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STATIC BEHAVIOUR OF REINFORCED HIGH STRENGTH CONCRETE HAUNCHED BEAMS STRENGHENED BY USING EPOXY BONDED EXTERNAL STEEL PLATES

ABD EL-RAHMAN MEGAHID
Professor of structural Eng. Civil Eng. Dept., Assiut University, Egypt
RASHWAN M. M.
Professor of structural Eng. Civil Eng. Dept., Assiut University, Egypt
AHMED MOHAMED SAYED
Demonstrator in civil Engineering Dept., Assiut University, Egypt

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Strengthening of concrete haunched beams with epoxy bonded external steel side plates in shear is becoming on increasing by popular retrofit technique among researchers and engineering worldwide. Concrete of higher compressive strength have been produced currently and increasingly used by the designers and contractors. Therefore, the main purpose of the research described in this paper is to give better and full understanding of the shear behavior of high strength concrete rectangular beams strengthened with epoxy bonded external steel side plates and subjected to static load. The main variables studied were the geometric dimensions of bonded steel plates, width, position and arrangements, thickness of plate bonded on both sides of shear zone of beams, the effect of haunches (Negative haunches (-0.20) and positive haunches (+0.20)) and effect of quality degree of used concrete strength. During the tests cracking load, ultimate load, concrete strains, steel strains and deflection under load application were measured

Test results showed that the width, position, arrangements and thickness of plate used considerably affects strength, deformation and mode of failure of the tested beams. Increasing the width, position, arrangements and thickness of plate bonded on both sides of shear zone of beams increases the cracking and ultimate capacities of the strengthened beams. Increasing the quality degree of concrete strength decreases the relative cracking and ultimate capacities of the strengthened beams compared to unstrengthened beams. The change from positive haunches (+0.20) to Negative haunches (-0.20) increases the cracking and ultimate capacities of the strengthened beams.

INTRODUCTION

Some of the existing reinforced concrete structures may require strengthening or stiffening in order to increase their structural performance. Strengthening by using Epoxy bonded external Steel Plates has been established as an effective method applicable to many types of such structures.

Several studies have been focused on the potential use of carbon fiber reinforced polymer "CFRP" and external Steel Plates for flexural and shear strengthening of normal strength concrete beams and some of high strength concrete beams of constant depth. But relatively little researches have been done on the use of external Steel side Plates in shear strengthening of high strength concrete haunched beams [1-28]. In addition to that the current understanding of the shear behavior of R.C. beam strengthened with external Steel side Plates is limited and much further research is still needed. Therefore, the aims of this study were to gain a better understanding and enhance the experimental database of shear behavior of R.C. beams, with constant cross-section, shear span to depth ratio (a/d) equal (1.80), strengthened externally with steel side plate and to develop a simple accurate model to predict the contribution of steel side plate to the shear capacity of such beams at the complete debonding of steel side plate. The main variables investigated were, the geometric dimensions of bonded steel plates (width, position and arrangements), thickness of plate, the effect of the shape of haunches (Negative haunches (-0.20) and positive haunches (+0.20)) and effect of quality degree of concrete strength.

EXPERIMENTAL PROGRAM

Beams Having Negative Haunches

Fourteen high strength concrete beams and four reinforced normal strength concrete beams having 1.50 m total length with rectangular cross – section of 0.12 m breadth and constant height equals to 0.28 m . along the mid zone of beam (40 cm) and variable height along the shear span of beams equals to 0.36 m. these beams were tested over a simple span of 1.30 m. under two equal point loading of 40 cm apart. All beams were reinforced with four tension bars of 16.0 mm diameter and two top bars of 10.0 mm. diameter plus stirrups of 6.0 mm diameter at variable spacing, These beams were divided into five series ("AN", "BN", "CN", "DN" and "EN" = 250,400, 550,700 and550 kg/cm^2) respectively according to the quality degree of high strength concrete and thickness of plate bonded on both sides of shear zone of beams, having constant negative haunch, (tan α = -0.20) and with constant shear span to depth ratio (a/d) equal (1.80).

