Effect of Using Different Aspect Ratio of Longitudinal Steel Plates in Reinforced Concrete Beams

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Abstract. In the past few years, new techniques have emerged using steel plates instead of traditional reinforcement in the reinforced concrete beams. This study deals with using a new method for reinforced concrete beams using steel plates instead of traditional steel bars with different thicknesses of (4, 5, and 6 mm) placed vertically inside the lower part of the beam. Four reinforced concrete beams were cast and tested under a two-point load. All beams had the same cross-sectional area of reinforcement and dimensions of 2100 mm in length, 350 mm in height, and 250 in width. The results showed that as the thickness of the steel plate increases, the samples would have greater resistance until more deflection is produced. In addition, there is a reduction in the crack load, ultimate load, and yield load when replacing reinforcing bars with steel plates. In which, a reduction in crack load by about 11.1, 15.5, and 22.2% plate thicknesses of 4,5,6 mm respectively, compared to reference beam that had a deformed steel bar (Dia. 16 mm). In addition, a reduction in yielding load was observed about 42, 53, and 60% for steel plate thickness of 4, 5, and 6 mm respectively, compared to the reference model. Finally, the cracks for all the steel plate specimens compared to reference specimens were wider and smaller.

Keywords: Flexural reinforcement**;** steel plates; yield load; ultimate load; crack load.

Introduction

Concrete beams use as a significant part of structural frames has witnessed a noticeable improvement in the last decades. The reinforced concrete structure consists of bundles to carry the horizontal loads over the openings. Indeed, very little literature has been seen to discuss the utilizing of steel plate as a flexural member up to date; although it has been used to strengthen the reinforced concrete beams, there are no attempts to use the plates as an alternative to reinforcing stirrups, and other used the external steel plate or internal instead of flexural reinforcement. Alfeehan [1] presents a practical and theoretical study on the effect of replacing internal tension reinforcement with external steel plates on cracking, structural deformations, and their maximum resistance, using a new technique by linking the internal shear steel with the outer plates.

The results show that the use of steel sheets as an External steel reinforcement showed a restriction in the measured displacements at the center of the beam and an increase in the thickness of the plate led to an increase in the acceptability of the sill. Steel replacement ratio with 33, 67, and 100% yielding declination drops of 12.5, 7.7, and 4.6% respectively. Thamrin and Sari [2] presented the results of an experimental study on the behavior of strengthened concrete beams reinforced with steel plate bonded on the flexural capacity. Test results showed that steel plates bonded to the web increase the stiffness of the beam and the flexural capacity by values ranging from 6 to 28%.

Mansor et al. [3,4,5] present experimental work on the behavior of bubbled wide reinforced concrete beams of four longitudinal plates of 3mm thickness, and the dimension was 165×1700 mm and included a circular opening with 146 mm diameter and 26 mm the distance between any opening to get the same area of equivalent stirrups. The experimental results reveal that the exterior strain of longitudinal and transverse plate in legs is 17 and 2%, respectively, less than strain at a yield of stirrups, and the ultimate is less about 62% and 68%, respectively. Hadi et al. [6] revealed the results of an experimental work of reinforced concrete beams with steel plate checker and its performance compared to sample reinforced with deformed steel bars. Compared to the reference sample, Samples reinforced with a horizontal plate showed a lot Greater ductility. Concrete models reinforced with vertical plate showed weak ductility, with an eventual severe reduction in ultimate load limit state. All plate-reinforced specimens gained access to ultimate loads ranges from 90 to 96% of theoretical values.

