

Reinforced Concrete Moderate Deep Beams with Embedded PVC Pipes

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ABSTRACT:

The test results of six reinforced concrete moderate deep beams with embedded PVC pipes are reported. The tests studied the effect of installation of PVC pipe on behavior of reinforced concrete moderate deep beams. The test parameters were the diameters and locations of the pipes. The dimensions of beams were 1000 mm length, 150 mm width and 300mm depth. One beam was constructed without pipe as control and the remaining five had embedded pipes. Four pipe diameters were used: 25.4, 50.8, 76.2, and 101.6 mm and these pipes were inserted longitudinally either at the center of the beams or near the tension reinforcement. The beams were simply supported and tested under central concentrated load up to failure. The test results indicated that, the pipe diameter less than 1/3 of the beam width had limited effect on the capacity and rigidity of beam. For larger pipes, the ultimate strength of beams decreased between 16.7% and 33.3% and the beams stiffness decreased between 103% and 297%.

Keywords: Deep beam, PVC pipes, Shear strength, Diagonal tension, Hollow

عتبات خرسانية مسلحة معتدلة العمق والحاوية على انابيب بلاستيكية

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الخلاصة:

في هذه الورقة البحثية تم تناول النتائج التجريبية لفحص ست عتبات خرسانية مسلحة معتدلة العمق وحاوية على انابيب بلاستيكية. ان الهدف من هذا البحث هو دراسة تأثير كلاً من أقطار ومواقع الانابيب البلاستيكية على سلوك العتبات الخرسانية. ان ابعاد تلك العتبات هي: 1000 مم طول و 150 مم عرض و 300 مم ارتفاع. احد هذه العتبات تم انشاءها بدون انبوب لغرض المقارنة اما العتبات المتبقية فقد احتوت على انابيب بأقطار مختلفة (25.4 و 50.8 و 76.2 و 101.6 ملم) وتلك الانابيب تم تنصيبها اما في مركز مساحه العتبة او بالقرب من حديد تسليح الشد. تم فحص هذه العتبات تحت تأثير حمل مركز وسطي الى حد الفشل وكانت ذات اسناد بسيط. النتائج التجريبية وضحت التأثير المحدود للأنبوب على مقاومه وصلاده العتبة عندما يكون قطره اقل من ثلث عرض العتبة. اما الانابيب ذات الاقطار الاكبر فقد قلت مقاومه العتبات بين 16,7% الى 33,3% وكذلك قلت صلابه العتبات بين 103% الى 297%.



1. INTRODUCTION:

ACI-ASCE committee 426 [1] classifies beams according to the shear span-to-depth ratio into: deep, moderate, and ordinary beams. A beam has a ratio smaller than 1.0 named as deep beam and beams with ratio greater than 2.5 as ordinary beams. A moderate deep beam has ratio in between these two limits. The beams with hollow cross section have several advantages such as: maximizing the efficiency of structures in term of strength/mass and stiffness/mass ratios, decreasing the beams contribution to seismic response and high carrying requirement on foundation. It is economical to use hollow reinforced concrete beams where the concrete cost is relatively high, or in cases aim to minimize the weight of concrete members. Openings and holes are often provided in reinforced concrete beams to allow access for services such as pipes for plumbing and electric wiring [2]. However, plastic deformation capacity and energy dissipation of reinforced concrete hollow beams may not be adequate to ensure effective confinement of the thinner web cause the drop of members shear strength. For safety of RC members, these behaviors shall critically be investigated [3]. In the last decade, many researches have been conducted on behavior of reinforced concrete deep beams. Some of these researches have investigated experimentally the effect of steel and polypropylene fibers on behavior of deep beams [4, 5, 6]. While, the others confirmed the effectiveness of shear reinforcement on the behavior and strength of concrete deep beams [7, 8]. Abduljalil [9] studied the behavior of reinforced concrete deep beams with lateral opening strengthened with externally bonded CFRP strips. The experimental results showed that externally CFRP strips increased both the ultimate shear strength, and the stiffness of the deep beams with opening. However, there seems to be no available test data for moderate deep beams with embedded PVC pipes. The tests reported in this paper partially fill this void.