Beams Having Positive Haunches

Fourteen high strength concrete beams and four reinforced normal strength concrete beams having 1.50 m total length with rectangular cross – section of 0.12 m breadth and constant height equals to 0.28 m . along the mid zone of beam (40 cm) and variable height along the shear span of beams equals to 0.20 m . these beams were tested over a simple span of 1.30 m. under two equal pint loading of 40 cm apart. All beams were reinforced with four tension bars of 16.0 mm diameter and two top bars of 10.0 mm. diameter plus stirrups of 6.0 mm diameter at variable spacing. These beams were divided into five series ("AP", "BP", "CP", "DP" and "EP" = 250, 400, 550, 700 and 550 kg/cm^2) respectively according to the quality degree of high strength concrete and thickness of plate bonded on both sides of shear zone of beams, having constant positive haunch, (tan α = +0.20) and with constant shear span to depth ratio (a/d) equal (1.80).

The test program was mainly intended to cover the testing of high strength concrete haunched beams taking into account the following parameters :

1. The geometric dimensions of bonded steel plates, width, position and "arrangements of steel plates bonded on both sides of shear zone of beams"
2. Thickness of plate bonded on both sides of shear zone of beams.
3. The effect of the sign of slope haunches: Negative haunches (-0.20) and positive haunches (+0.20).
4. Effect of grade of used concrete (concrete strength)

Figure (1-a) and (1-b) and tables (1-a) and (1-b) give details of the test beam specimen.

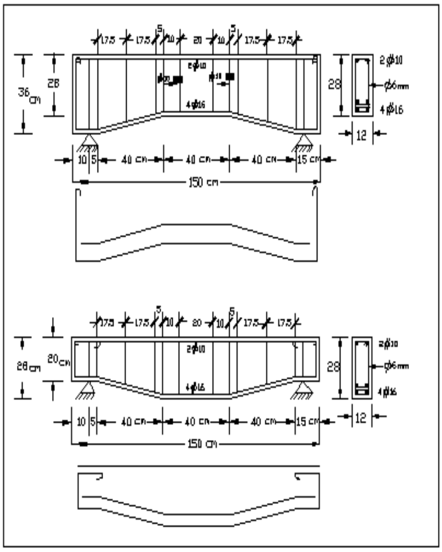


Fig. (1-a) : Details of reinforcement of tested beams.

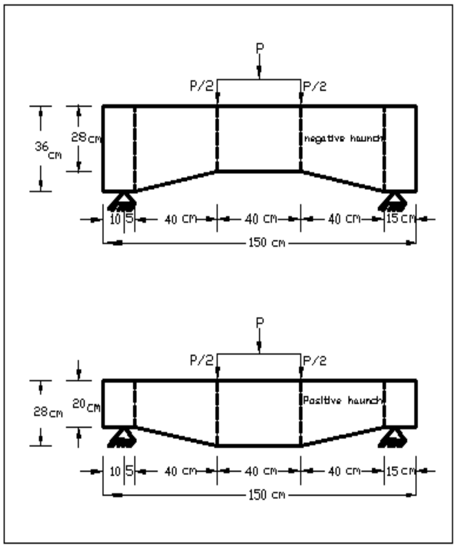


Fig . (1-b) : Load configuration of beams

2- MATERIALS

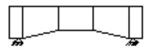
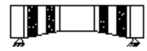
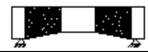
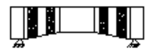
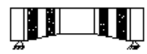
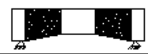
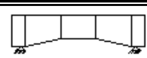
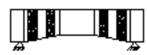
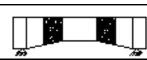
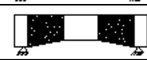
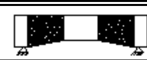
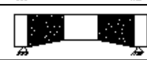
(2-1) Concrete

The beams were made from concrete having variable strengths. Therefore, concrete mixes design was made to produce concrete having a cube strength of about (250 , 400 , 550 , 700 kg/cm^2) at 28days age. The mix proportions by weight as follows in Table (2-a).