Zuhdiy and Abbas [7] conducted the effect of corrugated steel plate strengthening on the structural behavior of reinforced concrete box girder using corrugated steel plates with vertical and horizontal corrugation and studying the effect of the shape of cells using rectangular and circular shape with the same web width and strengthening the circular cell with a flat plate. The experimental results showed that in the first group, using the vertical and horizontal corrugated steel plates strengthening increased the ultimate load by (7.14 and 11.03%) compared with the control box girder and decreased the crack width. The results also showed that in the second group, the circular and circular strengthened cells increased the ultimate load by (17.85 and 29.22%) compared with the control box girder with rectangular cell and decreased the crack width. In this research, due to the fast development of manufacturing by Computer Numerical Control (CNC) machine and some difficulties in longitudinal reinforcement stand with high cost and time entailed. Also, some efforts have been made to discover new techniques are adopted for longitudinal reinforced concrete beams depend on using the elongated steel plate as flexural reinforcement instead of deformed steel bars. The objective of the study will be to investigate the flexural behavior of reinforced concrete beams using longitudinal steel plates instead of the traditional longitudinal reinforcement with different numbers, thicknesses, and dimensions as an equivalent area of longitudinal reinforcement in concrete beams.

Experimental work

Description of beams specimens and details. Four reinforced concrete beams were cast and designed to fail in flexure. All specimens have the same cross-section and the amount of reinforcement. They had an overall length of 2100 mm, an overall depth of 350 mm, a width of 250 mm. The reference beam specimen was reinforced with 2-Ø16 mm steel bars, and the others reinforced with 4, 5, and 6 mm steel plate thickness as longitudinal tension reinforcement at the bottom face beams. Also, to prevent shear failure of the section, 10 mm diameter stirrups at 125 mm c/c spacing were provided in the beams. The beam reference (A-1) details are shown in Figure 1 and Table 1 sums up the description names of beams specimens.

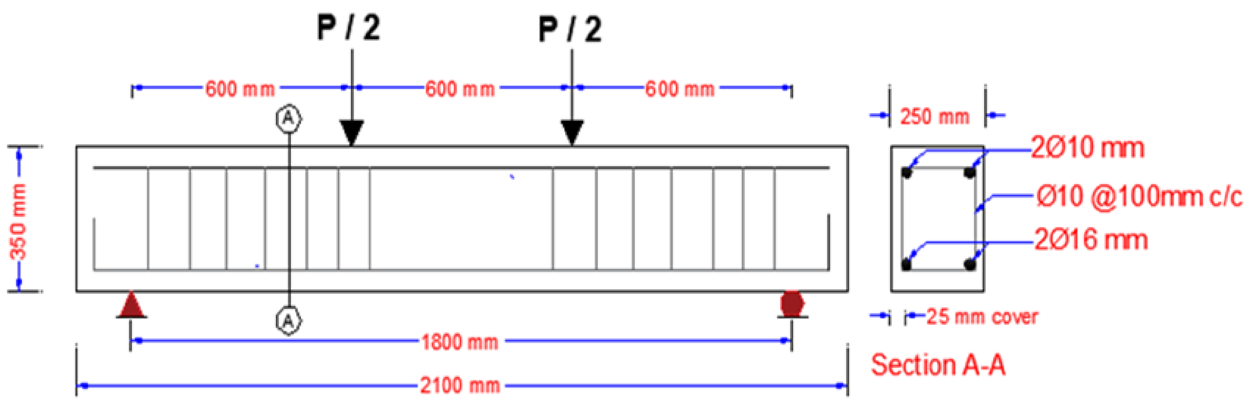
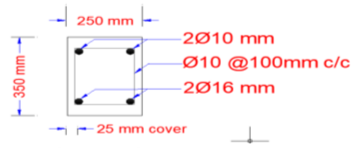
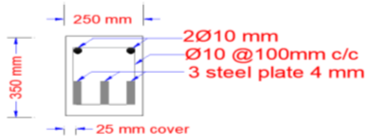
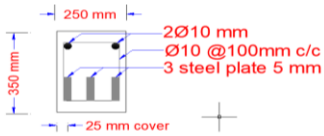
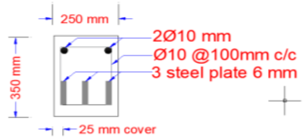


Figure 1. Details of reference beams A-1.

Table 1. The description names and details of beams specimens.