2. RESEARCH SIGNIFICANCE:

In design and construction of reinforced concrete members, the brittle failure (shear failure) should be prevented. The presence of PVC pipes as hollow parts in reinforced concrete moderate deep beams decrease the shear strength of beams. Therefore, understanding the behavior of RC moderate deep beams with embedded PVC pipes is important for developing safe design procedures.

3. TEST SPECIMENS AND MATERIALS:

A total of six reinforced concrete moderate deep beams were constructed to fail in shear. All beams were 1000mm length, 300mm depth, and 150mm width. The main parameters of this study were the diameters and locations of the pipes. The reference specimen (S) had a solid cross section. Four specimens (P1, P2, P3, and P4) had PVC pipes inserted longitudinal at their center, the diameters of the pipes were (25.4, 50.8,



76.2, and 101.6mm), respectively. The sixth specimen (P4E) had 101.6mm- diameter pipe inserted with eccentricity of 40mm below the center of the specimen. Ordinary Portland cement was used in the concrete mixes with washed sand and well graded crushed gravel of 19mm maximum size. The proportions by weight of cement: sand: aggregate were 1: 1.77: 2.22 with a water/cement ratio of about 0.55. The specimens were cast using two concrete batches. Each batch consisted of three specimens, and three 150×150×150 mm cubes were taken from each batch to determine the actual concrete strength .Table (1) and Fig. (1) Show the details of the beams considered. All specimens were reinforced with four longitudinal bars as flexural reinforcement, 2-Ø12mm and 2-Ø16mm at the top and bottom, respectively. The shear reinforcement consisted of 8-Ø6mm vertical stirrups spaced at 130mm c/c. 20mm clear concrete cover was provided at the top, bottom, and two sides of beams. The properties and details of the reinforcement bars are shown in Table (2) and Fig.(2). The specimens were cast in wooden forms made of plywood. The forms were cleaned and oiled. Then the steel reinforcement was placed in its position. The concrete mixes for all specimens were produced using a mechanical concrete mixer of 0.15 m³ capacity. A standard compactor rod was used to compact the concrete manually, then the surfaces of beams were evened using a straight piece of wood. After 24 hours specimens were cured keeping them wet for 28 days.

Table (1) Details of Test Specimens.

Beam designation	Diameter of PVC pipe (inch) (mm)	The location of PVC pipe center	Cubic compressive strength of beams (MPa)
S	-----	-----	29.1
P1	(1)(25.4)	At the center of beam	29.1
P2	(2)(50.8)	At the center of beam	29.1
P3	(3)(76.2)	At the center of beam	30.3
P4	(4)(101.6)	At the center of beam	30.3
P4E	(4)(101.6)	40 mm below the center of beam	30.3

Table (2) Properties of Steel Bars.

Nominal diameter (mm)	Actual diameter (mm)	Yield stress (MPa)	Ultimate stress (MPa)
6	5.9	381	550
12	11.94	482	571
16	15.9	520	618

