CHAPTER (5)

EXPERIMENTAL RESULTS FOR EMRC BEAMS IN SHEAR

5.1 Introduction

In order to study the behavior and performance of the epoxy-modified reinforced concrete (EMRC) beams in shear, eighteen epoxy-modified reinforced concrete beams were tested. The detailed description of these beams was given in the chapter (3). The experimental results of shear tests are described in the present chapter. The eighteen beams were tested as simply supported beams under one vertical concentrated load at the mid span up to failure with shear span-to-depth (a/d) ratio of 2.5, 3.5, and 4.5. The cross section of the all eighteen beams was rectangular with dimensions (120 mm x 250 mm). All the beams sections were over-reinforced to ensure that shear failure takes place before the yielding of the main longitudinal bottom tension steel reinforcement.

Throughout the testing at each load increment, measurements of vertical deflections at mid-span and quarter-span points of the tested beams were recorded using LVDTs. Also, the compressive strain in concrete at the top of mid-span section was recorded using horizontal LVDT. To measure the strains in the main longitudinal bottom tension steel and the vertical stirrups, electrical strain gauges were used. The initiation and propagation of the cracks were noticed, detected, and marked up to failure. The diagonal tension and diagonal compression strains of concrete at the middle of the shear span were measured using mechanical strain gauge

In the current chapter, complete analysis of the experimental results are presented. The relationships between load and mid-span deflection, load and longitudinal bottom tension steel strain, and load and vertical stirrups strain are plotted in curves form. In addition, the deflection profiles and strain profiles are drawn.

5.2 General Behavior of EMRC Shear Beams

5.2.1 Cracking Pattern and Failure Modes

The cracking patterns of the eighteen tested beams for shear at failure are shown in Figures (5-1), (5-2), and (5-3). Also, cracking loads, failure loads, and modes of failure for the tested beams are scheduled in Table (5-1). As shown in the figures, it cloud be established that the crack development in all the tested beams followed a similar pattern. In general, the first crack for all the tested beams in shear was a nearly vertical crack appeared approximately in the central region of the beam perpendicular to the direction of the maximum stress induced by maximum moment and shear.

After the first crack formation, additional nearly vertical cracks appeared close to the mid span sections. The cracks were formed in the mid span region of the tested beams at low load level. At intermediate loading stages, inclined cracks initiated in the shear span region between the load and the support points, then propagated with the increased inclination towards the supports. It was noticed during the tests that most of these cracks developed and propagated towards the neutral axis of beams. As the load increased, shear stress become more significant than flexural stress and induced inclined cracks which propagated, spread and widened due to gradually load increased. At failure, one of these diagonal cracks extended suddenly into the compression zone towards the point of the applied load and down towards the supporting region causing the beams to fail in shear.

From the cracking patterns shown in Figures (5-1), (5-2), and (5-3), it could be established that the increasing of epoxy weight ratio led to an approximate decrease in the number of cracks, increase in the spacing between cracks, and decreases the crack width. These results are more noticeable in specimens with no stirrups. It could be attributed to the increased tensile and shear strengths of concrete combine with the increased epoxy weight ratio. Also, it was noticed from cracking patterns shown in the figures that the beams with stirrups have large number of cracks with smaller spacing between cracks but with much smaller widths when compared with beams with no stirrups, which can be attributed to the better distribution of shear stress patterns.

The shear-to-span depth ratio has a great effect on the mode of failure and the type and inclination of cracks for specimens tested for shear. It could be obtained from the cracking patterns shown in Figures (5-1), (5-2), and (5-3) that increasing of (a/d) ratio led to increased number of cracks all over the beam length and especially in the center region of the beam. This could be because the increasing of shear span-to-depth (a/d) ratio resulted in increasing the effect of the flexure stress in the tested specimens. The mode of failure for specimens having (a/d) of 2.5 was the shear compression failure which is characterized by splitting of web concrete along the line goes from the support to the point of load with a sharp inclination. On the other hand, the mode of failure for specimens having (a/d) of 3.5 and 4.5 was the diagonal tension failure mode, where the cracks in the end section turn over at the top and then one crack starts from the main reinforcement and goes to the point of load with gentle inclination.

5.2.2 Measured Deflections Profiles

The deflection profiles of the eighteen beams specimens tested for shear are shown in Figures (5-4) through (5-9), where the deflections were measured for all beams tested for shear at the mid span and at quarter span of beams. Accordingly, the deflection profiles along the tested beams span were plotted at two stages, at the first diagonal cracking load stage and at the ultimate load stage. It was distinguished that, the deflection profile was generally symmetrical for all the tested beams with respect to the vertical axis passing through the beam mid span. Beyond the cracking level, the increase of load led to gradual increasing in the defection values with approximately gentle curvature of the deflection profile.

For beams with constant shear span-to-depth ratio and vertical steel ratio, it was established that by increasing the used polymer weight ratio in producing the EMRC beams, the deflection profile decreased. This could be attributed to the beneficial effect of epoxy weight ratio in improving resistance to crack initiation and propagation. Also, when comparing beams with constant shear span-to-depth ratio and constant epoxy weight ratio, beams with stirrups experience less deflection at different stages of loading. It could be argued to that the presence of stirrups led to a smaller number of wide cracks which led to much increase in the beam stiffness and smaller deflection values.

For beams with constant epoxy weight ratio and constant stirrups content, the increase of shear span-to-depth ratio leads to a significant increase in deflection along the beam span and at different loading levels. This occurred due to the increase of the effect of flexural stress with the increase of span-to-depth ratio, and consequently higher deflections were measured.

5.3 Measured Load-Deflection Curves

The effects of polymer weight ratio and main shear parameters on the measured load-deflection curves of the eighteen EMRC beams are illustrated in Table (5-1), Figure (5-10) through (5-19), and discussed in the following sections. Generally, the relationship between the load and the mid-span deflection was found almost linear until cracking happens, this was expected since the strains in steel and concrete are relatively small and both materials are in the elastic portion of their own response. After cracking occurs, the slope of the load-deflection curves reduces gradually by increasing the load due to cracking. The cracking load is typically taken as the load that causes the first diagonal cracking. Two methods were employed to determine the cracking load at the instant of diagonal cracking. A visual method noted the load at the instant the diagonal crack was seen to have crossed the mid-height of the beam. The second method from the load-stirrup strain curve, where the load at which the curve changed suddenly.

The parametric studies were carried out regarding the following structural measures:

a- The load carrying capacities at the first diagonal cracking (P_{cr}) and ultimate (P_u) levels.

b- The deflections at the ultimate (Δ_u) level.

5.3.1 <u>Effect of Weight Ratio of Epoxy (w_e)</u>

For the tested beams in shear, it was found that the increase of the epoxy weight ratio (w_e) leads to an increase in the load carrying capacities at different levels. Also, it was established that by increasing the epoxy weight ratio the vertical deflections at mid-span decreased for the same load level. This can be attributed to the gain in the compressive and tensile concrete strengths caused by the increased epoxy-weight ratio.

As shown in Table (5-1) and Figure (5-10) for specimens having (a/d) of 2.5 and without stirrups, the increase of epoxy weight ratio (w_e) from 0% to 5%, and 10% results in increasing the cracking load by 14% and 20%, and increasing the ultimate load by 3.1% and 10.2% respectively. Also, the figure shows that the increase of epoxy weight ratio decreases the vertical deflection at ultimate level with respect to beam A2 with 0% epoxy. The decrease in vertical deflection at mid-span of beams B2 and C2 was 8.3% and 18.3% due to the use of 5% and 10% epoxy weights.

For specimens having (a/d) of 3.5 and without stirrups, the results of Table (5-1) and Figure (5-11) show that the use of 5% and 10% epoxy weight ratio results in 13.3% and 15% increase in the cracking load, and 7% and 13.6% increase in the ultimate load capacity. Furthermore, the measured vertical deflections at mid-span for epoxy beams at ultimate level are less than that of the non epoxy beams A4. For beams B4 and C4, the decrease in deflection is 12.3% and 20.3% respectively.

For the specimens having (a/d) of 4.5 and without stirrups, the results of Table (5-1) and Figure (5-12) indicate that the use of 5% and 10% epoxy weight ratio results in 4.2% and 7% increase in the cracking load, and 6.7% and 11.1% increase in the ultimate load. Additionally, the ultimate deflection at mid-span of epoxy beams are less than that of non epoxy beams A6. For beams B6 and C6, the decrease in deflections is 15.3% and 34.5% respectively.

5.3.2 Effect of Flexural Steel Ratio (ρ_L) and Shear-to-Span Depth Ratio (a/d)

In the present study, the flexural reinforcement steel ratio (ρ_L) was increased with the increase of (a/d) ratio in order to prevent any premature flexural failure and to ensure that the specimens fail first in shear. In order to study the effect of changing longitudinal steel ratio and shear span-to-depth (a/d) ratio, a combined factor is used here to distinguish the shear behavior of different tested beams. This factor is denoted by (ρ_{Lad}) and is given by:

$$\rho_{Lad} = \frac{\rho_L}{a/d} \qquad (5-1)$$

The part (a/d) measures the interaction of flexure with shear behavior. The measured load-deflection curves of EMRC beams without stirrups are used to study the effect of (ρ_{Lad}) as shown in Figures (5-13) through (5-15). Also, the cracking, ultimate loads and corresponding deflections are given in Table (5-1). For the tested beam in shear, the increase of (ρ_{Lad}) factor leads to an increase in the ultimate load for different epoxy weight ratios. Also, a significant increase in the measured vertical deflection at mid-span at any level was noticed with the increase of (ρ_{Lad}) factor. It can be attributed to the increased effect of flexure on the structural response. Furthermore, the slope of the load-deflection curves is less and is showing stiffer response for smaller values of (ρ_{Lad}) factor.

As shown in Figure (5-13), for specimens having 0% epoxy ratio, the increase of (ρ_{Lad}) from 0.012 to 0.013, and to 0.015 results in increasing the ultimate load by 4.3% and 6.6%, and increasing the mid-span deflection at failure by 25% and 75% respectively with respect to beam A2. Also, the results of Figure (5-14) for beams having 5% epoxy ratio indicate that the ultimate load and peak deflection are higher by 8% and 29% for beam B4 with (ρ_{Lad}) equal to 0.013, and by 10.34% and 72% for beam B6 with (ρ_{Lad}) equal to 0.015 in comparison with beam B2 with (ρ_{Lad}) equal to 0.012. Similar observation is made for the results of Figure (5-15) of specimens having 10% epoxy ratio.

The increase of (ρ_{Lad}) from 0.012 to 0.013, and to 0.015 results in increasing the ultimate load and deflection by 7.5%, and 22.7% for beam C4, and 7.5% and 47% for beam C6.

5.3.3 Effect of Stirrups Ratio (ρ_v)

The effects of web steel ratio (ρ_v) on the load deflection curves are shown in Figures (5-16) through (5-19). For the ratio (a/d) of 3.5, three stirrups ratios were used as 0%, 0.24% and 0.48%. It was established from the measured curves that the increase of stirrups ratio leads to an increase in the ultimate load capacity and decreasing the vertical deflection at mid-span. Thus improvement in strength is due to the shear resistance of stirrups. Also, the stiffness is increased due to the fact that the existence of stirrups arrests the cracks propagation and widening. Generally, it was found that the effect of higher stirrups ratio is more significant for the higher epoxy weight ratio. It should be noted that the amount of web reinforcement satisfies the minimum requirement of Egyptian Code ECP 2007 [128] where the limit of minimum web steel is ($0.4/f_y$) and the maximum spacing is 200 mm.

As shown in Table (5-1) and Figure (5-16) for specimens having 0% epoxy and (a/d) = 3.5, the increase of stirrups ratio from 0% to 0.24%, and 0.48% results in increasing the cracking load by 12.7% and 33%, and increasing the ultimate load by 27.3% and 47.7% respectively. Also, the figure shows that the increase of stirrups ratio reduces the vertical deflection at the ultimate level with respect to beam A4 ($\rho_v = 0$). The decrease in the measured ultimate deflection at mid-span of beams A3 and A5 was 18% and 28% respectively.

For specimens having epoxy ratio as 5% and (a/d) = 3.5, the results of Table (5-1) and Figure (5-17) indicate that the use of 0.24% and 0.48% stirrups ratio results in 10.3% and 21.6% increase in the cracking load, and 29.8% and 53% in the ultimate load capacity. Furthermore, the measured vertical deflection at mid-span for beams B3 and B5 at the ultimate load level are less than that of beam B4 with ρ_v = 0%. For that beams, the decrease in deflection is 21% and 34% respectively.

For specimens having epoxy ratio as 10% and (a/d) = 3.5, the results of Table (5-1) and Figure (5-18) show that the use of 0.24% and 0.48% stirrups ratio results in 11% and 23.3% increase in the cracking load, and 30% and 56% increase in the ultimate load. Additionally, the ultimate deflection at mid-span for beams C3 and C5 are less than that of beam C4 with ρ_v = 0%. For such beams, the decrease in deflection is 23% and 40% respectively.

The results of Figure (5-19) for specimens having constant stirrups ratio as 0.24% and constant span-to-depth ratio as 2.5, indicate that the increase of epoxy ratio from 0% to 5%, and to 10% results in increasing the cracking load by 12.6% and 21.2 % and increasing in the ultimate load by 8.6% and 23.8% respectively. Furthermore, the measured vertical deflection at mid-span for epoxy beams at the ultimate level decreases with the increase of epoxy weight ratio. Compared to beam A1 with 0% epoxy, the ultimate deflection of beams B1 and C1 are less by 31% and 45% respectively. It is clear that the effectiveness of stirrups ratio is higher for beams with higher epoxy weight ratio.

5.4 Measured Load and Longitudinal Strains Curves

The effect of shear parameters on the relationships between the load and the steel strain at the bottom of mid-span section, and the concrete strain at top of the same section, are shown in Figures (5-20) through (5-29), and discussed in the following sub sections. Since all beams were over-reinforced and were designed to fail in a brittle shear failure mode, so the relationships between loads and measured concrete and longitudinal steel strains were found to be approximately linear with small ductilities. The measured steel strains are generally small and were in the elastic portion of its own response.

5.4.1 Effect of Weight Ratio of Epoxy

The measured load-strain curves of EMRC beams without stirrups are used to study the effect of using the epoxy weight ratio, and are shown in Figures (5-20) through (5-22). From these curves, it is recognized that the increase of epoxy weight ratio leads to decreasing the tensile steel strain and the concrete compressive strain at different load levels. Moreover, the slope of the load-steel strain curves are increased for beams with higher epoxy weight ratios. This stiffness improvement is due to the enhanced tension stiffening effect. In compression, the epoxy improves the bond condition for the aggregate-mortar surface and slows the propagation of micro cracking and consequently improves the stiffness.

As shown in Figure (5-20) for specimens having (a/d) of 2.5, the increase of epoxy weight ratio from 0% to 5%, and 10% results in decreasing the steel strains at failure by 12% and 28%, and the concrete strains at failure by 15% and 21% respectively. From the results of figure (5-21) for specimens having (a/d) of 3.5, the use of 5% and 10% epoxy weight ratio results in a decrease of steel strains by 17% and 23%, and concrete strains by 20% and 25% respectively for beams B4 and C4. Furthermore, the measured values in Figure (5-22) for specimens having (a/d) as 4.5, confirm the same findings. For beams B6 and C6, the decrease in concrete strains was 13.5% and 20%, and the decrease in steel strains was 11% and 20% respectively with respect to the response of beam A6.

5.4.2 Effect of Flexural Steel Ratio (ρ_L) and Shear-to-Span Depth Ratio (a/d)

The measured load-concrete strains and load-steel strains curves of EMRC without stirrups are used to study the effect of (ρ_{Lad}) factor as shown in Figure (5-23) through Figure (5-25). It is generally found that the increase of (ρ_{Lad}) factor leads to an increase of the concrete compressive strain and steel ensile strain at mid-span. The results of Figure (5-23) for non epoxy specimens indicate that the increase of (ρ_{Lad}) from 0.012 to 0.013, and to 0.015 lead to an increase in the measured maximum steel strain by 14% and 24 %, and increase the measured concrete strain by 19.6% and 31% respectively. With respect to the results of specimens with 5% epoxy weight shown in Figure (5-24), the increase in concrete strain and steel strain are 18.3% and 6% for beam B4, and 30% and 21% for beam B6 with respect to beam B2. In a similar fashion, the measured concrete and steel strains in Figure (5-25) for specimens having 10% epoxy ratio are higher by 16% and 18.5% for beam C4 and by 35.5% and 33% for beam C6.