Name of Beams	Main reinforcement in the tension zone	Sketch
A-1	2Ø16 in Tension zone	
APV4mm	Three longitudinal steel plate of 4mm thickness	
APV5mm	Three longitudinal steel plate of 5mm thickness	
APV6mm	Three longitudinal steel plate of 6mm thickness	

Concrete ingredients. The commercial brand of Tasluoja, which is classified as Type I of Portland cement, was used in the experimental work of the current study. This cement was found to satisfy the ASTM C150-16 [8]. After (48 hours), the beams were covered with canvas and sprinkled continuously with tap water. The temperature of the water inside the curing tank is set (23°C) according to ASTM C192 [9] for (28 days). The specimens were white painted and marked after they get enough curing to allow for the observation of cracks growth through testing. Self-compacting concrete with compressive strength of fc'=30 MPa. The natural sand that was used as fine aggregate and the coarse aggregate throughout the present study were brought from Al-Sudour region, Diyala governorate, Iraq. The coarse aggregate with (12 mm) maximum size. Both fine and coarse aggregate were fulfilling the ASTM C33-11 specification limits [10]. Table 2 shows the mixing proportions of the concrete.

Table 2. Mix proportions.

Material	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	w/c	Slump (mm)
C30	490	897	700	230	47%	120mm

Steel reinforcement and steel plates. Tensile tests of steel reinforcement were found out using three (450 mm) long specimens for each diameter test were performed using the available testing machine. According to ASTM A615/A615M-05a and ASTM A496-02, the average yield and ultimate stresses are listed in Table 3. Steel plates were tested in Engineering College of Baghdad University according to ASTM A370-05-a specification. Table 4 illustrates the result of typical testing samples 450 mm long.

Table 3. Yield and ultimate stresses and elongations of steel bars used.

Nominal bar diameter (mm)	Measured Diameter (mm)	Bar cross-area (mm^2)	Yield stress (MPa)	Ultimate stress (MPa)	% Elongation at ultimate stress
10	10.2	78.54	610.8	725.86	11.7%
16	15.8	201.061	528.9	642.32	13.2%
20	19.8	314.15	442.3	699.04	15.5%

Table 4. Result of testing of steel plate.

Thickness of steel plate (mm)	Measured Thickness (mm)	Yield stress (MPa)	Ultimate stress (MPa)	% Elongation at ultimate stress
4	3.8	400	545.6	22.5
5	4.8	416.5	563.21	24
6	5.8	433.6	580	25.3

Beam Fabrication, Test Setup, and Instrumentation

Longitudinal bars of (2Ø16 mm) were used at the bottom of the reference beam as tension reinforcement. While (2Ø10 mm) longitudinal bars were at the top to hold stirrups and put in position for all beams with conventional design. Three specimens relate to replacing deformed steel reinforcement with a steel plate in a longitudinal direction. All steel plates are fixed with reinforcement from the bottom with four positions for each plate. Steel reinforcement for all specimens is shown in Figure 2. The beams were simply supported over a span of 2100 mm, and the loads were applied using a 600 kN hydraulic testing system (Jet Materials Ltd. Company). The deflected shape of the beam at the midspan and under-point load applied was measured by three dial gauges.

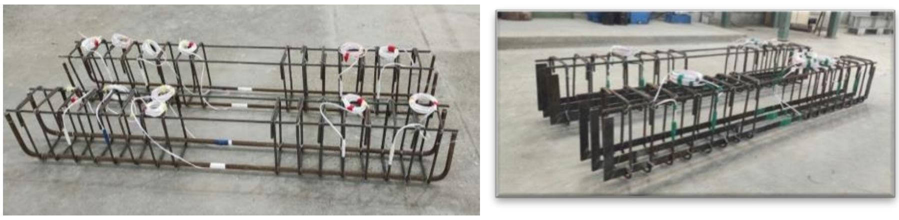


Figure 2. Steel reinforcement and steel plate arrangement.