Table (2-a) For mix design to give strength (250 kg/cm^2)

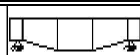
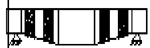
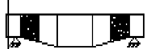
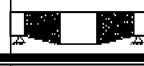
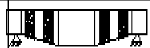
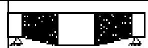
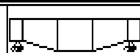
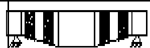
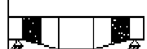
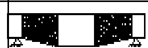
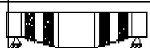
Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	Water liter/m^3
350	523	1220	192

Table (1-a) : Details and data of tested beams of series "AN","BN","CN","DN" and "EN".

Series	Beam NO.	Concrete strength (kg/cm^2)	Beam reinforcement				Data of bonded side plates			Shape of beams and position of side plate
			A. Steel	μ	A'_s	μ'	t mm	n	% areas.p.	
AN	**AN.0**	**250**	**4Φ16**	**2.57**	**2Φ10**	**0.50**	**2.0**	**----**	**----**	
	AN.1							**2**	**0.500**	
	AN.2							**1**	**0.469**	
	AN.3							**1**	**1.000**	
BN	**BN.0**	**400**	**4Φ16**	**2.57**	**2Φ10**	**0.50**	**2.0**	**----**	**----**	
	BN.1							**2**	**0.500**	
	BN.2							**1**	**0.469**	
	BN.3							**1**	**1.000**	
CN	**CN.0**	**550**	**4Φ16**	**2.57**	**2Φ10**	**0.50**	**2.0**	**----**	**----**	
	CN.1							**2**	**0.500**	
	CN.2							**1**	**0.469**	
	CN.3							**1**	**1.000**	
DN	**DN.0**	**700**	**4Φ16**	**2.57**	**2Φ10**	**0.50**	**2.0**	**----**	**----**	
	DN.1							**2**	**0.500**	
	DN.2							**1**	**0.469**	
	DN.3							**1**	**1.000**	
EN	**EN.1**	**550**	**4Φ16**	**2.57**	**2Φ10**	**0.50**	**1.5**	**1**	**1.000**	
	EN.2						**1.0**	**1**	**1.000**	

% area s.p. = relative area strengthed plate to area of haunch
n = number of side plate bonded on one side of haunch

Table (1-b) : Details and data of tested beams of series "AP","BP","CP","DP" and "EP".

Series	Beam NO.	Concrete strength (kg/cm^2)	Beam reinforcement				Data of bonded side plates			Shape of beams and position of side plate
			A. Steel	μ	A′s	μ′	t mm	n	%areas. p.	
AP	**AP.0**	**250**	**4Φ16**	**2.57**	**2Φ10**	**0.50**	**2.0**	**----**	**----**	
	AP.1							**2**	**0.500**	
	AP.2							**1**	**0.458**	
	AP.3							**1**	**1.000**	
BP	**BP.0**	**400**	**4Φ16**	**2.57**	**2Φ10**	**0.50**	**2.0**	**----**	**----**	
	BP.1							**2**	**0.500**	
	BP.2							**1**	**0.458**	
	BP.3							**1**	**1.000**	
CP	**CP.0**	**550**	**4Φ16**	**2.57**	**2Φ10**	**0.50**	**2.0**	**----**	**----**	
	CP.1							**2**	**0.500**	
	CP.2							**1**	**0.458**	
	CP.3							**1**	**1.000**	
DP	**DP.0**	**700**	**4Φ16**	**2.57**	**2Φ10**	**0.50**	**2.0**	**----**	**----**	
	DP.1							**2**	**0.500**	
	DP.2							**1**	**0.458**	
	DP.3							**1**	**1.000**	
EP	**EP.1**	**550**	**4Φ16**	**2.57**	**2Φ10**	**0.50**	**1.5**	**1**	**1.000**	
	EP.2						**1.0**	**1**	**1.000**	

% area s.p. = relative area strengthed plate to area of haunch
n = number of side plate bonded on one side of haunch

*For high strength concrete mix design was made to produce high strength concrete having 28 days cubic strength of (400,550,700 kg/cm^2). Concrete mix proportions are given in Table (2 - b).