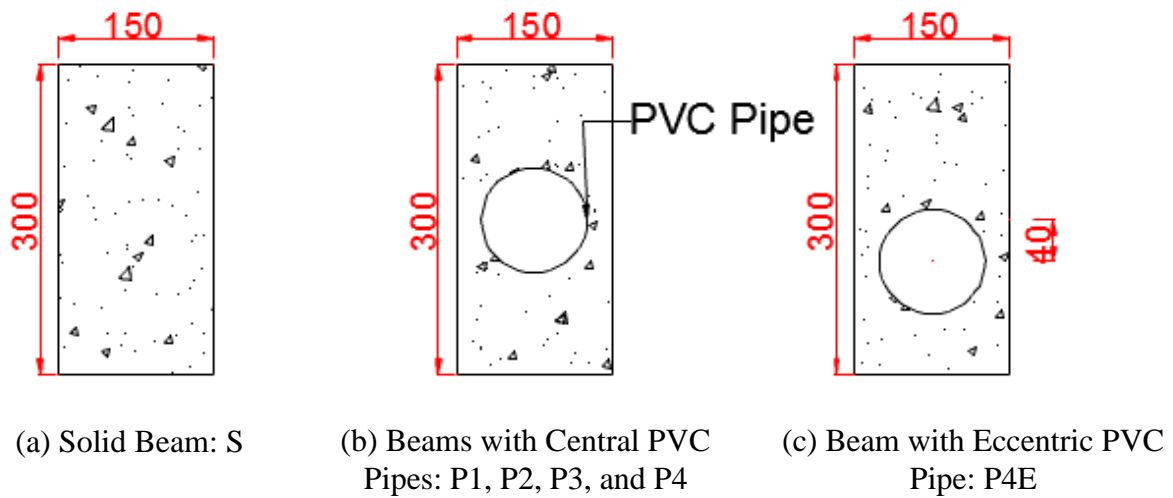


Fig. (1) Details of Test Specimens (dimensions in mm)

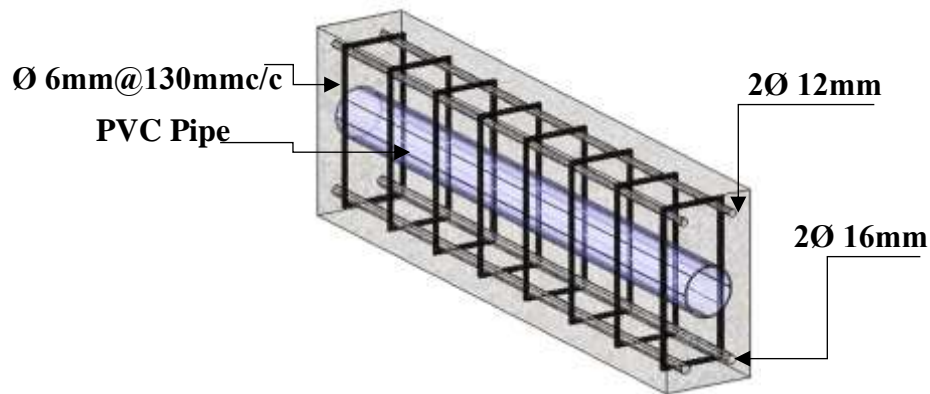


Fig. (2) Typical Reinforcement Arrangement for all Beams.

4. TEST PROCEDURE:

All beams were tested as simply supported beams under central concentrated load (P) with shear span to depth ratio of 1.50, the load was applied on the top surface through a square steel plate (150 × 150mm), see Fig.(3). The test was performed at concrete laboratory at Engineering College of Wasit University. Universal Testing machine of 150 Tons capacity, Fig. (4), was used to apply load gradually at increments of (10 kN) up to failure. Beams surface were white painted on all sides to facilitate visual observation of the propagation of cracks. Three dial gauges having the smallest division of 0.01mm were employed to measure the deflection of test beam at each load increment. One dial gauge was set at mid span and the remaining two at the quarters of the span. At each load increment, the readings were taken, cracks were deeply marked upon their formation on the beam surface and the load intensity at which it was formed was noted.

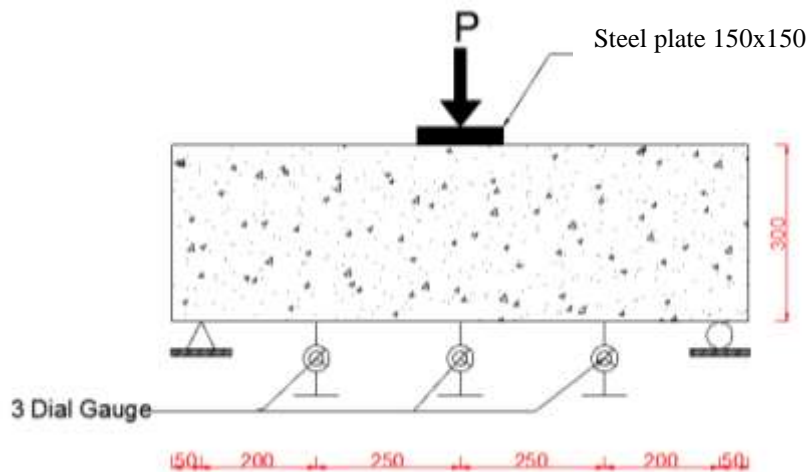


Fig. (3) Typical Loading for all Beams (dimensions in mm).