5.4.3 Effect of Stirrups Ratio

The effect of web reinforcement ratio on the load-strains curves for concrete and steel are shown in Figures (5-26) through (5-29). As mentioned before, three stirrups ratios were used as 0%, 0.24%, and 0.48% for specimens of (a/d) =3.5. It was established from the measured curves that the increase in the stirrups ratio leads to an increase in the shear carrying capacities and to decrease in the tensile steel strain and concrete compressive strain at mid-span section of tested beams. Also, stiffness improvement is observed due to the fact that the existence of stirrups arrests the cracks propagation and widening.

As shown in Figure (5-26) for the specimens having 0% epoxy ratio, the increase of stirrups ratio from 0% to 0.24% and 0.48% results in decreasing the steel strain by 10% and 19.5%, and in decreasing the concrete strain by 5% and 13.3% respectively. For specimens having epoxy ratio as 5%, the results of Figure (5-27) indicate that the use of 0.24% and 0.48% stirrups ratio leads to 9% and 20% decrease in steel strain, and to 11% and 16.4% decrease in the concrete strain respectively. The results of Figure (5-28) for specimens having 10% epoxy ratio, the concrete and steel strains are less by 8.4% and 11% respectively for beams C3 (ρ_v=0.24%) and 17% and 20% for beam C5 (ρ_v=0.48%).

The results of Figure (5-29) for specimens having constant ratio as 0.24% and constant (a/d) ratio as 2.5, indicate that the increase of epoxy ratio from 0% to 5% and 10% results in decreasing the measured steel and concrete strains by 12% and 14% respectively for bean B1, and 31% and 22.6% for beam B2.

5.5 Measured Load-Stirrups Strain Curves

Figure (5-30) through Figure (5-35) shows the load-tensile strain relationships in the vertical legs of the stirrups passing the failure plane which is approximately at the middle of the shear span. It was noticed that before shear inclined cracking, the stirrups strain were relatively small which indicate the minor role of stirrups as a shear transfer mechanism in un-cracked reinforced concrete beams. After diagonal cracking, a significant decrease in slopes of the load stirrup strain curves occurred reflecting the importance of stirrups in this stage for shear resistance. After cracking, the relationship completes linearly with high increment in strain opposite to small increments in load till failure (yield) of stirrups.

5.5.1 Effect of Weight Ratio of Epoxy

Figure (5-30) through (5-32) traces the effect of epoxy weight ratio on the load-stirrups strain relationship. From these curves, it is clear that the increase of the epoxy weight ratio resulted in an increase in the load carrying capacities and decreasing the stirrups strain at different load levels. And, the slope of the load-stirrups steel strain curve decreased by increasing the weight ratio of the used epoxy due to the improvement in cracked shear stiffness.

As shown in Figure (5-30), with regard to specimens having (ρ_{Lad}=0.012), increasing the epoxy weight ratio from 0% to 5%, and to 10% caused a decease in the stirrups strain by about 20% and 25.5% respectively at the same load level which was taken as the failure load of the beam of 0% epoxy weight ratio. The reduction in stirrups strain when increasing the epoxy weight ratio from 0% to 5%, and to 10% at the same load level was 23% and 41% for specimens having (ρ_{Lad}=0.013, ρ_v = 0.24%) as shown in Figure (5-31), and was 15.5% and 29% for specimens having (ρ_{Lad}=0.015, ρ_v = 0.48%) as shown in Figure (5-32).

5.5.2 Effect of Flexural Steel Ratio (ρ_L) and Shear-to-Span Depth Ratio (a/d)

The effect of (ρ_{Lad}) factor on the load-stirrups strain curves is shown in Figures (5-33) through (5-35). It was found from these curves that the increasing of (ρ_{Lad}) factor leads to an increase in the tensile stirrups strain at failure and a decrease in the stirrups strain at the same load level. As shown in Figure (5-33), for specimens having 0% epoxy weight ratio, it was found that increasing the (ρ_{Lad}) factor from 0.012 to 0.013, and to 0.015, it results in decreasing the stirrups strain by about 10% and 22.5% respectively.

While, as seen in Figure (5-34), the increase of (ρ_{Lad}) factor from 0.012 to 0.013, and to 0.015 reduces the stirrups strain by 18% and 33.33% respectively for specimens having 5% epoxy weight ratio. Also, as shown in Figure (5-35), the reduction in the stirrups strain was 4% and 20% when the (ρ_{Lad}) factor increased from 0.012 to 0.013, and to 0.015 respectively for specimens having 10% epoxy weight ratio.

5.6 Sensitivity Study of Cracking and Ultimate Shear Strengths

The measured load values at the diagonal cracking and ultimate levels are used to study the effects of concrete strength, epoxy weight ratio, combined (ρ_{Lad}) factor, and web reinforcement ratio on the cracking shear strength as shown in Figure (5-36), and on the ultimate shear strength as shown in Figure (5-37).

5.6.1 Cracking Shear Strength

Figure (5-36-a) shows the influence of concrete compressive strength on the cracking shear strength. It is clear from the figure that the increasing of concrete strength (f_{cu}) results in increasing of the cracking shear strength for different (ρ_{Lad}) values. By increasing of f_{cu} from 66 MPa to 72 MPa, and to 77 MPa, the increase of cracking shear strength was 14% and 20% for ρ_{Lad} =0.012, and was 13% and 15.4% for ρ_{Lad}=0.013, and was 5% and 11% for ρ_{Lad} = 0.015.

Also, as revealed in Figure (5-36-b), the increase of (ρ_{Lad}) factor increases the cracking shear strength for different epoxy weight ratios. At 0% epoxy weight ratio, the increase of (ρ_{Lad}) from 0.012 to 0.013, and to 0.015 results in increasing of cracking shear strength by 30% and 61%, while at 5% epoxy weight ratio the increase was 29% and 47%, and at 10% epoxy weight ratio the increase was 25% and 44%.

Furthermore, the cracking shear strength increase when the stirrups content increased for different epoxy weight ratios as shown in Figure (5-36-c). When increasing the stirrups ratio from 0% to 0.24%, and to 0.48%, the cracking shear strength increased by 12.8% and 33.5% for 0% epoxy weight ratio, and by 10% and 22% for 5% epoxy weight ratio, and by 11% and 23.6% for epoxy weight ratio of 10%.

5.6.2 Ultimate Shear Strength

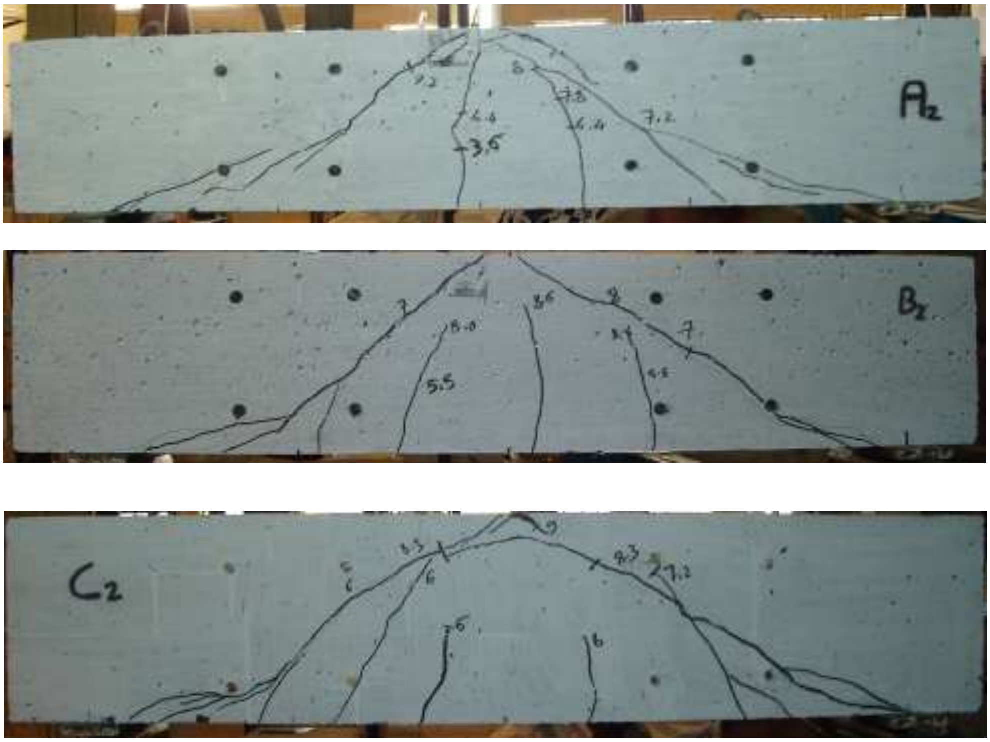
The ultimate shear strength is increased by the increasing of concrete compressive strength (f_{cu}) for different (ρ_{Lad}) values, as observed in Figure (5-37-a). The increasing of concrete strength from 66 MPa to 72 MPa, and to 77 MPa, results in increasing of the ultimate shear strength by 3% and 10% for ρ_{Lad} =0.012, and by 7% and 13.6% for ρ_{Lad}=0.013, and by 6.7% and 11.11% for ρ_{Lad} = 0.015.

In addition, as shown in Figure (5-37-b), the increase of (ρ_{Lad}) factor increases the ultimate shear strength for different epoxy weight ratios. At 0% epoxy weight ratio, the increase of (ρ_{Lad}) from 0.012 to 0.013, and to 0.015 results in increasing of ultimate shear strength by 13% and 19%, while at 5% epoxy weight ratio the increase was 17% and 23.4%, and at 10% epoxy weight ratio the increase was 16.5% and 20%. Moreover, the ultimate shear strength increase when the stirrups content increased for different epoxy weight ratios as shown in Figure (5-37-c). When increasing the stirrups ratio from 0% to 0.24%, and to 0.48%, the ultimate shear strength increased by 28% and 48.5% for 0% epoxy weight ratio, and by 30% and 53% for epoxy weight ratio of 5%, and by 30% and 56% for 10% epoxy weight ratio.

Table (5-1) Summary of the Experimental Results of the Tested Beams for Shear

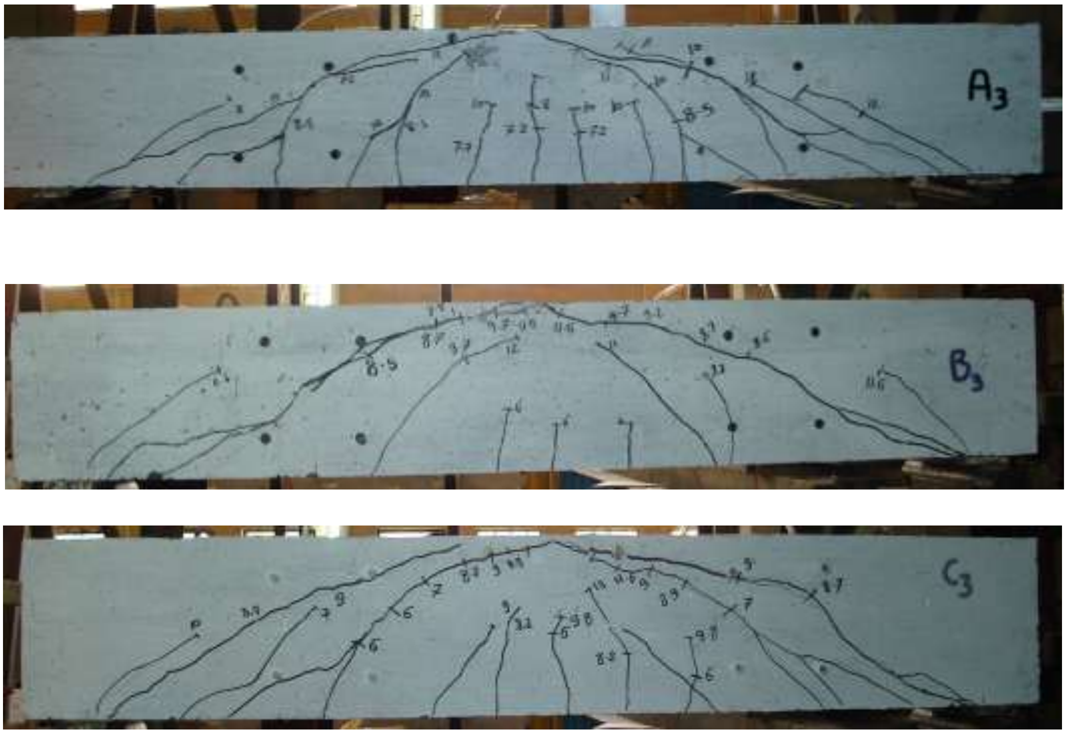
Series	w_e %	Beam	a/d	d (mm)	ρ_L %	ρ_{Lad} $=\rho_L/(a/d)$	ρ_v %	f_{cu} MPa	P_{cr} (kN)	V_{cr} (kN)	P_u (kN)	V_u (kN)	Δ_u (mm)	Failure Mode
A	**0**	A1	2.5	208	3.00	0.012	0.24	66	55.60	27.80	105	52.5	2.91	shear compression
		A2	2.5	208	3.00	0.012	0	66	50.00	25.00	84.4	42.2	2.47	shear compression
		A3	3.5	192	4.40	0.013	0.24	66	67.60	33.80	112	56.0	4.96	diagonal tension
		A4	3.5	192	4.40	0.013	0	66	60.00	30.00	88	44.0	3.45	diagonal tension
		A5	3.5	192	4.40	0.013	0.48	66	80.00	40.00	130	65.0	6.00	diagonal tension
		A6	4.5	186	6.80	0.015	0	66	72.00	36.00	90	45.0	5.00	diagonal tension
B	**5**	B1	2.5	208	3.00	0.012	0.24	72	62.60	31.30	114	57.0	2.73	shear compression
		B2	2.5	208	3.00	0.012	0	72	57.00	28.50	87	43.5	2.31	shear compression
		B3	3.5	192	4.40	0.013	0.24	72	75.00	37.50	122	61.0	4.60	diagonal tension
		B4	3.5	192	4.40	0.013	0	72	68.00	34.00	94	47.0	3.30	diagonal tension
		B5	3.5	192	4.40	0.013	0.48	72	82.70	41.35	144	72.0	5.70	diagonal tension
		B6	4.5	186	6.80	0.015	0	72	75.00	37.50	96	48.0	4.78	diagonal tension
C	**10**	C1	2.5	208	3.00	0.012	0.24	77	67.40	33.70	130	65.0	2.66	shear compression
		C2	2.5	208	3.00	0.012	0	77	60.00	30.00	93	46.5	2.19	shear compression
		C3	3.5	192	4.40	0.013	0.24	77	76.70	38.35	130	65.0	4.30	diagonal tension
		C4	3.5	192	4.40	0.013	0	77	69.00	34.50	100	50.0	3.16	diagonal tension
		C5	3.5	192	4.40	0.013	0.48	77	85.10	42.55	156	78.0	5.42	diagonal tension
		C6	4.5	186	6.80	0.015	0	77	77.00	38.50	100	50.0	4.43	diagonal tension

a) Beams A1, B1, and C1 with stirrups ρ_v = 0.24%

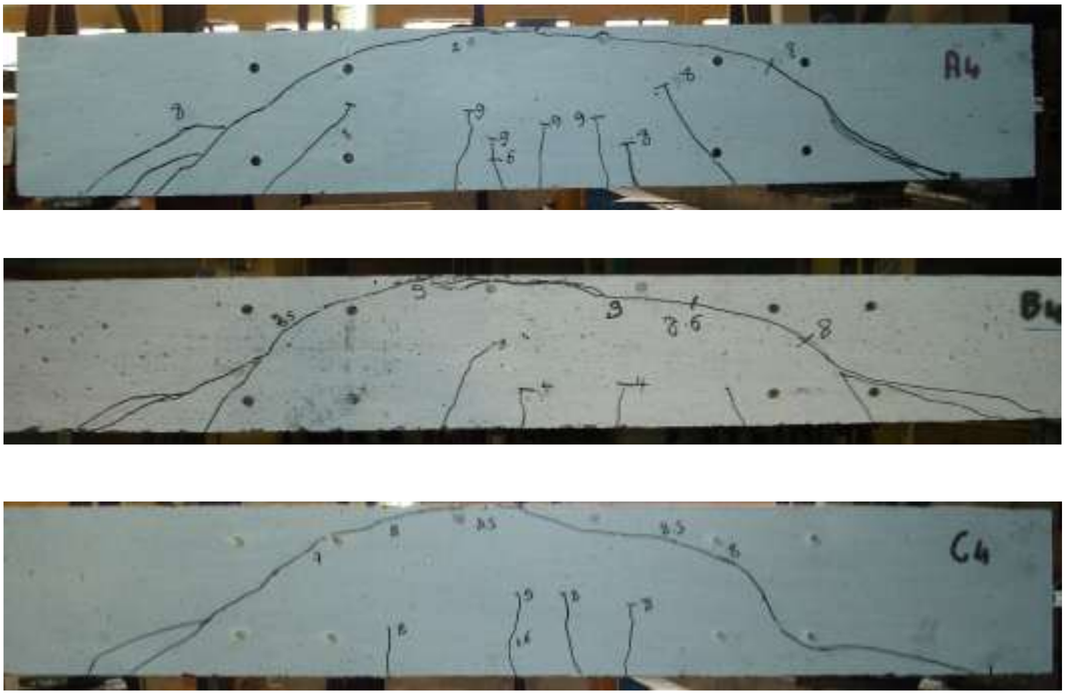


b) Beams A2, B2, and C2 without stirrups

Figure (5-1) Crack Patterns of the Tested Beams with (a/d = 2.5)