Table (2 - b): Concrete mix proportions.

Strength	Cement kg/m^3	Sand kg/m^3	Crushed basalt		Silica Fume kg/m^3	Additive B.V.F liter/m^3	Water liter/m^3
			< 10 mm kg/m^3	10 - 20 mm kg/m^3			
400	450	600	600	600	70	14	165
550	500	586	586	586	100	20	155
700	500	614	570	570	100	16	140

The constituent used materials were:

a) Ordinary Portland cement (Assiut Cement).
b) Local sand; the used sand had a specific gravity, volume weight and fineness modulus of 2.5, 1.71 t / m^3 and 2.50, respectively.
c) The coarse aggregate used was crushed basalt with (10 and 20 mm) maximum nominal size, 2.78 specific gravity and 1.56 t/m^3 volume weight.
d) Local natural gravel; the used gravel was 20 mms maximum nominal size, 2.50 specific gravity and 1.52 t/m^3 volume weight
e) Silica fume; it is produced by EFACO (Egyptian Ferro-Alloys company).
f) Additive: Addicrete BVF was used as superplastilizer for increasing both workability and strength for the purpose of obtaining homogeneous mixture. The additive was added to mixing water by percentage of weight of cement dose of 1.18 kg / liter volume weight.

(2-2) Steel Reinforcement

The used steel bars for stirrups of normal plain mild steel (M.S.) type and the used steel bars for the compression and tension reinforcement was high tensile ribbed steel bars (H.T.S.). The characteristics of the used bars (ø 6, Φ10and Φ16) are summarized in table (3) the values of the results included in this table are the average of three specimens.

Table (3): Properties of the used steel bars

Commercial diam.(mm)	ø 6 M.S.	Φ10 H.T.S	Φ16 H.T.S.
Actual diam.(mm)	6.14	10.03	16.07
Yield or proof stress. Fy. (kg/cm^2)	2760	4110	4330
Ultimate strength. Fu.(kg/cm^2)	3920	5807	5970
% of Elongation	25%	21%	18%

(2-3) External Bonded Steel Plates

The external used steel plates of thickness (2.00, 1.50 and 1.00mm) for side plates. Tests of steel plates were carried out according to standard specification. The mechanical properties of tested steel plates are listed in table (4).

Table (4): Mechanical properties of used external bonded steel plates.

Properties	Bonded steel plate thickness (mm)		
	1.00	1.50	2.00
Yield stress (kg/cm^2)	2710	2960	3080
Tensile strength (kg/cm^2)	3805	3985	3895
% of Elongation	29.00%	27.5%	27.00%

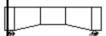
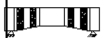
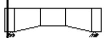
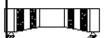
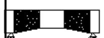
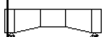
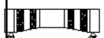
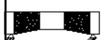
(2-4) Adhesive Material

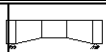
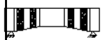
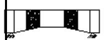
The epoxy adhesive mortar used in the study was manufactured and supplied by CHEMICALS FOR MODERN BUILDINGS, under commercial name of KEMAPOXY 165 compound. The compressive and bending strength of the adhesive material as given by the manufactures are 800 and 400 kg/cm^2 respectively. Also its adhesive strength on concrete is recorded to be 103 kg/cm^2.

(2-5) Testing Procedure

The available testing machine (EMS 60 tons) was used mainly in tested beams. The used machine has three ranges of loading (15, 30 and 60 tons) .The ranges were used, depending upon the predicted ultimate load of the tested beam through a tare having a weight of (1.40 ton).The load was applied in an increment of 0.50 ton up to cracking load , and in increment of 1.00 ton up to failure load. At each load stage, beam deflection was measured, and the developing crack pattern was marked on the beam surface. The final failure was carefully observed and the concrete, steel strain at mid-span of beams was measured by using an electrical strain gauges.

