after first cracking with a proportion of P_{cr}/P_u of 67%.

For the other beams, the proportion of P_{cr}/P_u ranges between (29%-41%), which is an evident of improving the beam strength when adding steel fibers or steel plates after removing its intermediate support. It seems from the obtained results that the most effective way to improve the strength capacity of the beam is by attaching the inclined plate to the reinforcement at the region where the stiffness of the cross-section changes resulting in moment redistribution.

Table 6. Experimental results for the tested beams

Beam	Cracking Load P_{cr} (kN)	Failure Load P_u (kN)	$P_{u)}$ /$P_{cr)}$ %	$P_{u)}$ /$P_{u)}$$_{Cont.Beam}$ %
BC	11.5	42.5	25.8%	100.0%
BSN	9	13.5	67%	32%
BSF0.5	8.5	20.5	41%	48%
BSF1	9	24	38%	56%
BSPA	8.5	29	29%	68%
BSPF	9	25	36%	59%
BSPI	10.5	32	33%	75%

3.2 Mode of Failure: The tested beams mainly had two modes of failure; a flexural crack initiated in the span of the less thickness of the continuous beam at the bottom at the tension zone. With the increase of loading, the number and width of cracks increased. After yielding of the tensile reinforcement, one crack propagated towards the load location resulting in crushing of concrete. At the same time, one diagonal crack propagated at the middle support starting from the span with the smaller thickness toward the span of larger stiffness, both of actions led the beam to fail.

For BSN, small crack initiated in the tension region, then a large diagonal crack propagated towards the stiffer span at the middle of the beam and a collapse occurred with crushing of concrete at that region due to the large deflection.

Concerning the other beams, a same crack pattern was experienced by one large diagonal crack extended from the bottom of the middle beam towards the span with larger stiffness because of the large deflection due to stress concentration at the region where the section stiffness changes. However, the crack width was not the same for the beams. The beams at failure in Figure 5 demonstrate the crack pattern.

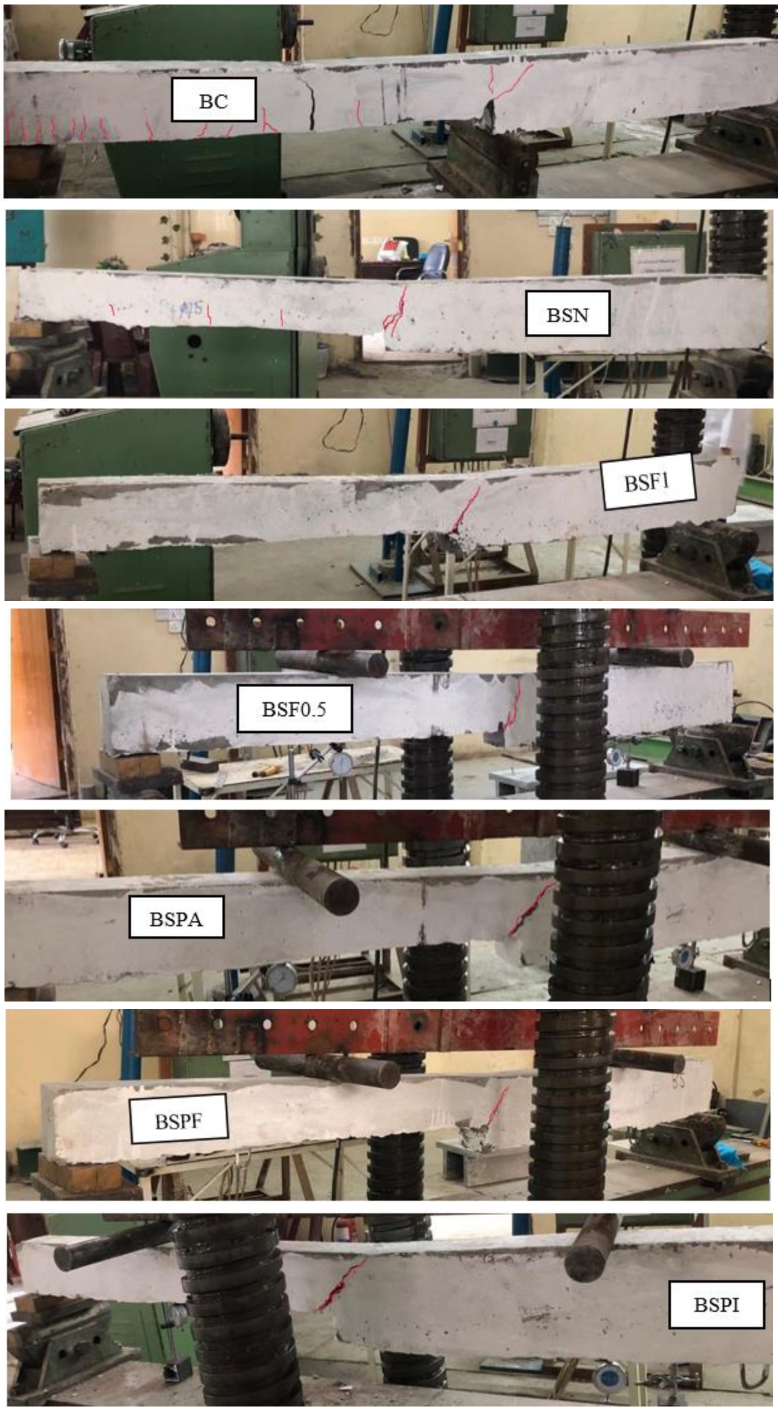
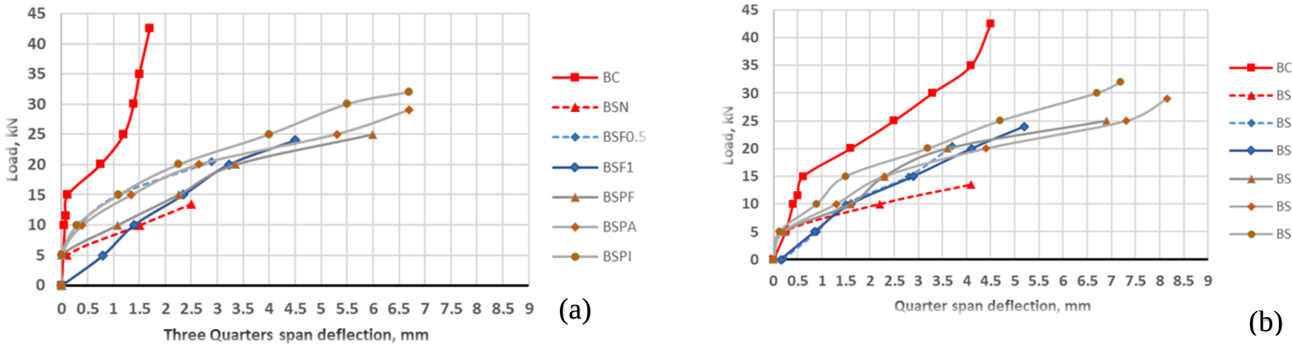