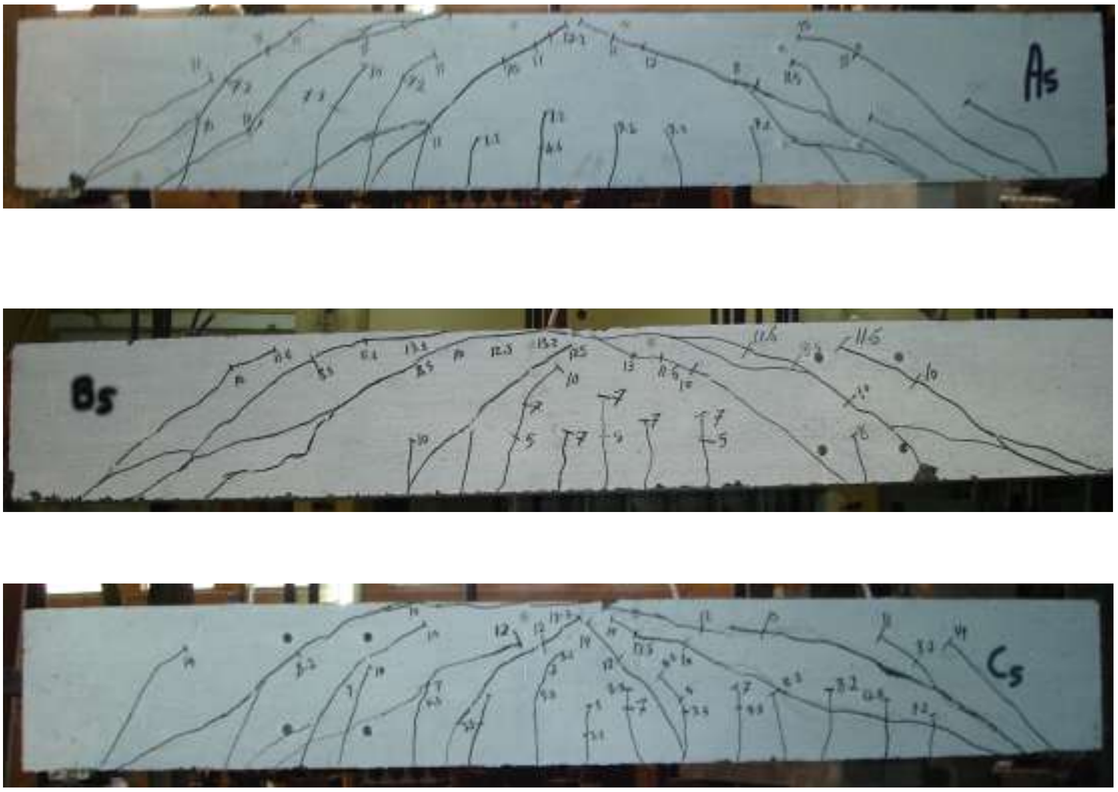


a) Beams A3, B3, and C3 with stirrups ρ_v = 0.24%



b) Beams A4, B4, and C4 without stirrups

Figure (5-2) Crack Patterns of the Tested Beams with (a/d = 3.5)



c) Beams A5, B5, and C5 with stirrups $\rho_v = 0.48\%$

Figure (5-2) (cont.) Crack Patterns of the Tested Beams with (a/d = 3.5)

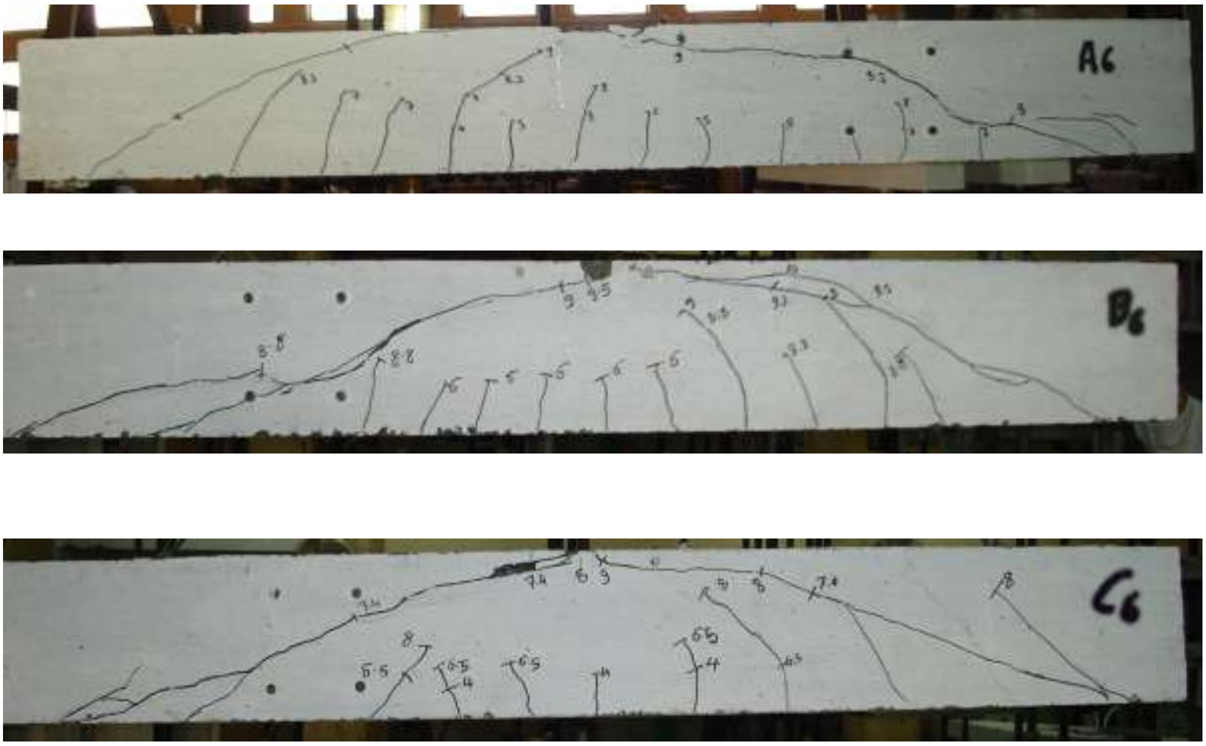


Figure (5-3) Crack Patterns of the Tested Beams with (a/d = 4.5)

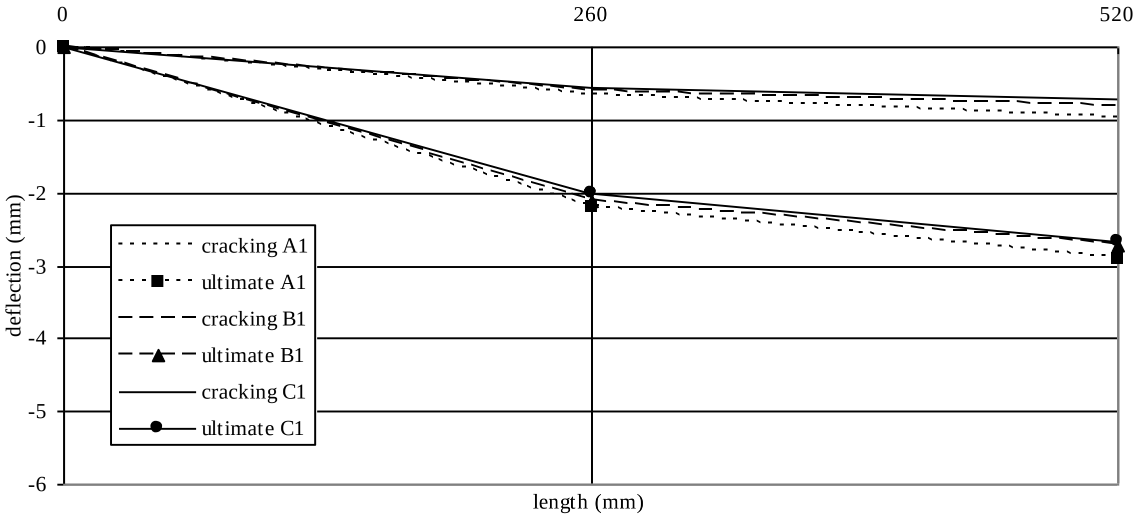


Figure (5-4) Deflection Profiles of Beams with (a/d) =2.5 and with Stirrups = 0.24%

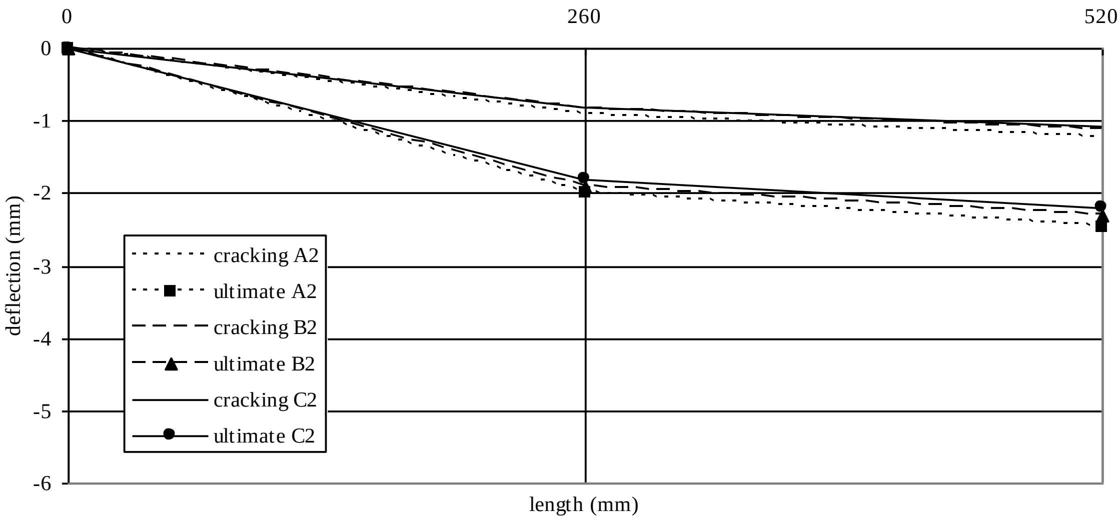


Figure (5-5) Deflection Profiles of Beams with (a/d) =2.5 and without Stirrups

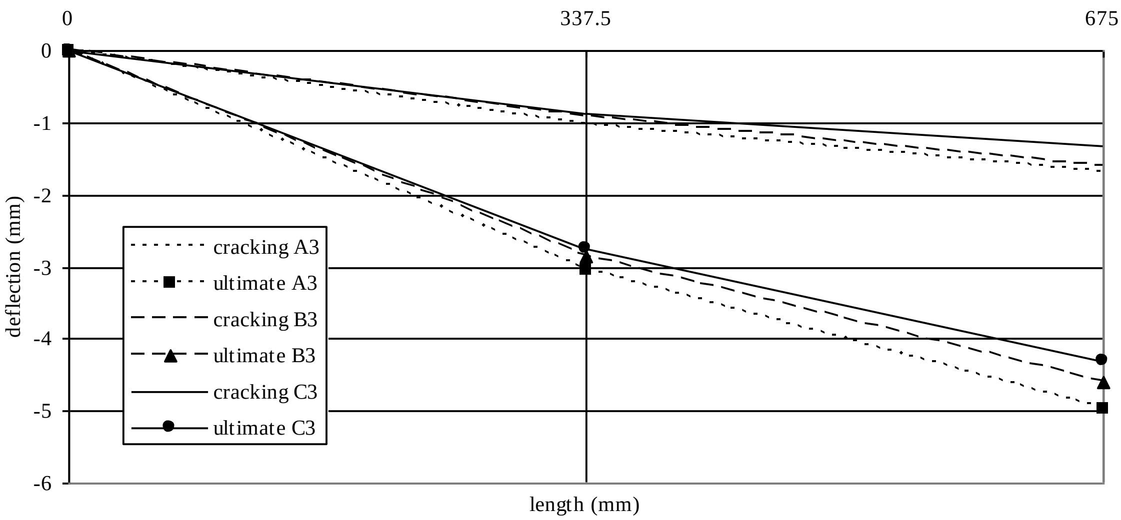


Figure (5-6) Deflection Profiles of Beams with (a/d) =3.5 and with Stirrups = 0.24%

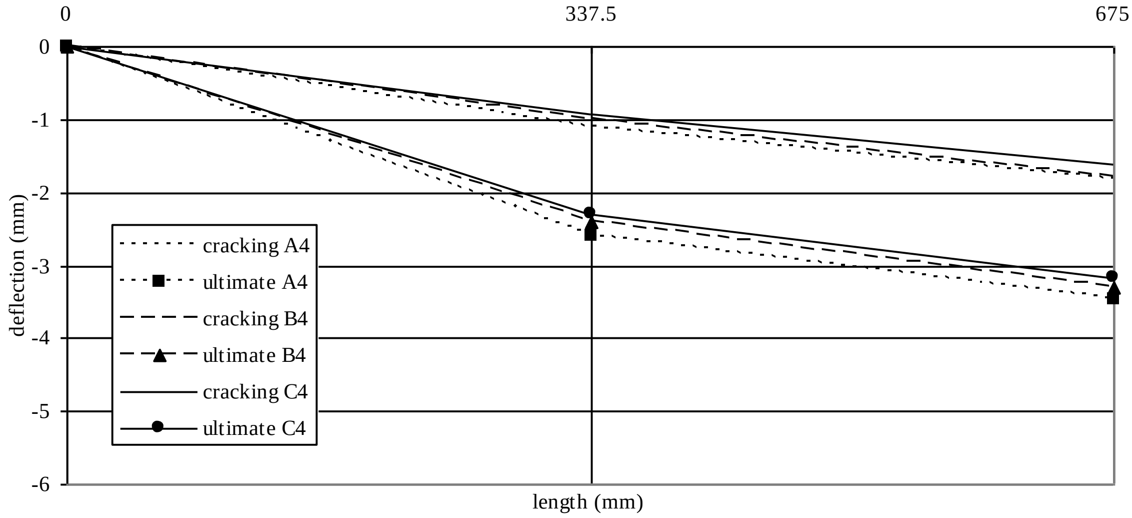


Figure (5-7) Deflection Profiles of Beams with (a/d) =3.5 and without Stirrups

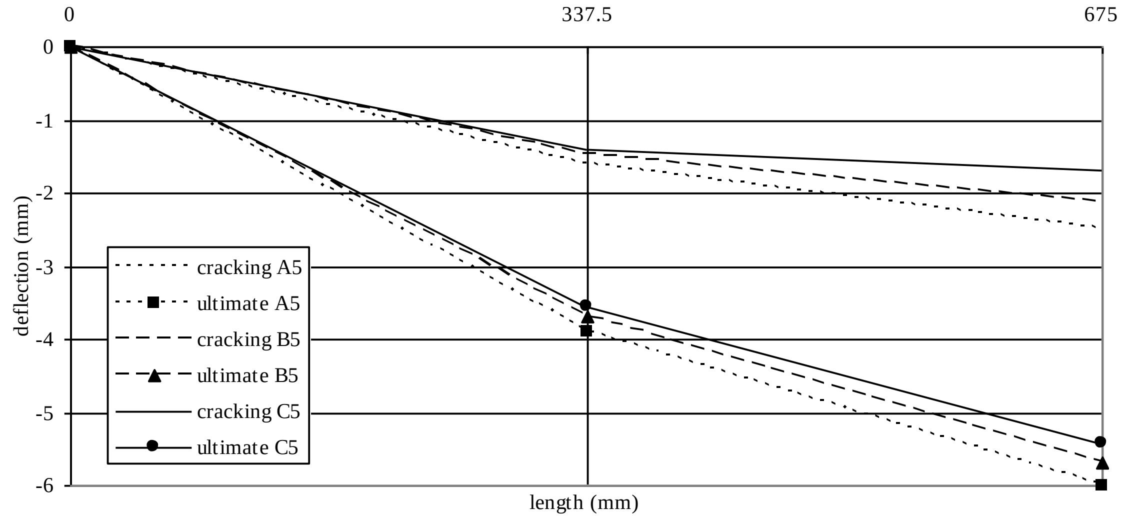


Figure (5-8) Deflection Profiles of Beams with (a/d) =3.5 and with Stirrups =0.48%