Table (5): Results of tested beams having negative haunch (tan α = -.20):

Series	Beam NO.	Position of plates	Experimental Results										P ul .The . Res (ton)	Pcr str. / pcr ori.	Pul str. /pul.ori.	(K) (ton/mm)	Tou. (t-mm)	Mode of failure
			P cr. (ton)	P ul. (ton)	δcr 1 (mm)	δu 1 (mm)	δcr 2 (mm)	δu 2 (mm)	εcr.co 10^-5	εu.co1 0^-5	εcr.st 10^-5	εu.st 10^-5						
A N 250	AN0		5	17	1.56	5.10	1.55	5.30	23	96	18	101	9.32	1.00	1.00	0.322	48.8	S
	AN1		6.5	25.2	1.26	6.39	1.21	6.48	20	115	17	183	23.00	1.30	1.48	0.527	97.7	S.C
	AN2		6.5	24	1.47	6.54	1.57	6.39	22	110	22	169	16.74	1.30	1.411	0.428	90.5	S.C
	AN3		6	26	1.04	7.19	1.00	7.35	11	291	10	210	23.00	1.20	1.53	0.589	125.0	F
BN 400	BN0		7	23.6	1.85	6.17	1.79	6.30	26	104	21	115	10.24	1.00	1.00	0.385	83.2	S
	BN1		9	32	1.51	8.77	1.38	8.39	23	129	23	188	26.77	1.285	1.355	0.624	179.2	S.C
	BN2		10	31	1.79	8.11	1.98	8.61	30	140	31	190	18.40	1.428	1.314	0.532	159.8	S
	BN3		8	35	1.12	9.87	1.21	10.30	11	271	12	233	26.77	1.143	1.48	0.688	243.3	F
CN 550	CN0		6.5	26.1	1.55	7.00	1.62	6.86	22	108	16	119	11.01	1.00	1.00	0.410	108.0	S
	CN1		8	34	1.27	8.44	1.20	8.02	17	133	15	208	28.34	1.23	1.302	0.649	179.2	S.C
	CN2		10.5	31.2	1.89	7.68	2.02	7.86	27	129	25	149	19.76	1.61	1.20	0.538	148.1	S.C
	CN3		9	37	1.14	10.67	1.10	11.31	11	264	9	244	28.34	1.38	1.42	0.804	297.4	F

DN 700	DN0		8	29	1.27	6.61	1.38	7.11	24	120	13	139	11.63	1.00	1.00	0.605	122.9	S
	DN1		9	36	0.99	8.67	0.80	8.98	14	139	13	230	29.20	1.125	1.24	1.017	224.8	S. C
	DN2		11	35	1.30	8.32	1.33	8.32	26	136	18	196	20.88	1.375	1.207	0.837	190.3	S.C
	DN3		11	38.2	0.76	11.3	0.74	11.98	11	233	12	260	29.20	1.375	1.32	1.467	348.8	F
EN 550	EN1		10	36.5	1.39	11.0	1.34	10.42	18	276	14	239	28.34	1.538	1.398	0.733	279.2	F
	EN2		9	35.8	1.61	9.98	1.68	9.88	23	272	13	220	28.34	1.384	1.371	0.548	234.2	F

S = shear , S.C = shear compression , F = flexure

δcr , δu = cracking and ultimate deflection in mm

εcr.co , εu.co = cracking and ultimate mid-span concrete strain.

εcr.st , εu.st = cracking and ultimate mid-span steel strain.

P cr str. , P cr ori. = cracking load for both strengthened and original beams.

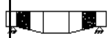
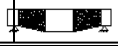
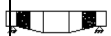
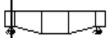
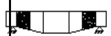
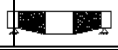
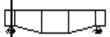
P ul str. , P ul ori. = ultimate load carrying capacity for both strengthened and original beams.