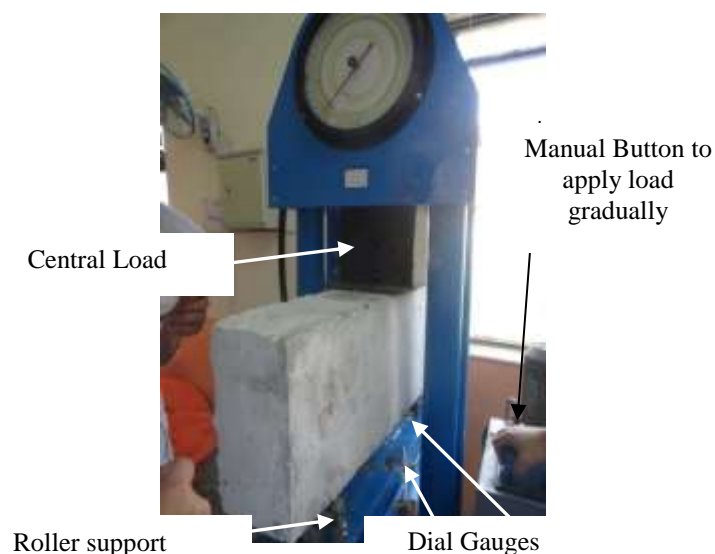


Fig. (4) Specimen inside the Universal Machine before Testing.



5. TEST RESULTS AND DISCUSSION:

5.1. General Behavior and Crack Patterns:

All beams except for beam with 101.6mm-diameter central pipe (P4) experienced diagonal tension failure. At loads of 70 to 100 kN, few fine vertical flexural cracks started to develop at mid span of these beams, followed by the destruction of the bond between the reinforcing steel and the surrounding concrete at support. Thereafter, one or more diagonal crack developed in region between the face of support and the point load. As the external load increased, the diagonal cracks widened and extended to the top compression fibers of the beams. In general, the failure modes were brittle and the flexural cracks did not propagate neutral axis of beams. In beam (P4E) where PVC pipe was inserted near the tension reinforcement, bond failure resulting from splitting of concrete in vertical direction also occurred extending from the perimeter of pipe to the bottom face of beam. Specimen (P4) with 101.6mm-diameter central pipe failed in direct shear. The formation of flexural cracks on the tension face of beam was initiated at load of 60 kN. At higher load, the flexural cracks near the supports bent and propagated toward the neutral axis to form flexural shear cracks. As the load increased, the in-plane shear stress at neutral axis of the beam increased, the effective width required to resist this stress reduced by about 67.7% due to the presence of pipe at this region led to splitting the beam horizontally along its length. Fig.(5) shows crack patterns of all beams.

5.2. First Cracking and Ultimate Loads Results:

A summary of test results showing the first cracking and ultimate loads are presented in Table (3). The first cracks initiated at (66.7%, 55.2%, 57.1%, 56%, 54.5%, and 70%) of the ultimate loads of beams (S, P1, P2, P3, P4, and P4E), respectively. The decreases in first cracking loads of beams with embedded PVC pipes ranged between 20% and 40% in comparison with solid beam (S). This is the result of a decrease in moment of inertia of beams cross sections due to the presence of pipes. Also, the specimens with embedded pipes failed at loads smaller than that of solid beam. For the beams with central pipes, the reduction in the ultimate loads increased with increasing the diameters of the pipes. In general when the diameters of pipes did not exceed one third of beams widths as in beams P1 and P2, the reductions in ultimate loads were relatively small about 3.3% and 6.7%, respectively. For other beams P3 and P4, the effect of the pipes on ultimate loads was quite large and the reductions reached 16.7% and 26.7%, respectively. The location of the pipes has a significant effect on the ultimate load of beams. For beam P4E with 101.6mm -diameter eccentric pipe, the ultimate load reduced by 33.3% and this reduction was the larger than that of beam P4 with same diameter pipe installed at its center. This is due to the installation pipe near the tension reinforcement in beam P4E, led to the appearance of bond failure between



concrete and flexural reinforcement in the vertical and horizontal planes. Finally, beam P4E failed in bond as well as diagonal tension.