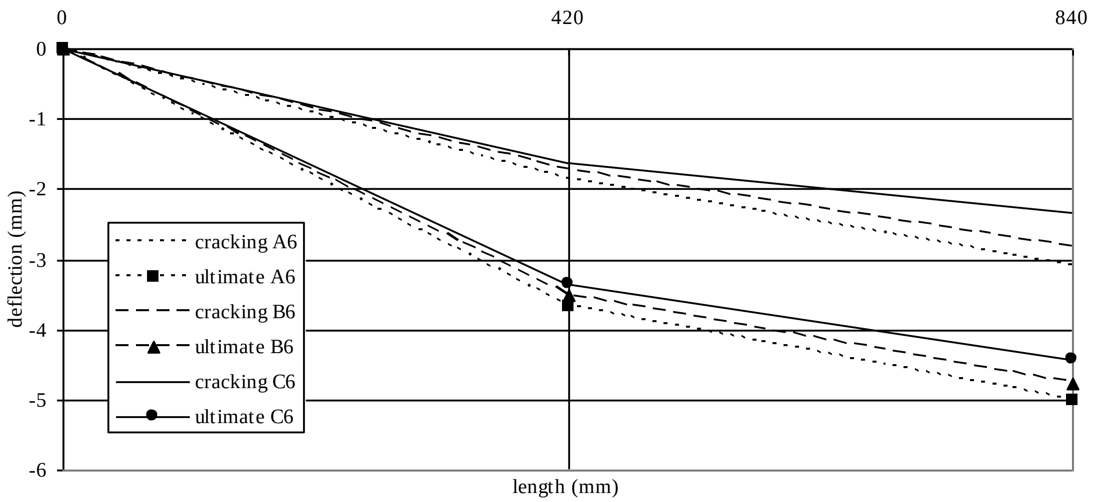


Figure (5-9) Deflection Profiles of Beams with (a/d) =4.5 and without Stirrups

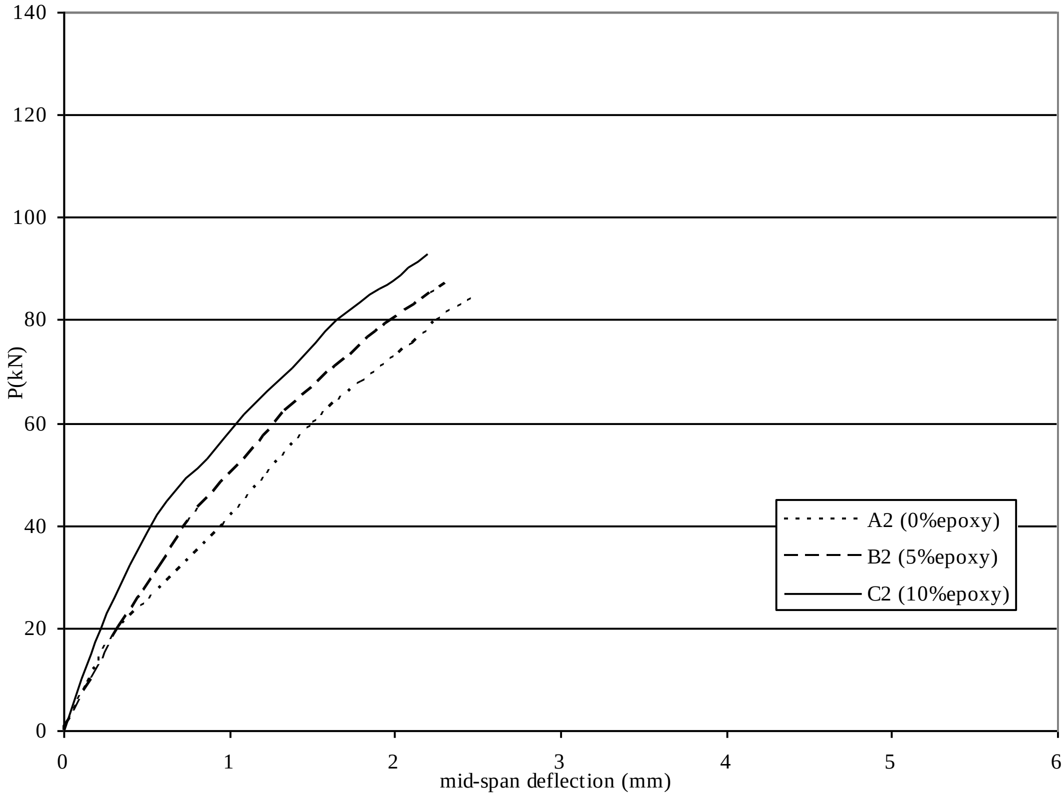


Figure (5-10) Load-Deflection Curves of Beams with (a/d)=2.5 and without Stirrups

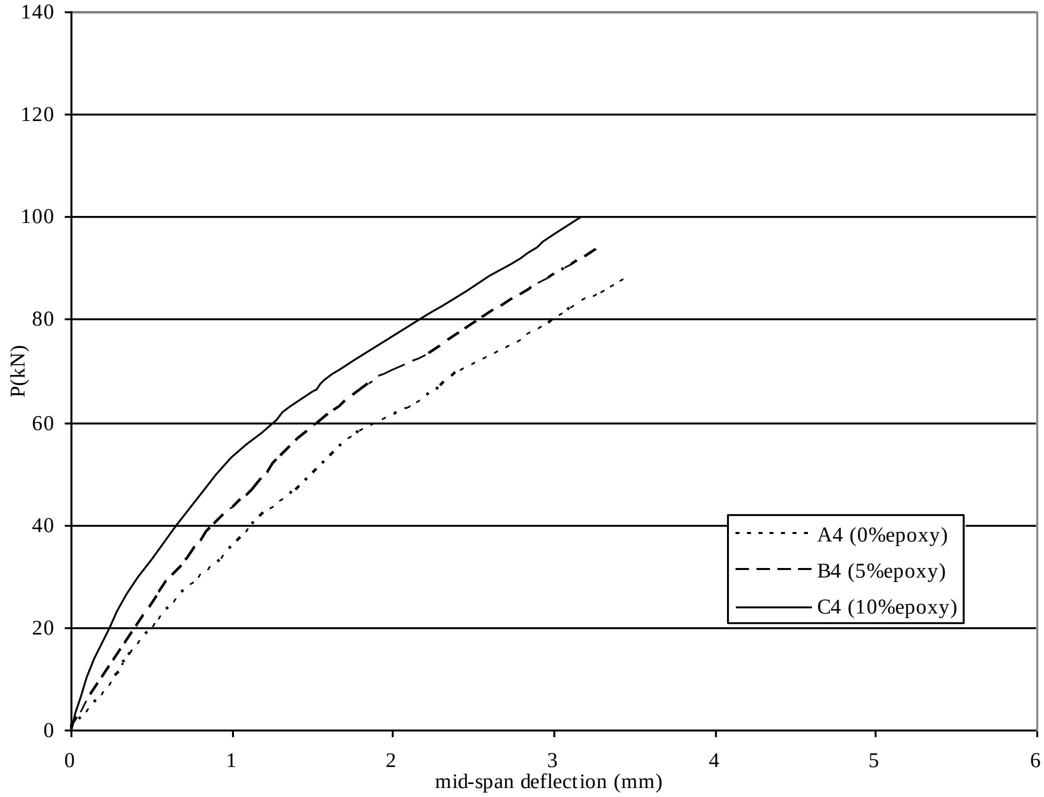


Figure (5-11) Load-Deflection Curves of Beams with (a/d) =3.5 and without Stirrups

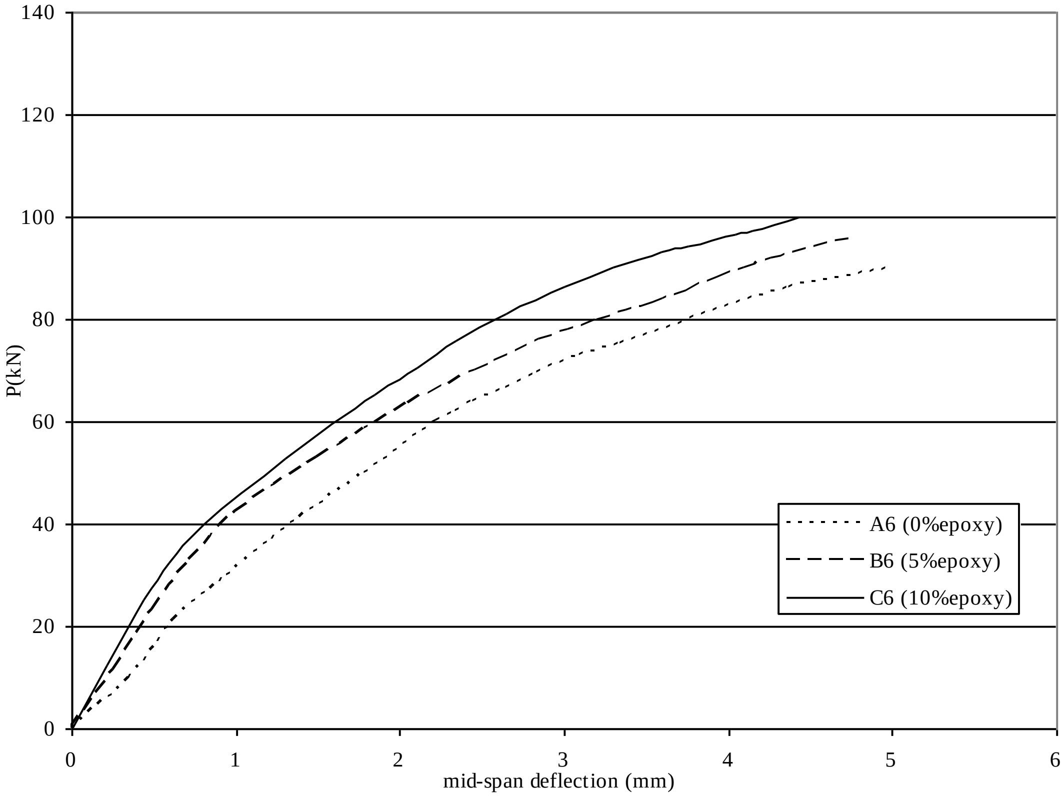


Figure (5-12) Load-Deflection Curves of Beams with (a/d)=4.5 and without Stirrups

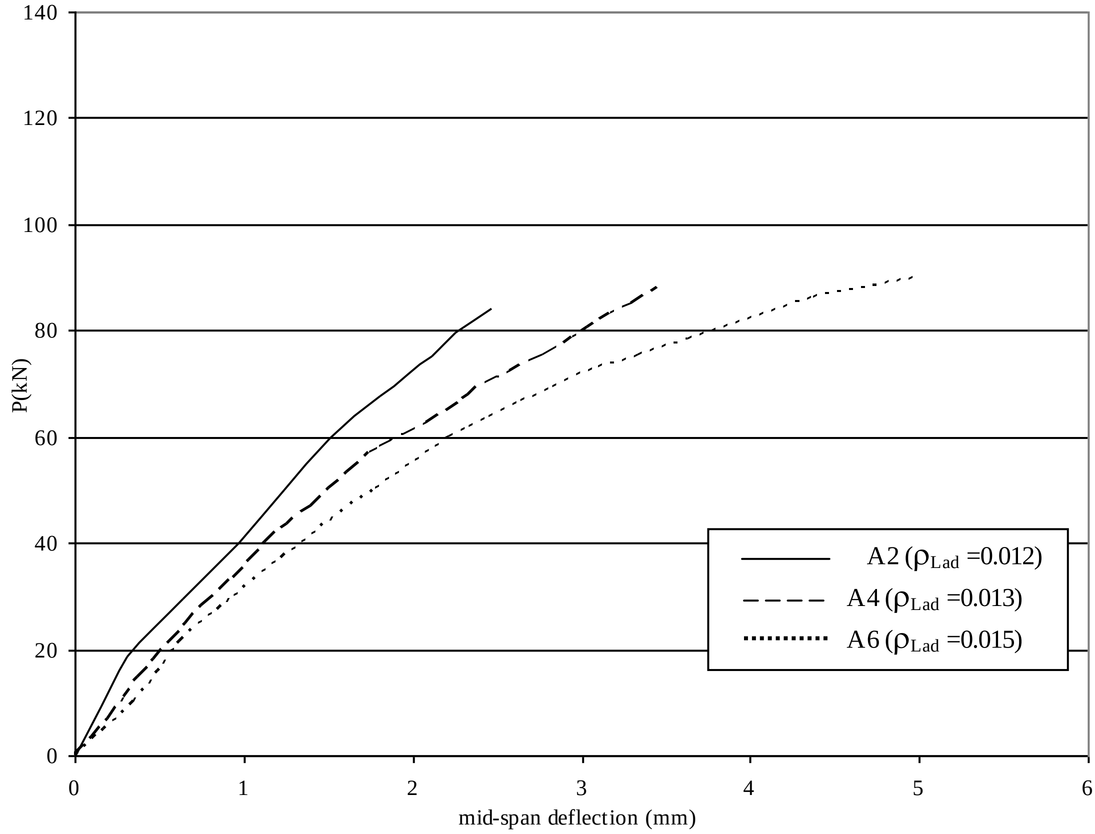


Figure (5-13) Load-Deflection Curves of Beams with 0% Epoxy and without Stirrups

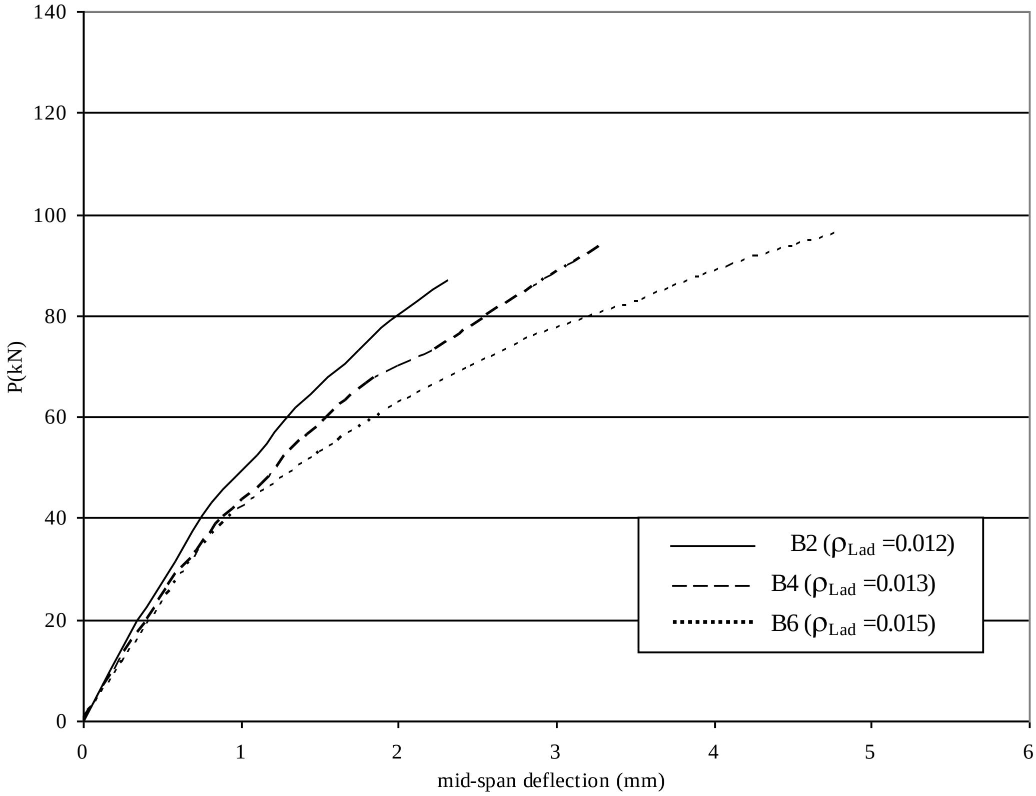


Figure (5-14) Load-Deflection Curves of Beams with 5% Epoxy and without Stirrups

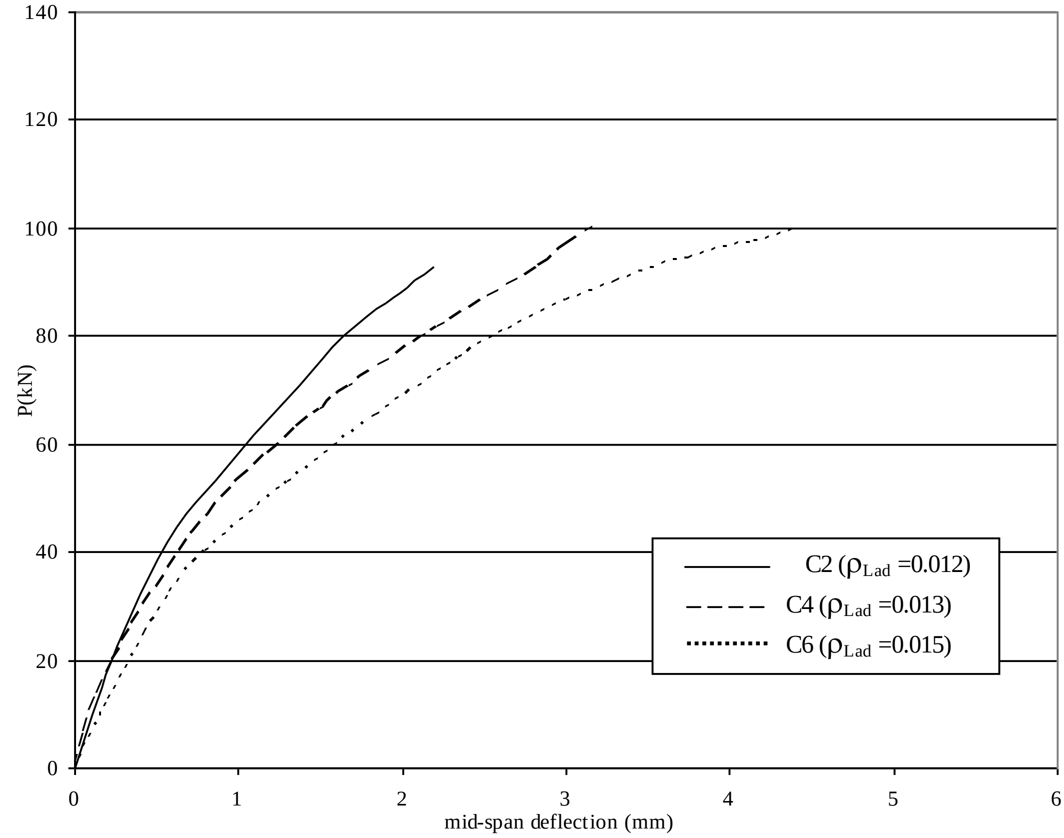


Figure (5-15) Load-Deflection Curves of Beams with 10% Epoxy and without Stirrups