Testing Procedure

A hydraulically universal testing machine of (600 kN) capacity was used to test all beams. The supports and load points beams were equipped for testing by checking the positions. After setting the beam machine and strain gauge with a data logger, the LVDT is fixed at the middle of the upper surface of the specimens. Rubber pads were placed under the line loads to provide an even surface. The test load with two points load is shown in Figure 3. The strain gauge position was pointed in the middle of the two intermediate main longitudinal steel reinforcement bars. The stain gauges wires were connected to the data logger at the beginning of the testing day. The concrete strain was measured using an electrical strain gauge (PFL-30-11) with resistance 120Ω and dimensions 30 mm length and 10 mm width. The steel strain gauges were fixed in the middle top face of the beam specimens.

Figure 3. Position of beams in the load-testing machine.

Experimental Results and Discussion

The measurements from testing the beam specimens were used to obtain actual information that has been used in the analysis of the beams specimens. Their values are shown in Table 5.

Table 5. Hardened properties of the four specimens.

Specimen designation	f'c (MPa), cylinders 28 days	fct (MPa), cylinders 28 days	fr (MPa), at 28 days	modulus of elasticity, Ec (MPa)
A-1	32.460	2.958	3.908	26779
APV4	33.564	3.306	5.435	27229
APV5	33.578	3.306	5.557	27234
APV6	31.784	2.941	3.849	26497

Aspect ratio. The aspect ratio is defined as the ratio of the steel plate width to the thickness measured at the bottom of the cross section. Table 6 shows the aspect ratio of specimens and explains the polynomial relationship for steel plate thickness. It is clear that the aspect ratio decreased from (APV4mm specimen) to 6mm steel plate (APV6mm). This means that the aspect ratio has undergone a gradual increment by the decrease of the steel plate thickness where increased. It can be concluded that the optimum aspect ratio is between:

$$5.5 < \text{aspect ratio} < 8.0 \tag{1}$$

Table 6. Aspect ratio for the specimen.

Beam Specimens	Width (mm)	Thickness (mm)	Aspect ratio
A-1	16	16	1
APV4mm	33.33	4	8.3325
APV5mm	26.66	5	5.332
APV6mm	22.2	6	3.7

Behavior of beams subjected to loading. As stated in the third chapter, two points of load have been subjected to the beam. Three dial gauges were used to read the deflection, and a data logger was utilized to monitor the strain in concrete and steel, and the crack widths at a loading of 10 kN to failure of beams have been read using the micro-cracks reader. The track of the development of deflection, strain, and width of cracks at each level of loading have been measured directly on the beam to follow up the growth, sequence, and pattern of cracking [11,12].

Result of specimens. Table 7 tabulated the strength characteristics for total specimens (ultimate load, deflection, yield load at first crack, and the deflection at (yield, ultimate load). Care was taken to determine the load at which the first crack was formed.

Table 7. Summary of test results for specimens.

Specimen designation	Dimension of steel plate (mm)	1st flex. Cracking load Pcr (kN)	Py (kN)	Pu (kN)	Δcr (mm)	Δy (mm)	Δu (mm)	Ductility $\frac{\Delta u}{\Delta y}$	Failure mode
A-1	2Ø16 bars	45	215	252.7	2.37	11.35	18.5	1.63	Flexural
APV4	3(4×33.33)	40	125	161	4.962	14.67	38.893	2.65	Flexural
APV5	3(5×26.66)	38	100	150	4.786	8.25	38.587	4.67	Flexural
APV6	3(6×22.2)	35	85	169.4	4.045	8.264	36.646	4.43	Flexural

The discussion of results will be concentrated on the effect of using steel plate as a substitution to steel bars with 4, 5, and 6 mm in the vertical and horizontal direction. The following will be discussed:

a) Beam load carrying capacity (cracking load, yield load, and ultimate load).
b) Deflection in mid span of specimens and ductility.
c) Strain in longitudinal reinforcement and steel plates.

d) Cracking pattern (crack width, crack spacing, and the number of cracks).