5.3. Load-Deflection Response:

Fig.(6) shows the effect of the installation of PVC pipes on the load-central deflection responses of reinforced concrete moderate deep beams. Each one of these curves initiated in a linear form with constant slope, changed to a nonlinear form with varying slope then a substantial increase in deflection with small increase in load occurred till reaching its ultimate load. In the present discussion of deflections, the service loads are considered equal to 100 kN (first cracking load of solid beam), and failure loads are equal to the recorded failure loads listed in Table (3). The behavior of the beams with embedded pipes is compared to the behavior of solid beam (S). Fig. (7) shows the deflection profile along the beams length at different load stages. In beams P1 and P2, the maximum measured deflections at service loads were 9 and 12 percent larger than that of beam S. at failure these percentages decreased to 3 and 1, respectively. In beam P3, the maximum recorded deflection at service load stage was 133 percent larger than that of beam S. at failure, this decreased to 103 percent. In beams P4 and P4E, when the diameters of pipes exceeded two thirds of the beams width, the influence of pipe on the recorded deflection was relatively large especially for pipe installed at the center of beam. At service load, the maximum measured deflection for beam P4 was 286 larger than that of solid beam. While at failure this percentage became 297. In beam (P4E), the measured deflection was 158 percent larger than that of beam (S) at both service and ultimate loads.

Table (3) Cracking and Ultimate Loads of Tested Beams

Beam designation	First Cracking Load Pcr (kN)	Ultimate Load Pult (kN)	(Pcr/Pult)%	% Decrease in First Cracking Load	% Decrease in Ultimate Load	Failure Type
S	100	150	66.7	----	----	Diagonal tension
P1	80	145	55.2	20.0	3.3	Diagonal tension
P2	80	140	57.1	20.0	6.7	Diagonal tension
P3	70	125	56	30.0	16.7	Diagonal tension
P4	60	110	54.5	40.0	26.7	Direct shear
P4E	70	100	70	30.0	33.3	Diagonal tension and bond failure