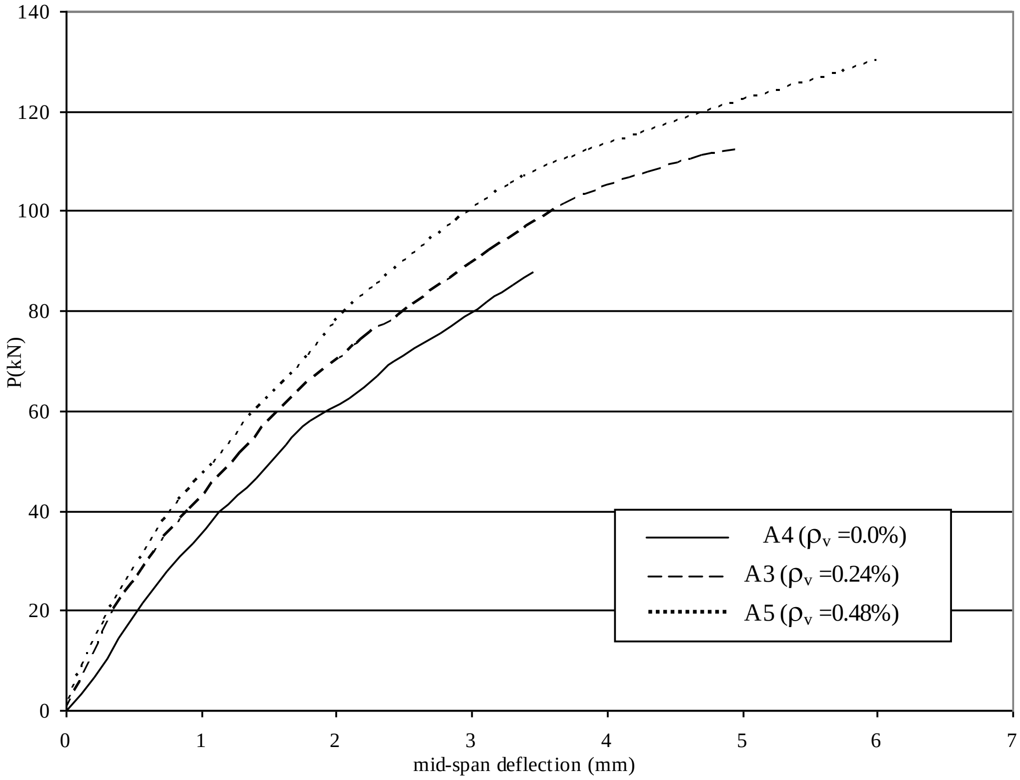


Figure (5-16) Load-Deflection Curves of Beams with 0% Epoxy and with Different Stirrups Contents

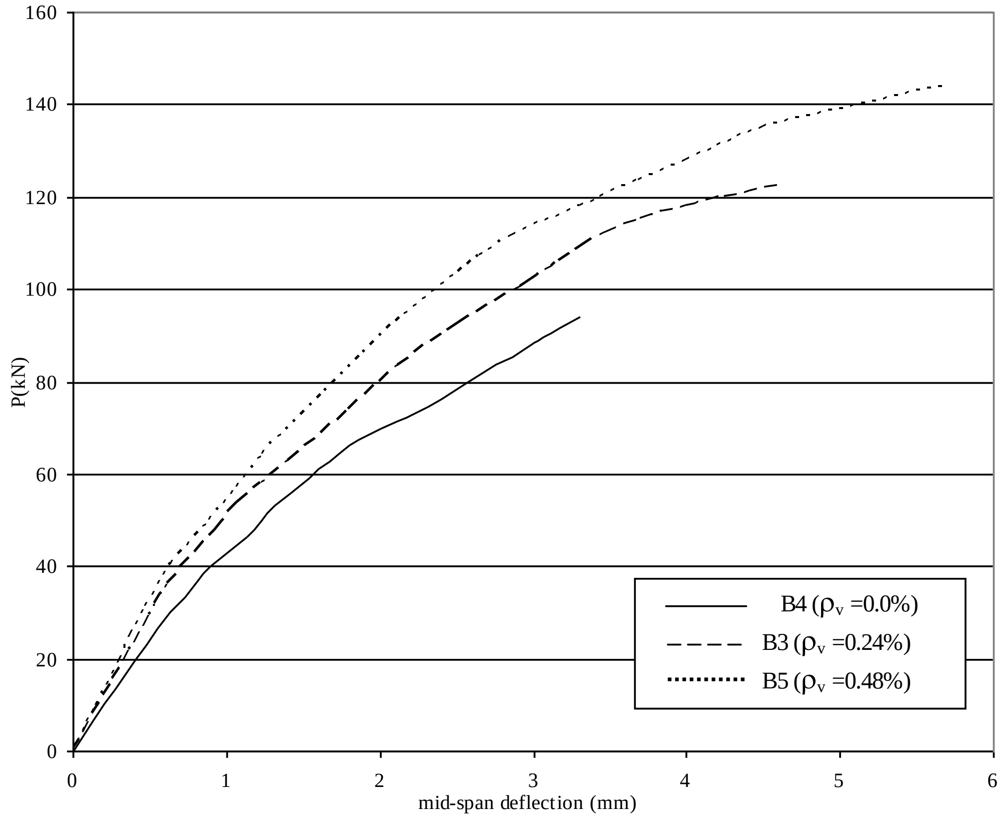


Figure (5-17) Load-Deflection Curves of Beams with 5% Epoxy and with Different Stirrups Contents

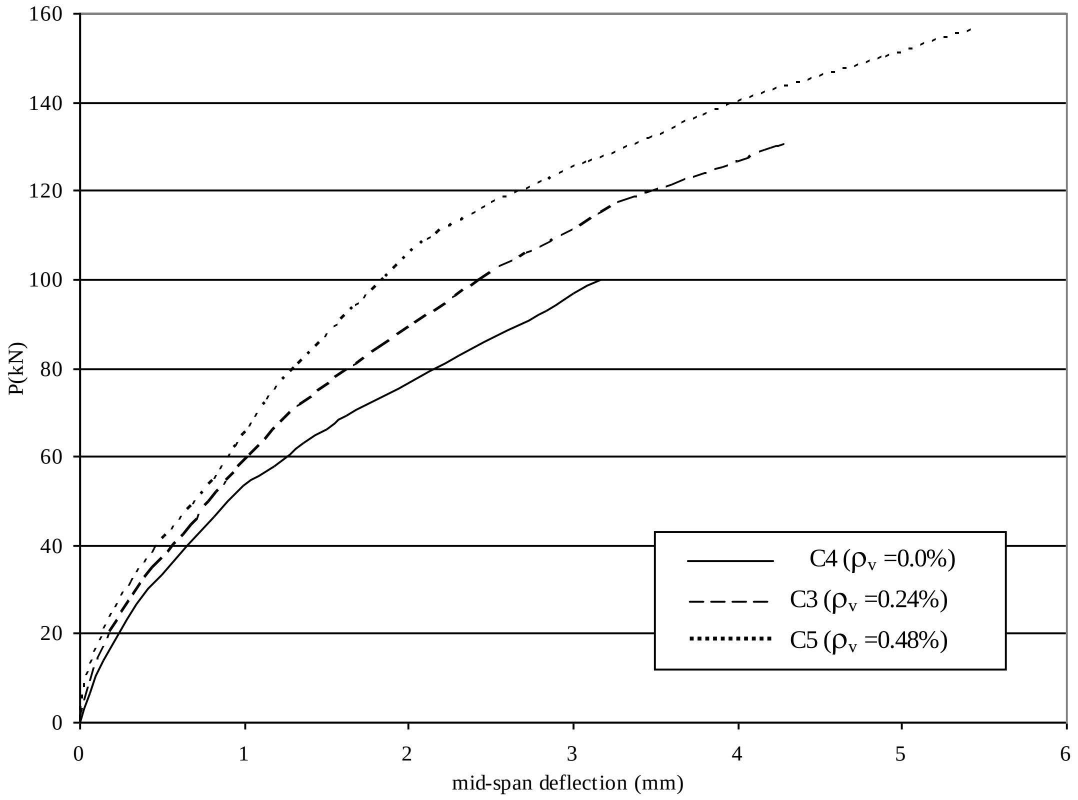


Figure (5-18) Load-Deflection Curves of Beams with 10% Epoxy and with Different Stirrups Contents

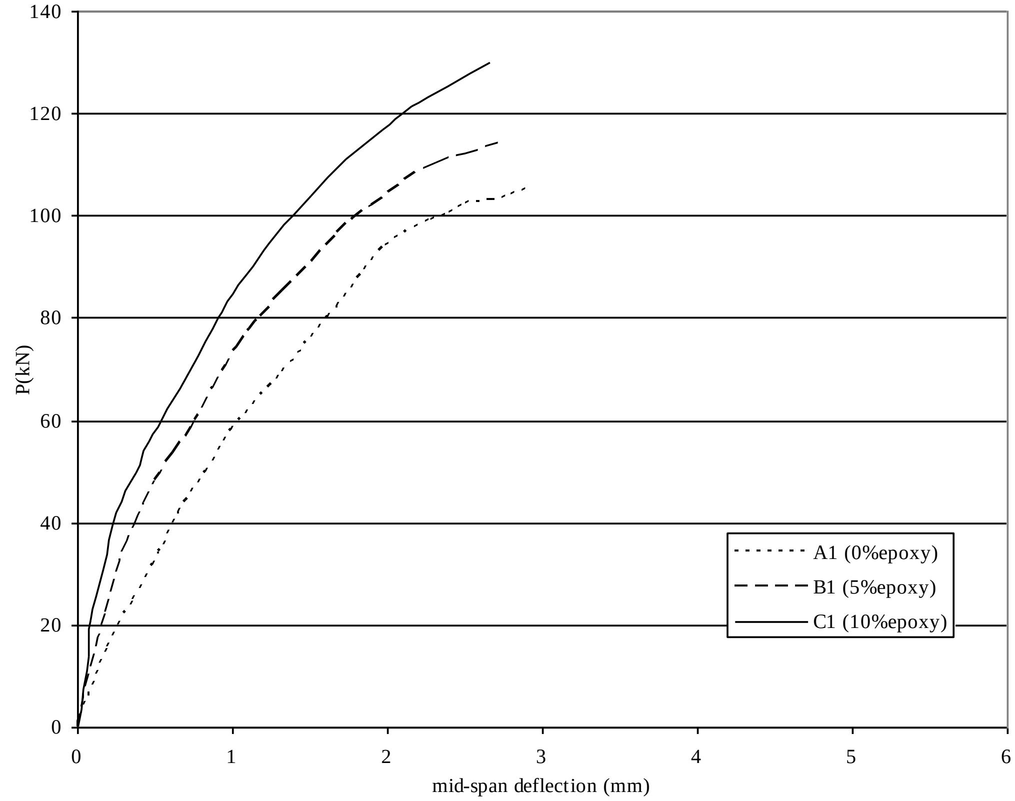


Figure (5-19) Load-Deflection Curves of Beams with Constant Stirrups Content and Different Epoxy Weight Ratios

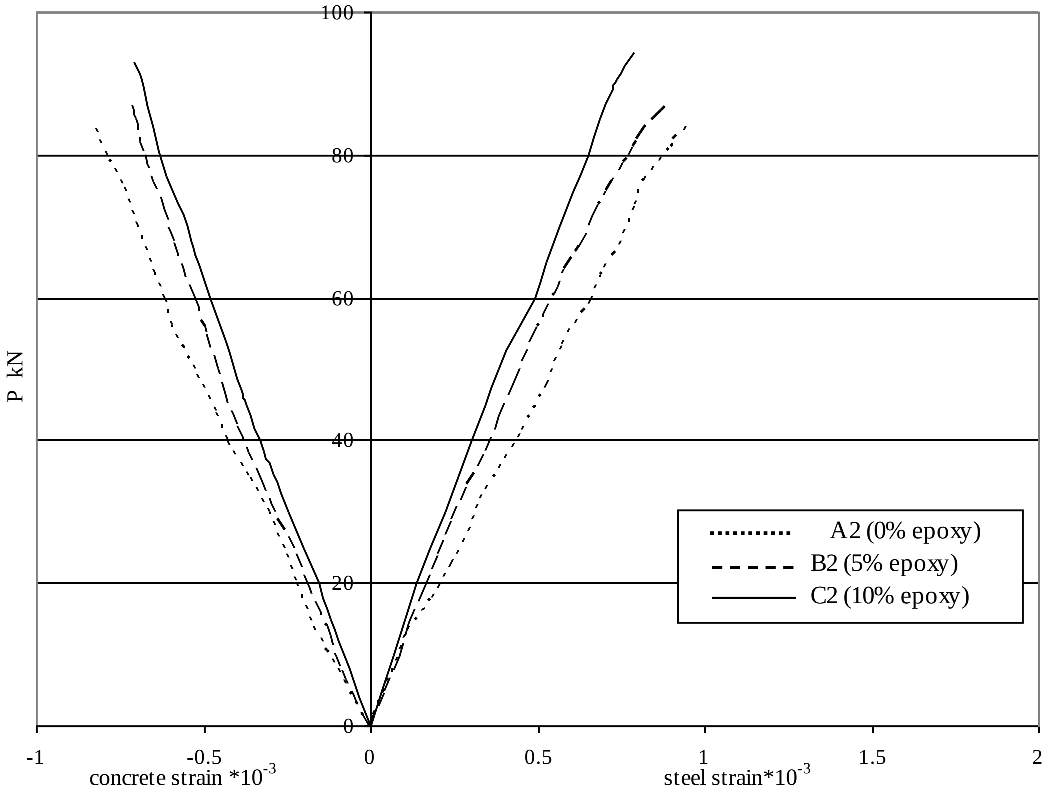


Figure (5-20) Load versus Steel and Concrete Strain of Beams with (a/d)=2.5 and without Stirrups