Cracking load. It can be seen from Table 7 and Figure 4, the crack load decreased about 11.1, 15.5, and 22.2% for APV4, APV5, and APV6, respectively, as compared with A-1; it indicates that replacing the reinforcing bars with the steel plate effects lead to reduce the ultimate load and this reduces crack load, this is also clear from comparison the pattern of the crack of the steel plate specimens and reinforced steel specimens. The cracks for all the steel plate specimens compared to A-1 specimens are wider and less number. This is due to the fact that dowel action, which is considered as one of the main factors that decrease the cracks, is lower in the steel plate than that of the reinforcing steel specimens due to the high bond between steel reinforcement compared to a steel plate, it is worth here of mentioning that the properties of the concrete are the same for all the specimens which will neglect the effect of other factors related to the concrete properties that may contribute to cracks.

Yielding load. Table 7 and Figure 5 show the yielding load values that have been obtained from load-deflection figures. Where an equivalent cross-section of steel plate has been used, it can be seen that the yielding load decreased by about 42, 53, and 60% for APV4, APV5, and APV6, respectively, as compared with A-1. This decrease is due to the difference between the yielding strength of steel plate and reinforced steel bars, where the latter has higher-yielding strength than the former [13].

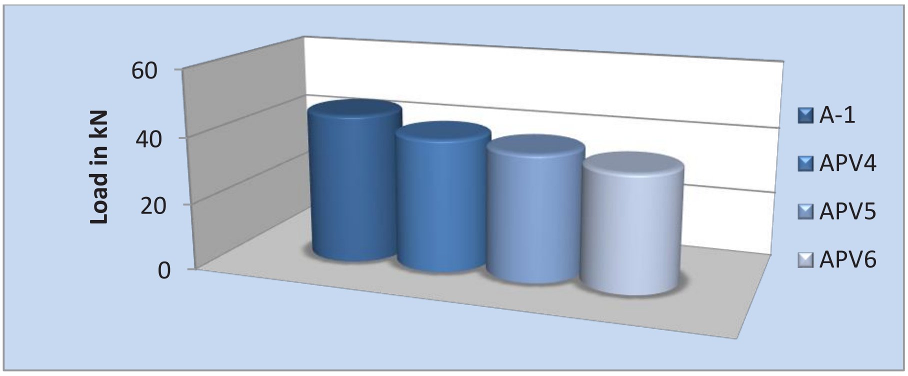


Figure 4. Crack load for APV4, APV5 and APV6.

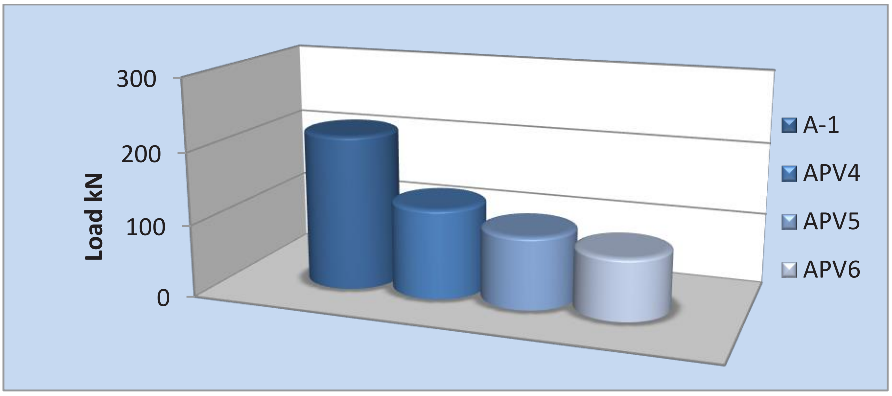


Figure 5. Yield load for APV4, APV5 and APV6.

Ultimate load. Table 7 and Figure 6 show the ultimate load that has been resulted from load-deflection figures. It is apparent that the ultimate load decreased by 36, 40, and 33% for APV4, APV5, and APV6, respectively, as compared with A-1. This decrease may be resulted from the difference between the ultimate load of the steel plate and reinforced steel bars, where the latter has higher-yielding strength than the former [14].