P ul . the. = Theoretical load carrying capacity.

(K) = stiffness reference (the initial tangent load deflection curve at cracking level).

(Tou.) = toughness of beam (the total area under the load deflection curve).

Table (6): Results of tested beams having positive haunch (tan α = +.20):

Series	Beam NO.	Position of plates	Experimental Results										P ul .The . Res (ton)	Pcr str. / pcr ori.	Pul str. /pul ori.	(K) (ton/mm)	Tou. (t-mm)	Mode of failure
			Pcr (ton)	Pu (ton)	δcr 1 (mm)	δu 1 (mm)	δcr 2 (mm)	δu 2 (mm)	εcr.co 10^-5	εu.co1 0^-5	εcr.st1 0^-5	εu.st 10^-5						
A P 250	AP0		4	10.1	1.62	5.29	1.59	5.11	17	50	17	56	9.13	1.00	1.00	0.250	31.0	S
	AP1		5.5	14	1.89	5.59	1.93	5.71	14	62	17	64	23.00	1.375	1.386	0.288	44.2	S.C
	AP2		6	13	1.98	5.46	2.03	5.39	15	56	21	62	19.82	1.50	1.287	0.300	41.6	S
	AP3		7	15.2	1.85	6.10	1.90	6.22	11	78	15	68	23.00	1.75	1.505	0.373	57.9	S.C
BP 400	BP0		5	16.5	1.72	6.74	1.77	6.88	18	85	18	81	10.03	1.00	1.00	0.287	66.4	S
	BP1		6	20	1.73	6.97	1.72	7.12	10	89	14	90	26.77	1.20	1.212	0.348	80.7	S.C
	BP2		6.5	22	1.75	6.59	1.85	6.98	11	101	10	88	21.76	1.30	1.333	0.361	81.4	S
	BP3		8	23.3	1.64	7.75	2.00	7.94	10	112	11	96	26.77	1.60	1.412	0.444	114.2	S.C
CP 550	CP0		6	17.1	1.80	6.00	1.96	6.69	18	78	15	72	10.78	1.00	1.00	0.320	63.4	S
	CP1		6.5	22.1	1.59	6.89	1.69	7.45	9	100	12	86	28.34	1.10	1.292	0.397	94.7	S.C
	CP2		7	24.2	1.68	6.98	1.71	7.02	9	119	11	79	23.40	1.17	1.415	0.413	95.2	S
	CP3		8.5	26.4	1.57	8.32	1.62	8.20	11	136	10	98	28.34	1.42	1.543	0.533	139.9	S.C
DP 700	DP0		7	20	1.89	8.30	1.95	7.88	18	91	13	70	11.38	1.00	1.00	0.365	104.2	S
	DP1		8	23.2	1.71	7.90	1.85	7.79	11	105	9	81	29.20	1.14	1.160	0.450	117.4	S.C
	DP2		8	25	1.58	7.33	1.68	7.69	11	125	9	80	24.70	1.14	1.25	0.491	114.3	S
	DP3		9	27.5	1.29	8.93	1.61	9.13	7	135	8	95	29.20	1.285	1.375	0.629	171.3	S.C

EP 550	EP1		8.5	24.1	1.75	7.11	1.80	7.50	16	129	12	88	28.34	1.416	1.41	0.479	107.7	S.C
	EP2		8	22.4	1.81	6.89	1.92	7.64	18	122	14	82	28.34	1.333	1.31	0.430	99.1	S

S = shear , S.C = shear compression , F = flexure

δcr , δu = cracking and ultimate deflection in mm

εcr.co , εu.co = cracking and ultimate mid-span concrete strain.

εcr.st , εu.st = cracking and ultimate mid-span steel strain.

P cr str. , P cr ori. = cracking load for both strengthened and original beams.

P ul str. , P ul ori. = ultimate load carrying capacity for both strengthened and original beams.

P ul . the. = Theoretical load carrying capacity.