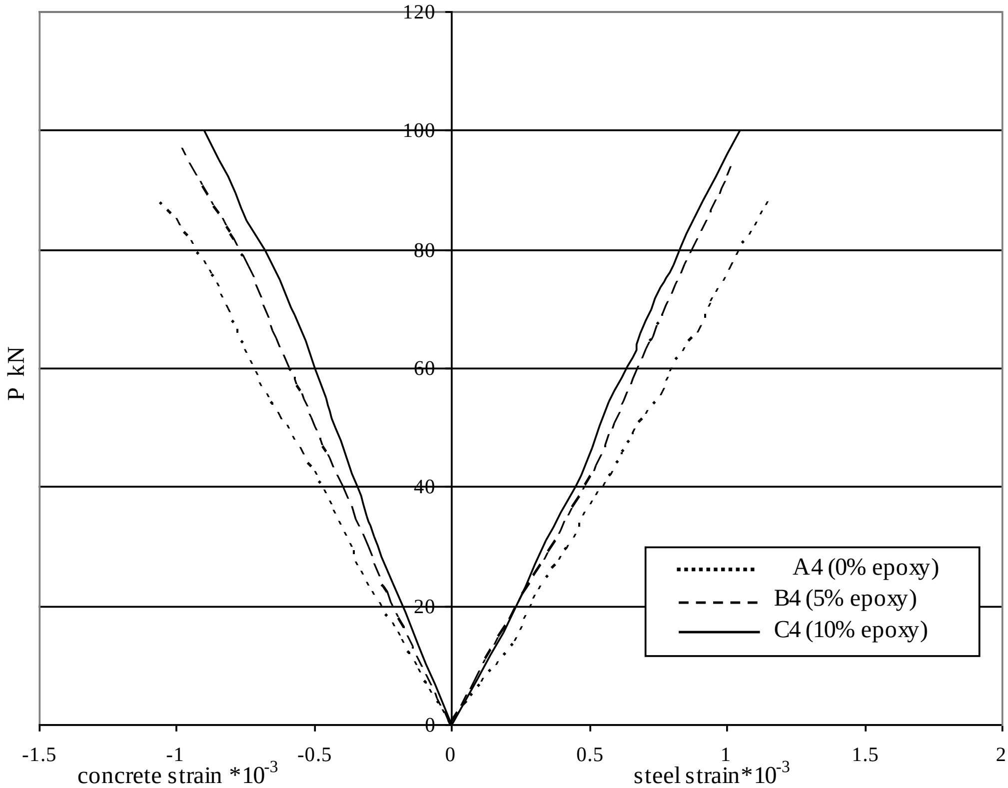


Figure (5-21) Load versus Steel and Concrete Strain of Beams with (a/d)=3.5 and without Stirrups

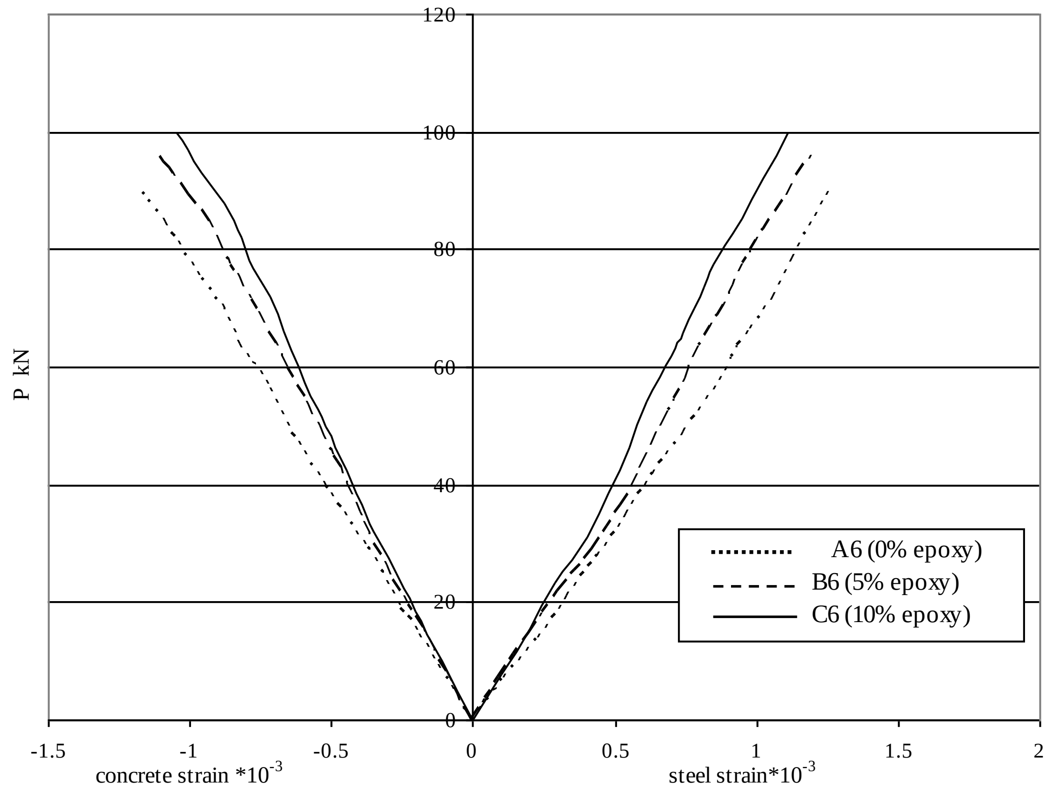
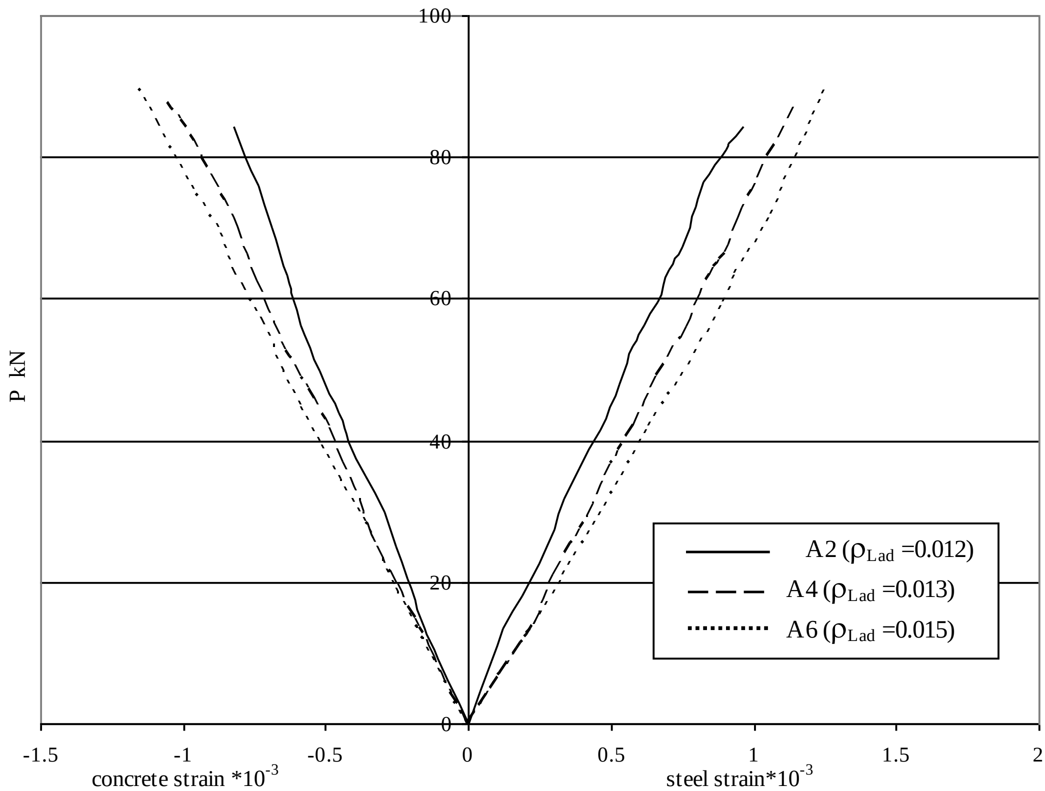


Figure (5-22) Load versus Steel and Concrete Strain of Beams with (a/d)=4.5 and without



Stirrups

Figure (5-23) Load versus Steel and Concrete Strain of Beams with 0% Epoxy and without Stirrups

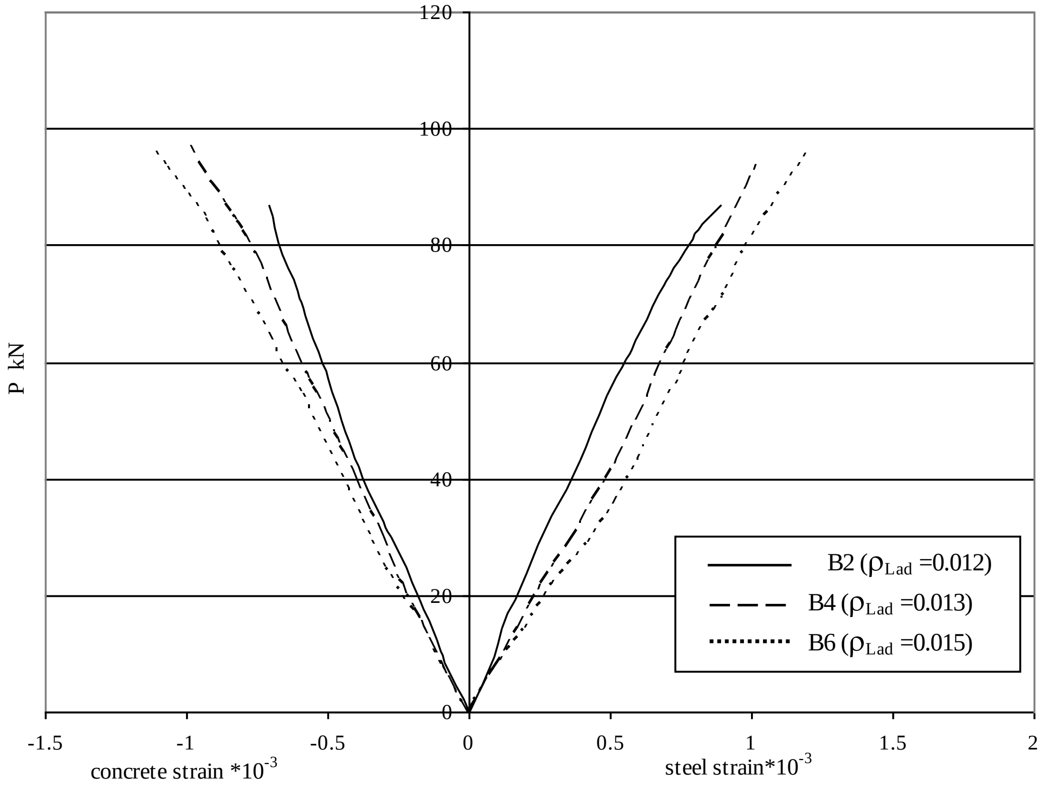


Figure (5-24) Load versus Steel and Concrete Strain of Beams with 5% Epoxy and without Stirrups

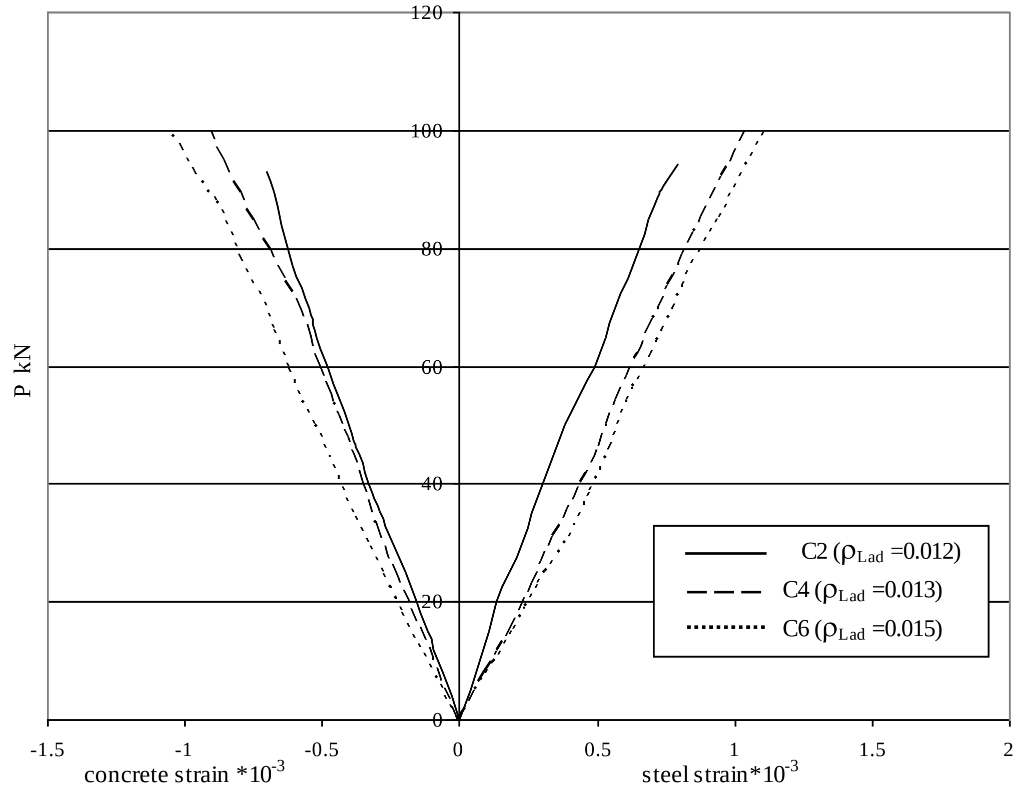


Figure (5-25) Load versus Steel and Concrete Strain of Beams with 10% Epoxy and without Stirrups

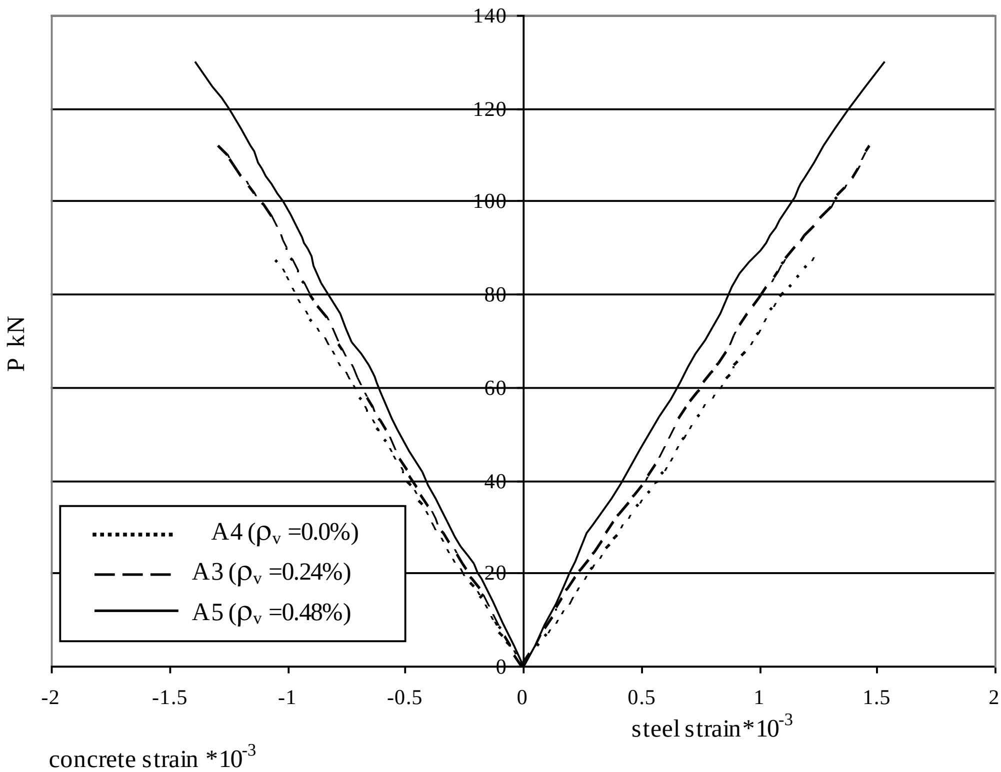


Figure (5-26) Load versus Steel and Concrete Strain of Beams with 0% Epoxy and with Stirrups