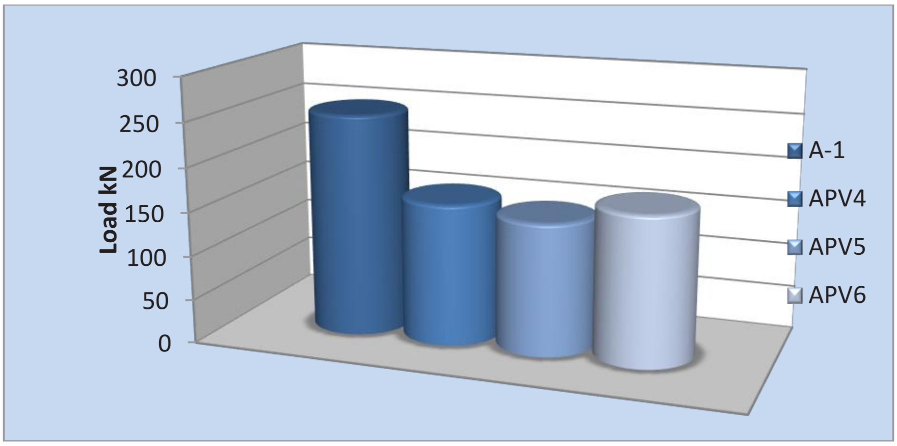


Figure 6. Ultimate load for APV4, APV5 and APV6.

Ductility index. It is clear from Table 7 and noticed that the ductility of A-1, APV4, APV5, and APV6 increased by 1.63, 2.65, 4.67, and 4.43, respectively, compared with A-1. This is readily supporting the definition of ductility index, which is to undergo considerable deflection prior to failure. From the above table it is clear that the deflection prior to failure load is increased with the increase of the thickness of the steel plate [15].

Load versus deflection relationship. The values of deflection monitored at yield load and ultimate load that has been attained from the diagram of load-deflection are shown in Table 7. Clearly, as in Table 7, at yield load, the deflection has been increased in specimens when using steel plate by about 110, 108, and 98% for APV4, APV5 and APV6, respectively, compared with A-1. This can be understood since the ductility of the steel plate has been larger than that of steel reinforcement bars. It is also clear from Table 7 that at ultimate load, the deflection is decreased in each specimen when using steel plate by about 29, 27.31, and 27.18% for APV4, APV5, and APV6, respectively, as compared with A-1. This can be understood since the ductility of the steel plate has been larger than that of steel reinforcement bars. Figure 7 shows the load-deflection curves specimens**.** The diagram reveals that the load-deflection curve behaved linearly up to the point of the crack for all of the samples, and beyond the yield point, the curve will be controlled by the yield strength corresponding to each steel plate sample. Also, when the loading increased, the curve shows non-linear behavior since it exceeds the point load at which it yields.

First crack width. Based on the results of tested specimens of beams at various stages of loading, the following conclusions can be pointed out from those figures:

- The crack's order of formation was observed to be random due to the constant moment applied within the beam middle of the third region, and as the applied load increased, cracks grew upward accordingly.
- Within the beam middle third area, the cracks seem to be vertical, and this can be attributed to the pure moment that has been applied on this segment of the beam. Outside this segment, the cracks became somewhat inclined, this can be attributed to the presence of shear forces besides the moment for beam A-1.
- Since the highest moments is existed in the middle third of the beam, then this segment witnessed the first cracks.