Figure 5. Failure modes of tested beams

3.3 Load-deflection relationship: Figure 6 shows the load-deflection relationship at the quarter span and three quarters span of the beam total length, the graphs reveal that the deflection values for all beams for the span with larger thickness (three-quarters the length) are more than those values for quarter span of the smaller thickness due to the decrease in stiffness (EI). In addition, linear behaviour is observed for the load-deflection curves until cracking load, after that the relationship become nonlinear. For beam BC, minimum value of deflection is obtained for both locations, which is reasonable due to the smaller moment applied to the beam.
The simply supported beam with no strengthening, BSN, experienced the largest deflection for a certain value of load.

Regarding the other beams, it can be seen that the beams with plates deflected less than the beams with steel fiber at most of load values. However, the beam with the inclined plates shows less deflection than BSPA even if they have approximately the same failure load.



(a) (b)

Figure 6. Load-Deflection Relationship for the Tested Beams:
a) Quarter span of the beam; b) Three quarters span of the beam

4. Conclusions

Based on the experimental results obtained to investigate the enhancement in the strength of continuous beam after removing the middle support and adding steel fibers or steel plates within the middle third of the beam, the following conclusions could be drawn:

The ultimate load carried by the beams increases when adding steel fibers up to 1% by 24% of the load carried by the beam without middle support but is less than the continuous beam by 44%.

The steel plate welded to the reinforcement in three different ways improves the performance of the beam without middle support. The inclined plates have the most significant effect with an increase in the load capacity of 43% compared with the beam without middle support and 75% of the continuous beam, which is an evident to moment redistribution.

Regarding the failure mode, a flexural failure with cracks in the tension zone of the span with less stiffness of the continuous beam was observed, while the all the other beams fail due to the large deflection and stress concentration at the region of the change in the section stiffness with wide and deep diagonal crack towards the stiffer span.

There is no enough time between the first cracking and the failure and the beam without middle support, for the other specimen there is a significant warning before failure especially for beam with inclined plates.

The deflection response of the beams is less in the span with larger thickness. In addition, at a certain value of load the deflection of the beams with steel fibers is more than beams with steel plates.

It is recommended to use a horizontal steel plate welded to the reinforcement at the middle span of the beam to increase the flexural strength and decrease the deflection and hence increase the ultimate load.

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