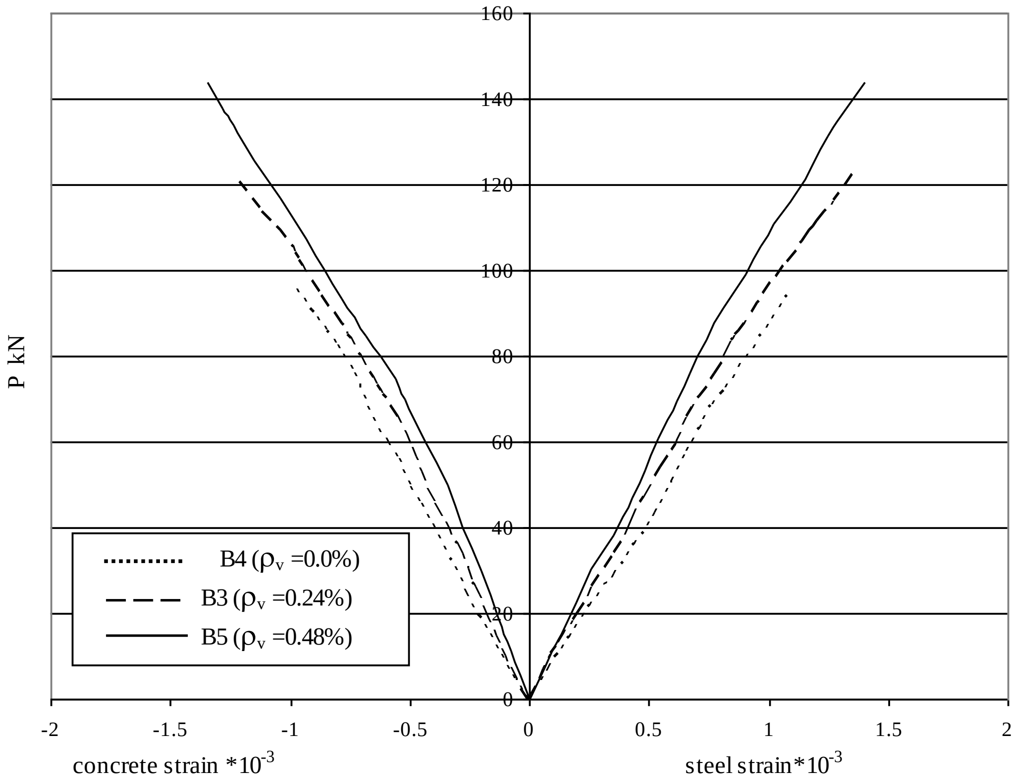


Figure (5-27) Load versus Steel and Concrete Strain of Beams with 5% Epoxy and with Stirrups

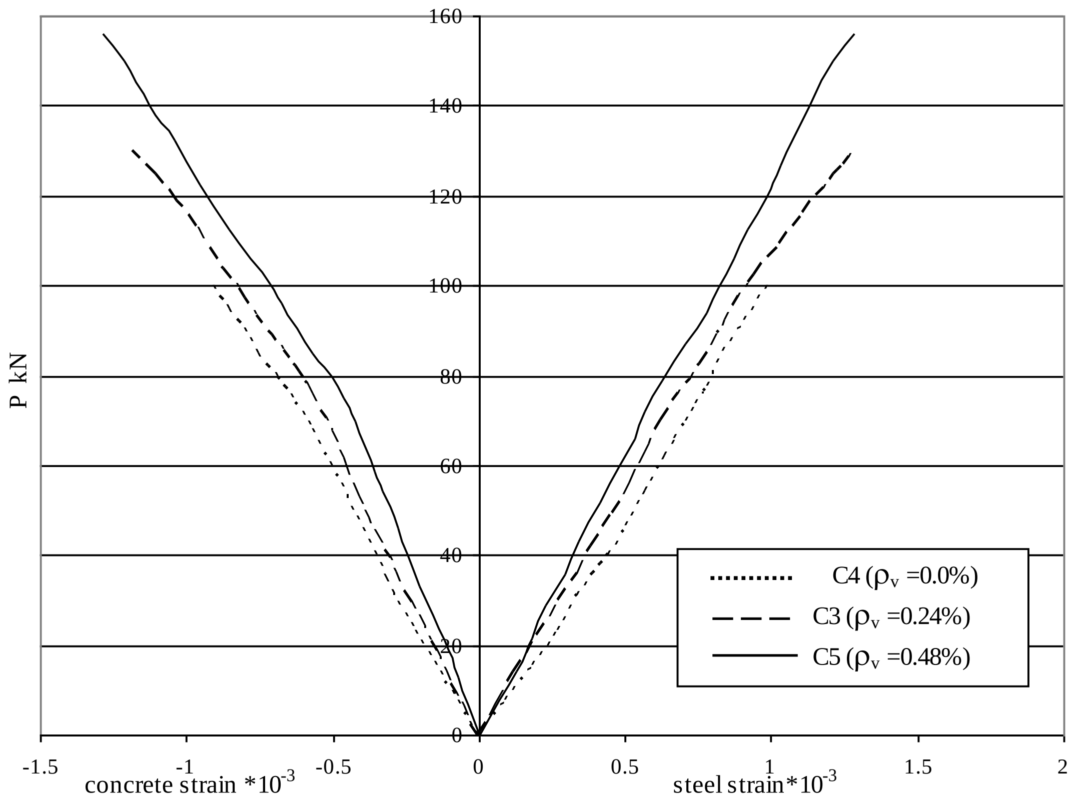


Figure (5-28) Load versus Steel and Concrete Strain of Beams with 10% Epoxy and with Stirrups

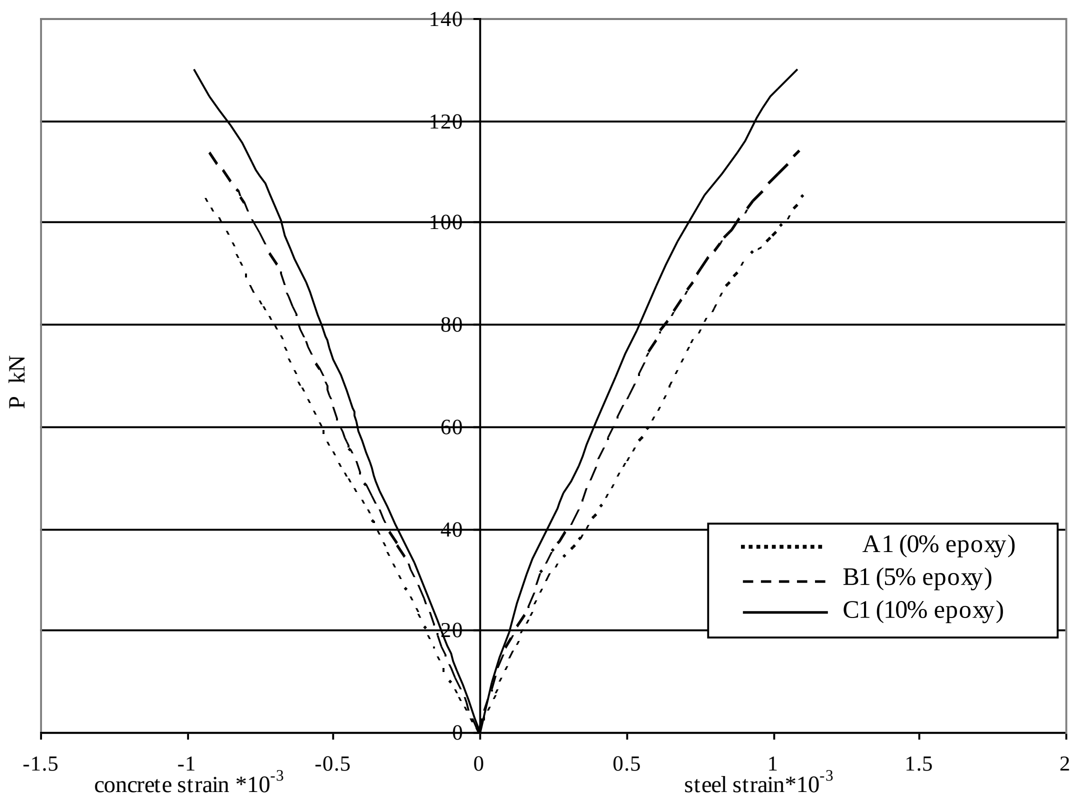


Figure (5-29) Load versus Steel and Concrete Strain of Beams with constant Stirrups Content and Different Epoxy Volume Ratios