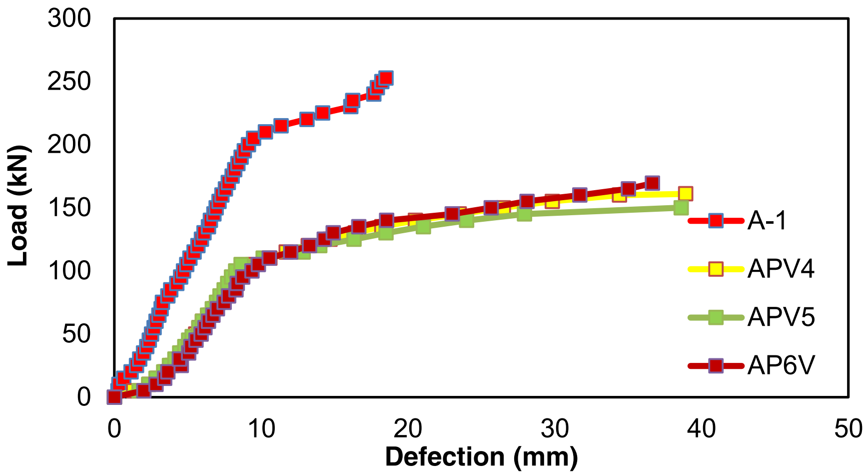


Figure 7. Load versus central deflection for specimens.

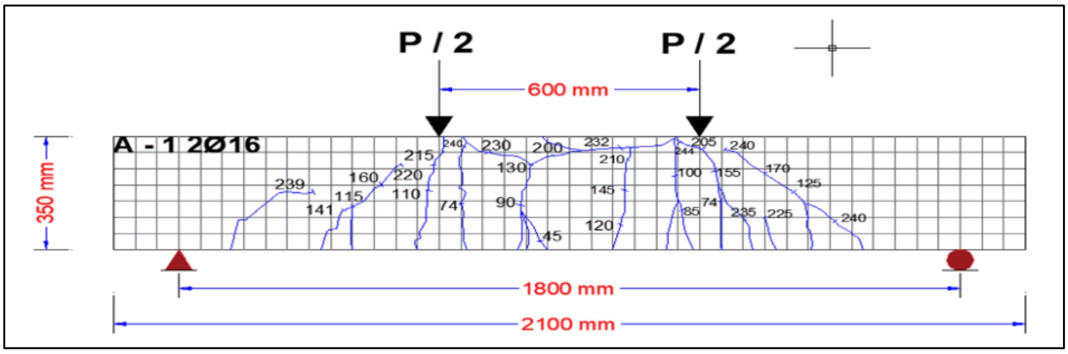
First crack width. It is clear from Table 8 that the width crack at the mid-point of the beams at loads corresponding to crack and yield is the maximum crack width if compared with other cracks. For beams with steel plates, three main cracks dominated through the test, under the load points, and in the middle of the beam. The failure occurs in flexure with a separation of concrete in the compression zone. The first crack randomly appears in the middle third of the span, which is the zone with the maximum moment and the widest one. Figure 8 shows the crack pattern of beams.

Table 8. First crack width and number of cracks for Group A.

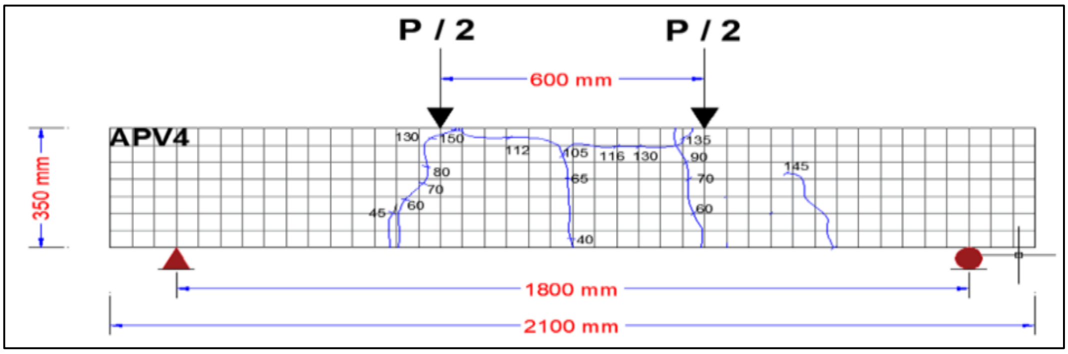
Specimen designation	1st Crack at Cracking		1st Crack at Yield		**Crack width at failure Measured by a ruler (mm)**
	Load (kN)	Width (mm)	Load (kN)	Width (mm)	
A-1	45	0.03	215	2.4	4
APV4	40	0.02	125	4	9
APV5	38	0.02	100	0.5	15
APV6	35	0.01	85	0.2	10