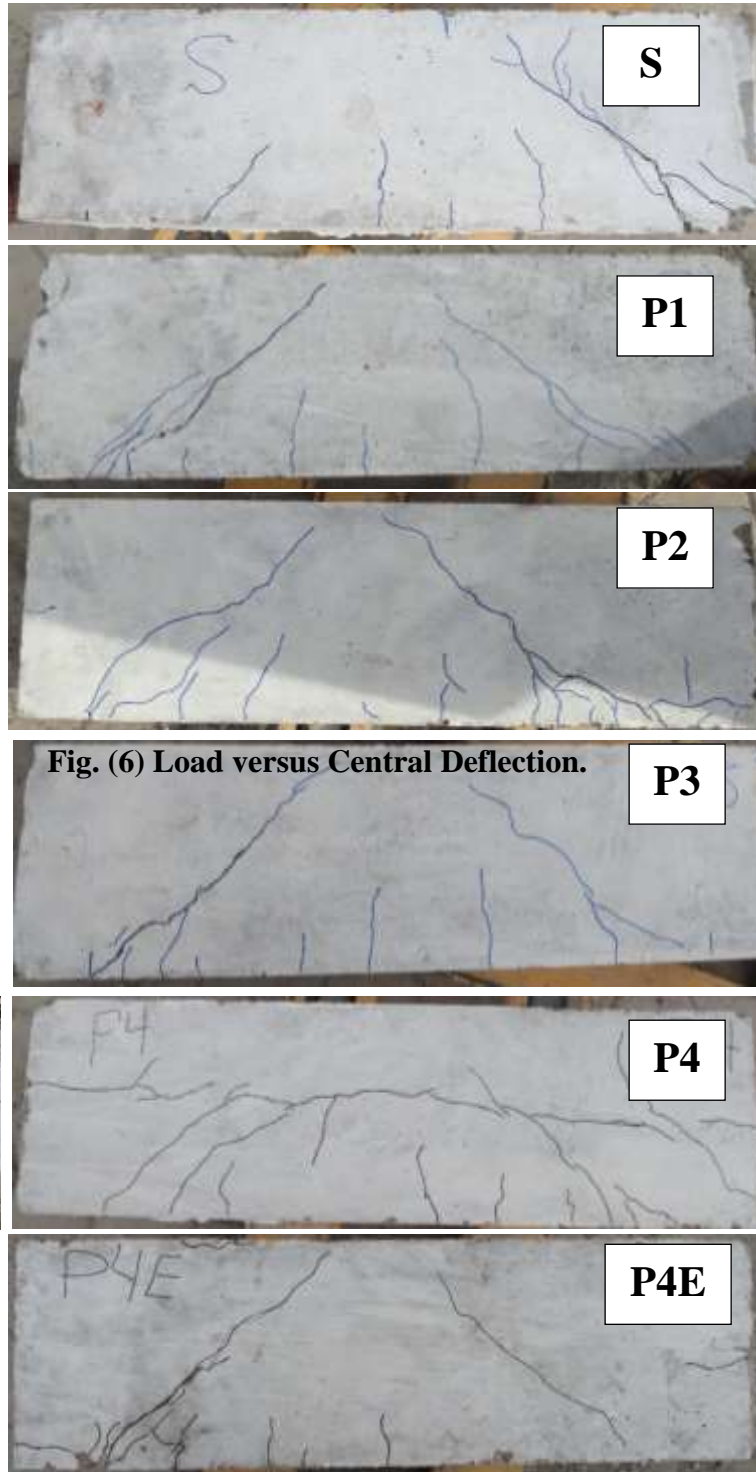


Fig. (6) Load versus Central Deflection.

Fig. (5) Crack Patterns for all Beams.

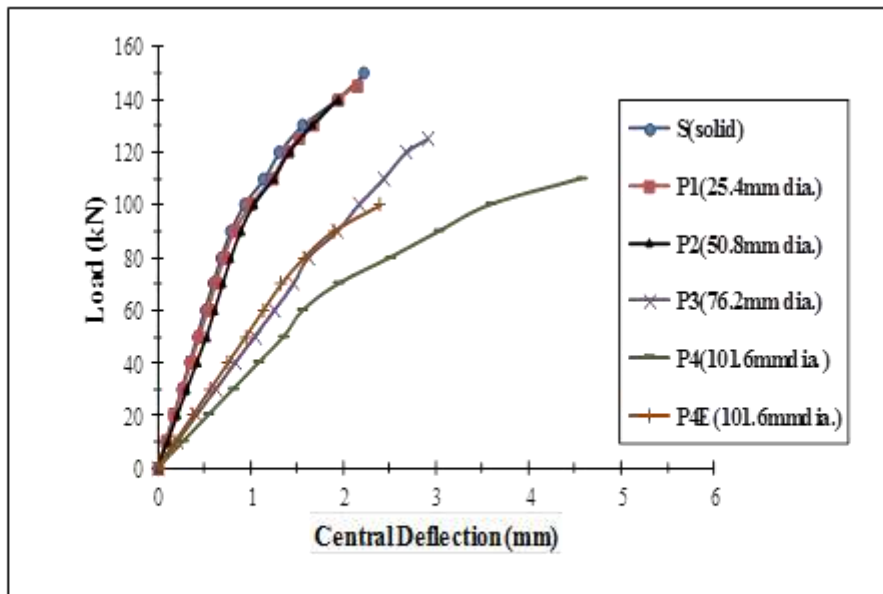


Fig. (6) Load versus Central Deflection.