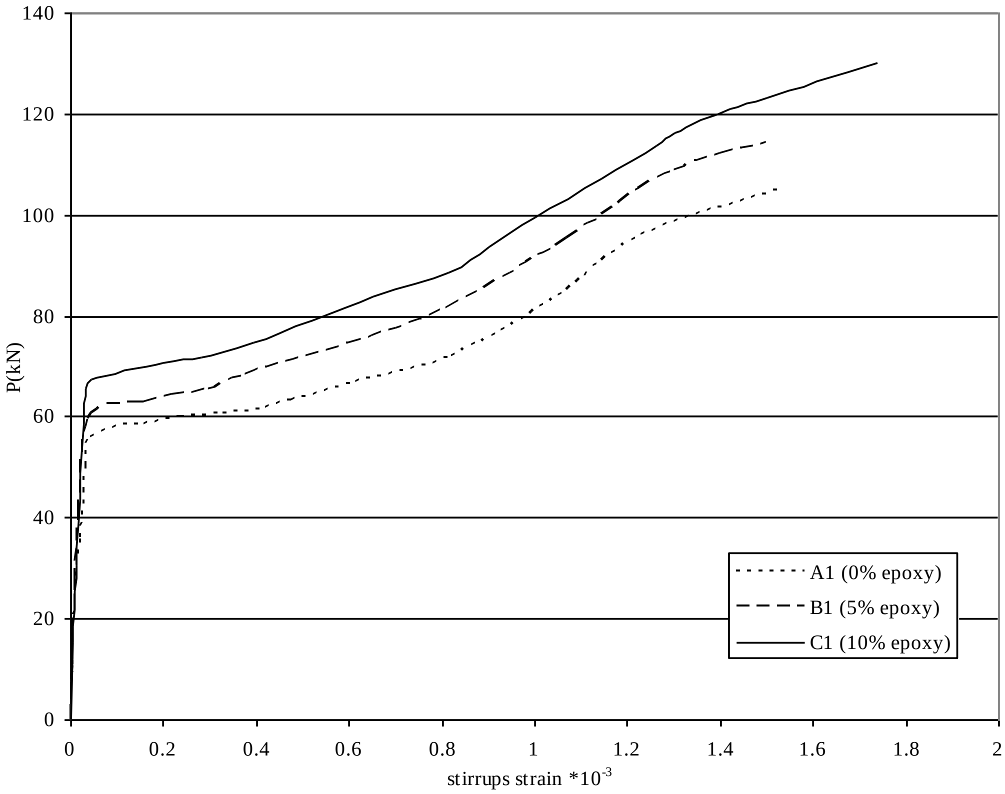


Figure (5-30) Load-Stirrups Strain Curves of Beams with ρ_{Lad}=0.012, ρ_v=0.24%

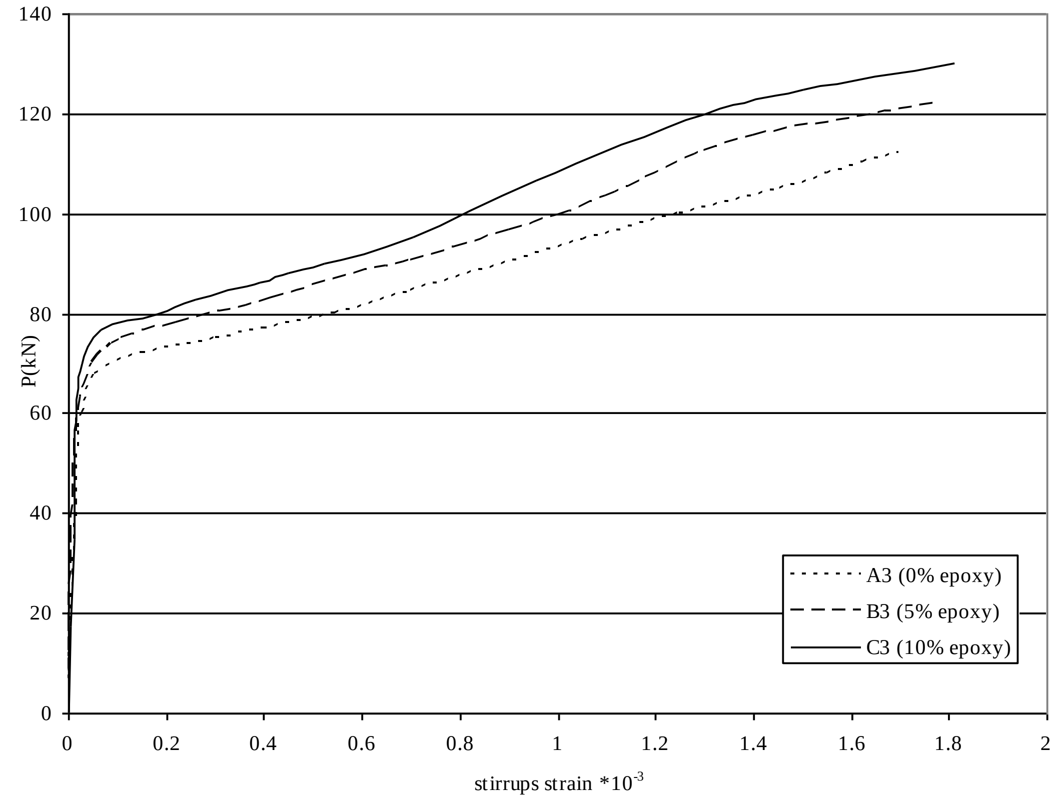


Figure (5-31) Load-Stirrups Strain Curves of Beams with ρ_{Lad}=0.013, ρ_v=0.24%

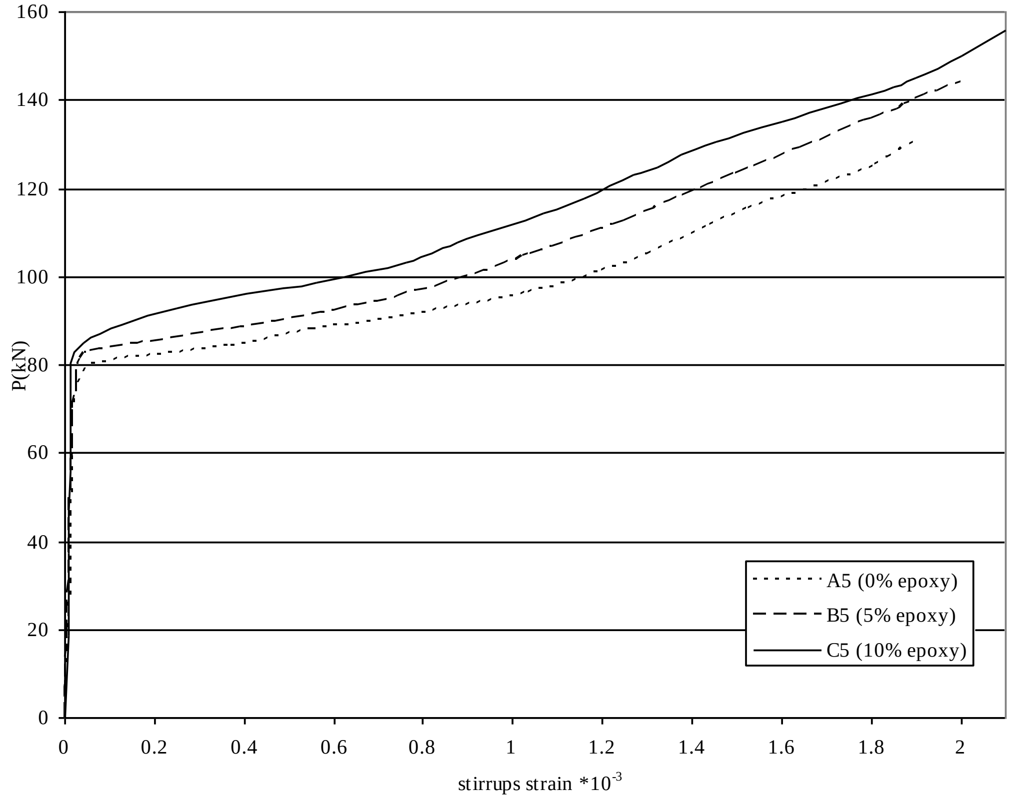


Figure (5-32) Load-Stirrups Strain Curves of Beams with ρ_{Lad}=0.013, ρ_v=0.48%

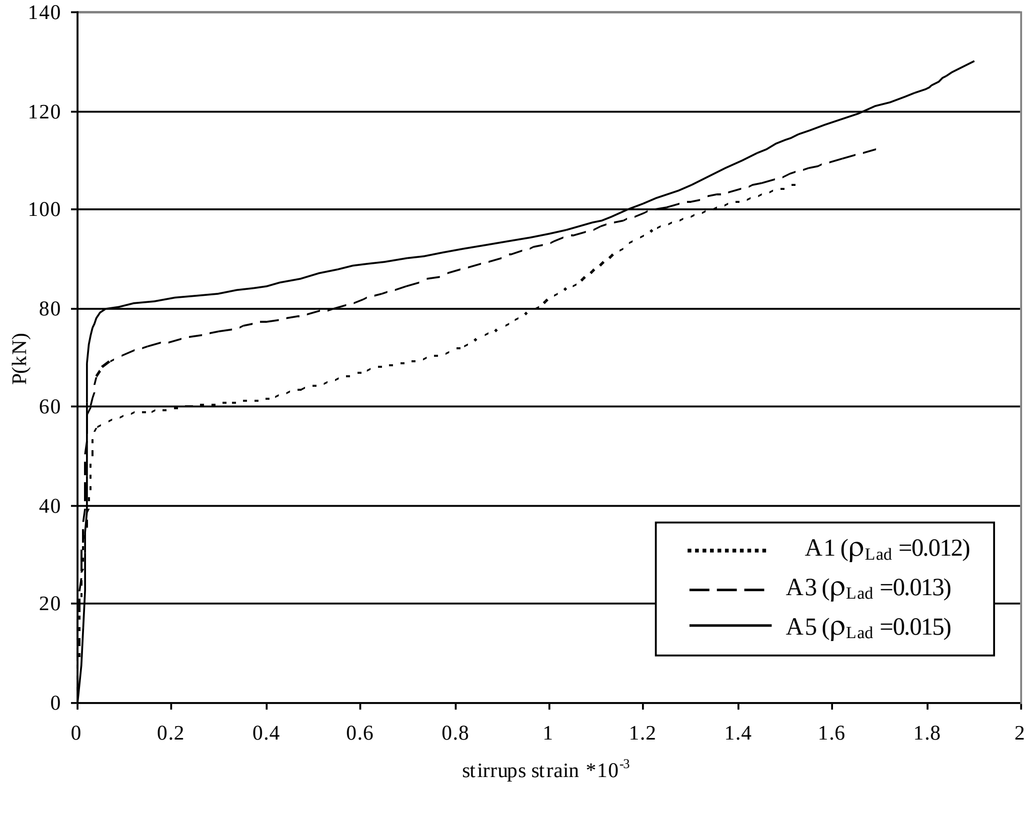


Figure (5-33) Load-Stirrups Strain Curves of Beams with 0% Epoxy

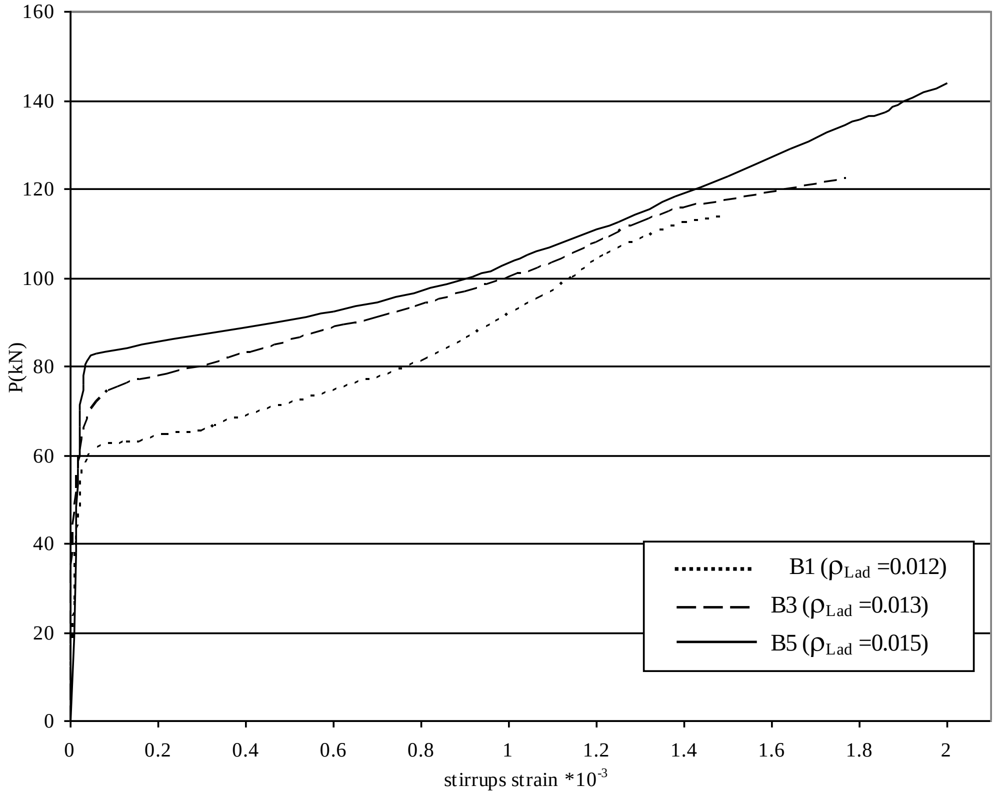


Figure (5-34) Load-Stirrups Strain Curves of Beams with 5% Epoxy

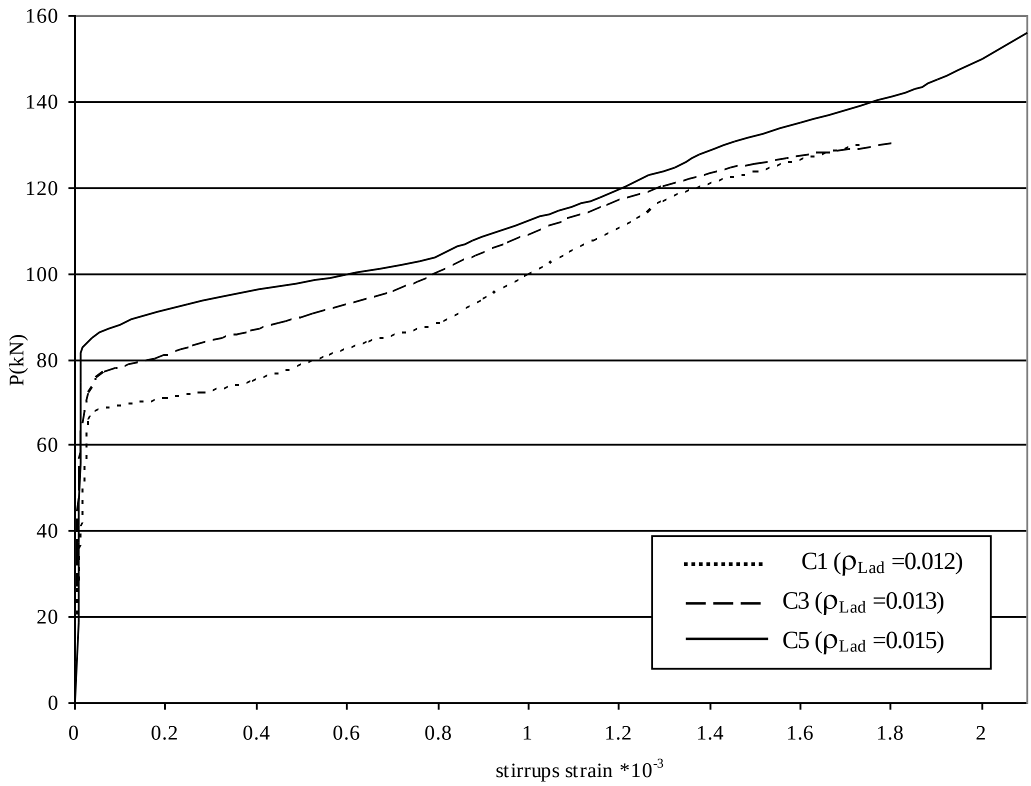
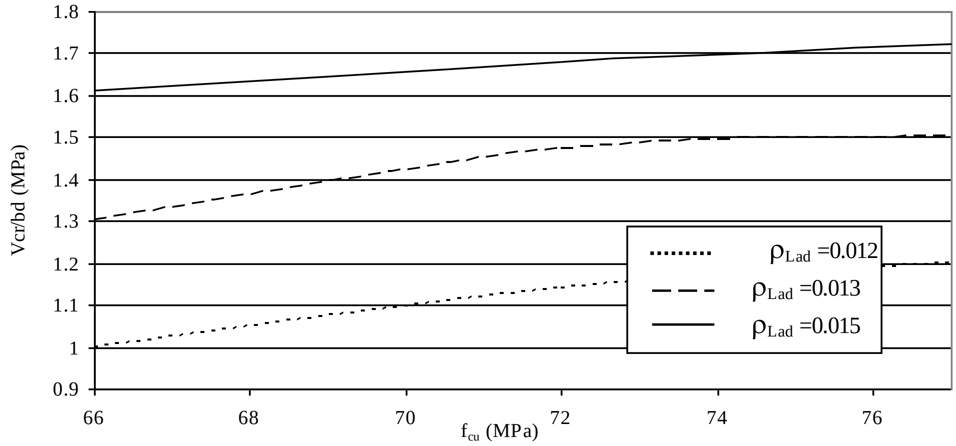
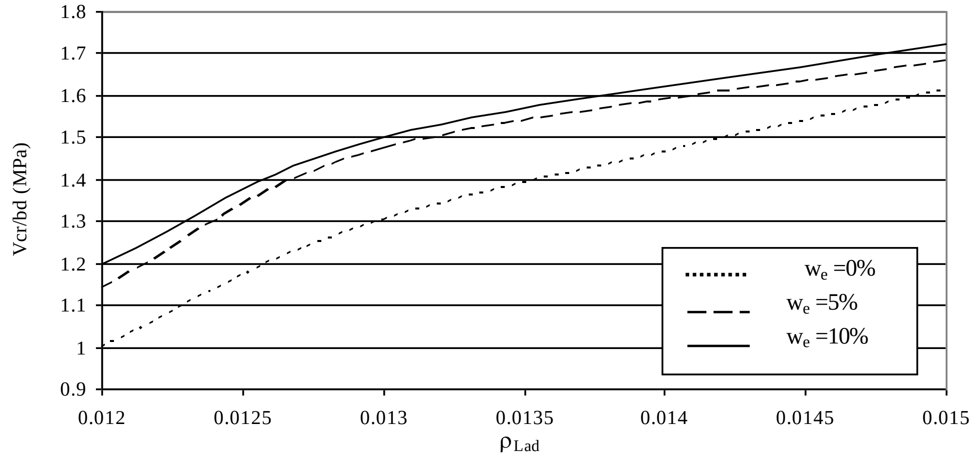


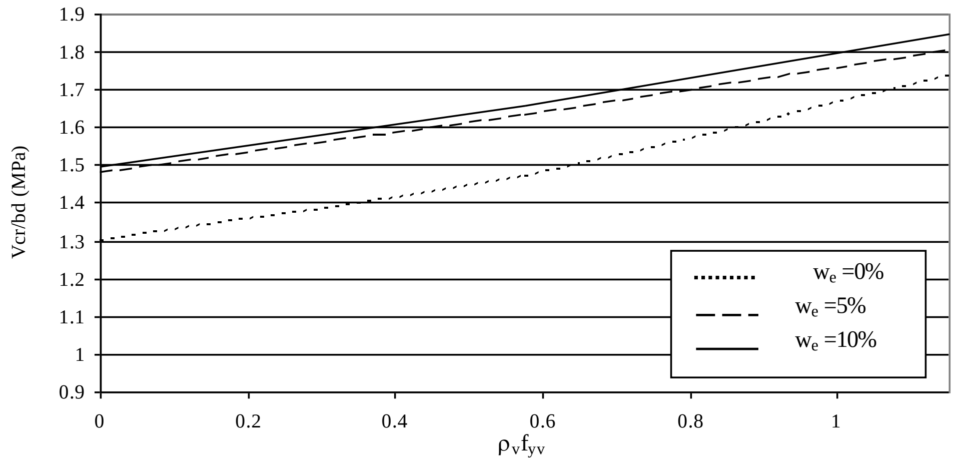
Figure (5-35) Load-Stirrups Strain Curves of Beams with 10% Epoxy



a) Influence of concrete strength (f_{cu}) with respect to ρ_{Lad} [beams with no stirrups

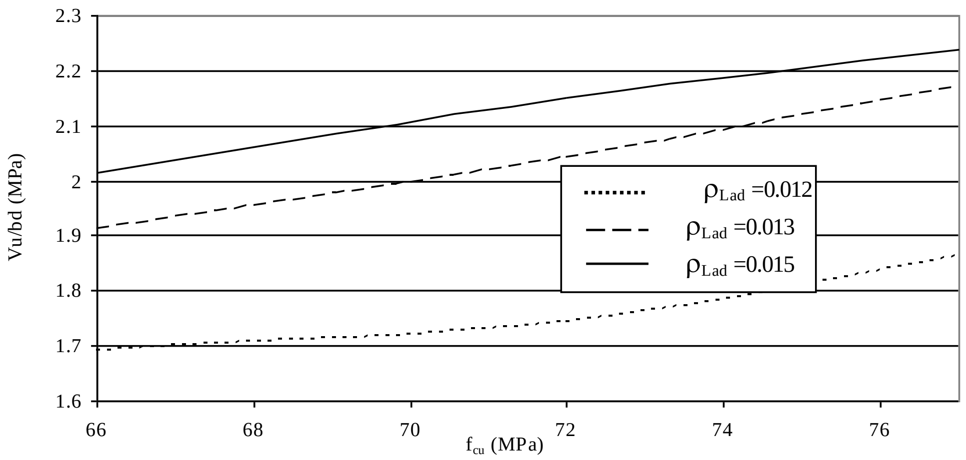


b) Influence of ρ_{Lad} with respect to epoxy weight ratio (w_e) [beams with no stirrups]

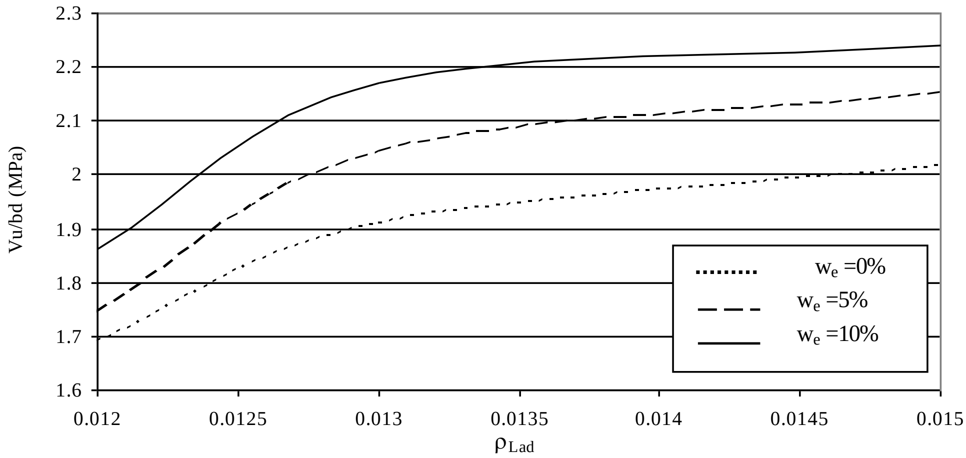


c) Influence of stirrups content ($\rho_v f_{yv}$) with respect to epoxy weight ratio (w_e) [ρ_{Lad}=0.013]

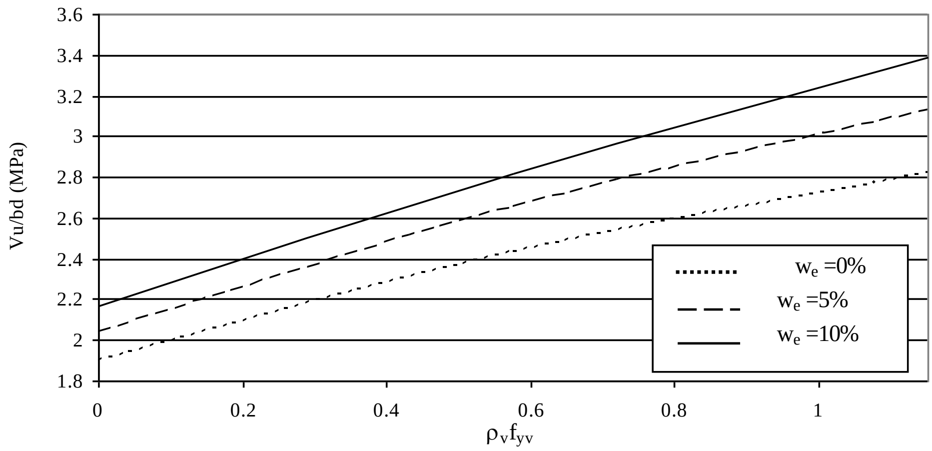
Figure (5-36) Influence of Concrete Strength, Epoxy Weight Ratio, Stirrups Content, and ρ_{Lad} on the Cracking Shear Strength



a) Influence of concrete strength (f_{cu}) with respect to ρ_{Lad} [beams with no stirrups]



b) Influence of ρ_{Lad} with respect to epoxy weight ratio (w_e) [beams with no stirrups]



c) Influence of stirrups content ($\rho_v f_{yv}$) with respect to epoxy weight ratio (w_e) [ρ_{Lad}=0.013]

Figure (5-37) Influence of Concrete Strength, Epoxy Weight Ratio, Stirrups Content, and ρ_{Lad} on the Ultimate Shear Strength