Conclusion

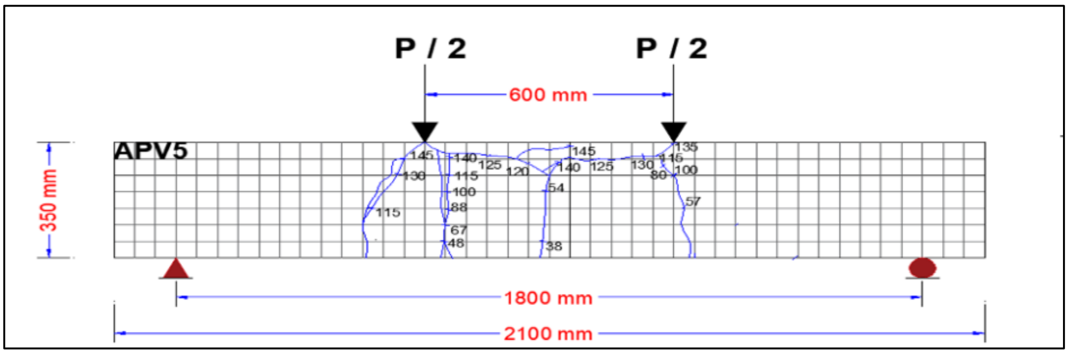
- It indicates that replacing the reinforcing bars with the steel plate effects reduces the ultimate load, which reduces crack load about 11.1, 15.5, and 22.2% for thickness 4, 5, and 6 mm, respectively, compared with the reference specimen.
- Replacing the reinforcing bars with the steel plate led to reducing the yielding load of about 42, 53, and 60% for thickness 4, 5, and 6 mm, respectively, compared with reference specimens.
- When steel plate is used, the deflection at yield has been seen to increase by about 110, 108, and 98% for steel plate thickness 4, 5, and 6 mm, respectively, compared with reference specimen. In addition, the deflection at ultimate load was decreased in specimens by about 29, 27.31, and 27.18% for thickness 4, 5, and 6 mm, respectively, as compared with the reference specimen.
- With increasing the thickness of the steel plate, the measured crack load and ultimate load and yield load are increased.
- The yield and ultimate load are increased by increasing the steel reinforcement's cross-sectional areas in the beam.
- The cracks for all the steel plate specimens compared to references specimens are wider and less number.
- It concluded that replacing the reinforcing bars with the steel plate has decreased the crack load, ultimate load, and yield load to approximately one-third on average.



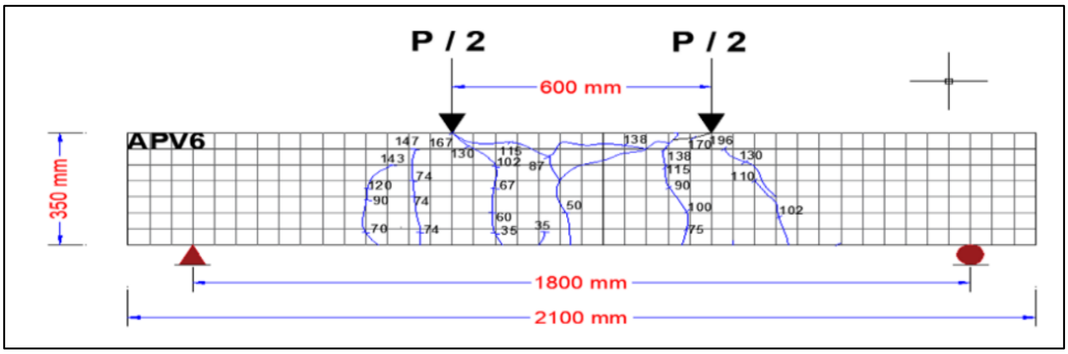
a- Crack Pattern of A-1.



b- Crack Pattern of APV4.



c- Crack Pattern of APV5.



d- Crack Pattern of APV6.

Figure 8. Crack pattern of beam.

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