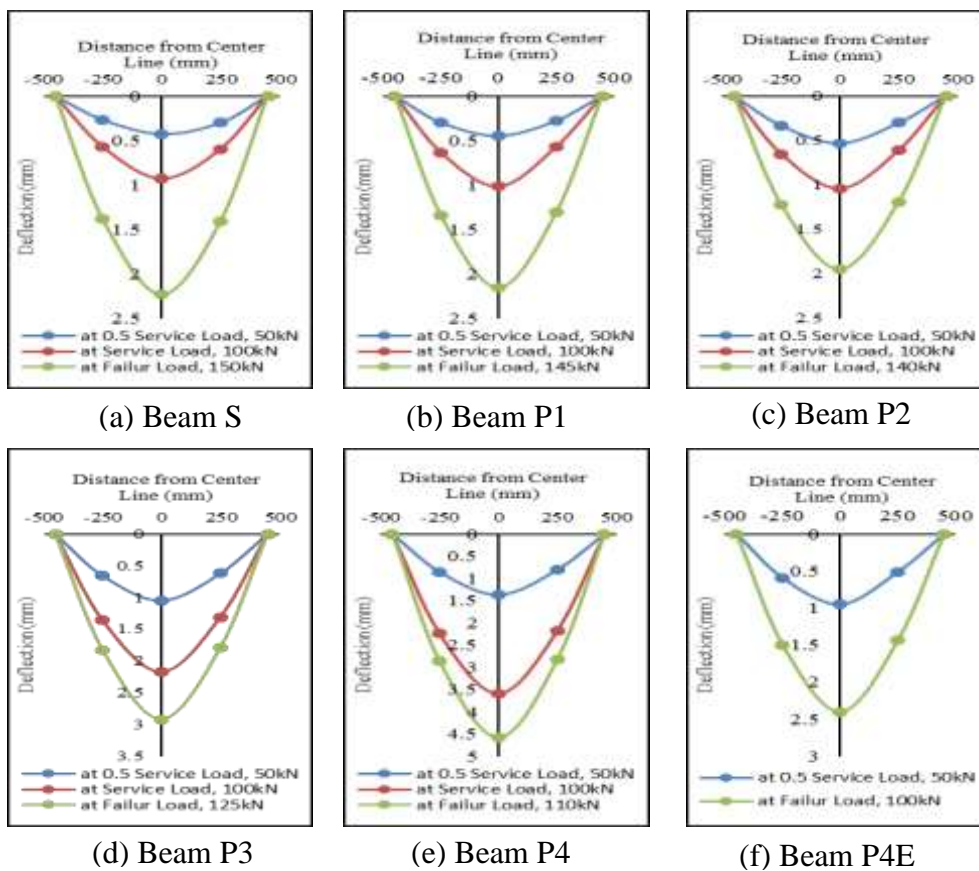


Fig. (7) Deflection Profiles for all Beams.



6. CONCLUSIONS:

Based on the presented experimental program, the following conclusions can be offered.

1. The installation of PVC pipes in reinforced concrete beams decreases the strength and rigidity of the beams depending on sizes and locations of these pipes.
2. The size of the pipe inserted in reinforced concrete beams influences the capacity of the beams. For the beam with pipe of smaller diameter, the ultimate strength decreased by 3.3% with respect to the ultimate strength of the solid beam. The decrease in capacity reached to 26.7% for the beam with pipe of larger diameter.
3. The pipe inserted at the center of the beam decreases the ultimate strength of beam less than the same size pipe installed below the center of beam near the tension reinforcement. The central pipe decreased the ultimate strength of the beam by 26.7%, while eccentric pipe decreased the capacity by 33.3%.
4. For the beams with embedded pipes of diameter larger than one third of beam width, significant reduction in stiffness (103 to 297 percent) was observed, while for beams with smaller pipes, the reduction in stiffness was much smaller (1 to 12 percent).
5. There is no need to take any precautions regarding the beam with central pipe if the diameter of the pipe is about or less than one third of the beams width.
6. The most preferable location to install pipe in reinforced concrete moderate deep beams is at the center of the beams away from the tension reinforcement in order to avoid bond failure.

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