(K) = stiffness reference (the initial tangent load deflection curve at cracking level).

(Tou.) = toughness of beam (the total area under the load deflection curve).

(3)- Results and Discussion

Test results of the five series of beams having negative haunch are presented in Table (5) and test results of five series of beams having positive haunches are presented in Table (6). The table also includes the experimental values of both cracking and ultimate loads for tested beams, the theoretical values of load carrying capacity, and stiffness of beams and mode of failure.

(3-1) Beams Having Negative Haunch (tan α = - 0.20)

(3-1-1) Effect of Width, Arrangements and Position of Bonded Side Steel Plates on:

a – Crack Pattern and Mode of Failure

For all strengthened beams it was observed that the major crack is initiated from the bottom concrete surface in small depth (tension zone) and propagated upwards towards the top surface (compression zone) between the two point of load application as shown in Figs.(3,4and 5) but for unstrengthened beam the major crack is initiated at one third of shear-span at bottom concrete surface and propagated upwards towards the point of load application as shown in Fig.(2) , this behavior is ascribable to the high shear capacity for zones including bonded side plates .The mode of failure was of shear type one for unstrengthened beam but it changed to shear compression type for strengthened beam having side plate of area according to area of haunched original beam of 0.50 , 0.469 . But the mode of failure changed to flexural failure for strengthened beam by increasing the area of side plate to complete area of haunched zone.

b- Maximum Deformation: (Deflection, Concrete and Steel Strain)

For all grades of concrete it was obvious that for beams having negative haunch, in general, the maximum deflection, mid-span concrete and steel reinforced bars strain decrease at any loading level before failure level by increasing the ratio of area of side plates to area of haunched original beam and change its position. However at the final failure level the maximum deflection, mid-span concrete and steel reinforced bars strain increases, as shown in Figs.(6 to 10). This is ascribable to the corresponding increase of both the stiffness and shear capacity for beams as a result of increasing the area, arrangements and changing the position of strengthened side plates on shear zone.

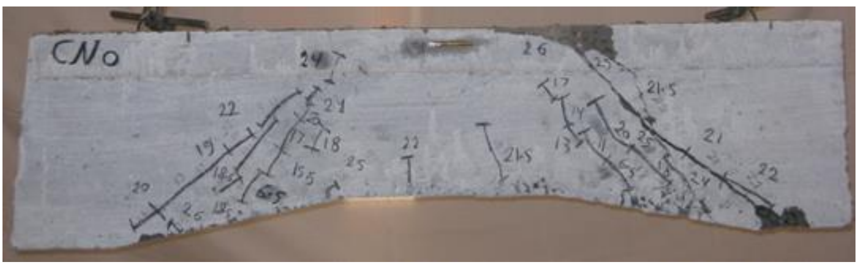


Fig. (2):Crack pattern of beam "CN.0".

Fig. (3):Crack pattern of beam "CN.1". With thickness of steel plate (2.00 mm)

Fig. (4):Crack pattern of beam "CN.2". With thickness of steel plate (2.00 mm)

Fig. (5): Crack pattern of beam "CN.3".with thickness of steel plate (2.00 mm)

c- Cracking Load

The cracking loads usually increases by bonding of external steel plates on both sides of haunches. The increase depends mainly on both grade of concrete as well as on the ratio of the area of strengthened plates to the area of haunched original beam. e.g, increasing the area of strengthened plate to area of haunched original beam, regarding the cracking load for the strengthened beams showed 1.30, 1.30 and 1.20 times than that of the original beam for concrete (cube strength = 250 kg/cm^2) and 1.285 , 1.428 and 1.143 for concrete (cube strength = 400 kg/cm^2) and 1.23 , 1.61 and 1.38 for concrete (cube strength = 550 kg/cm^2) and 1.125 , 1.375 and 1.375 for concrete (cube strength = 700 kg/cm^2) for case of beams having side plate the area of strengthened plate to area of haunches original beam of 0.50, 0.469 and 1.00 respectively, as shown in Fig.(11).

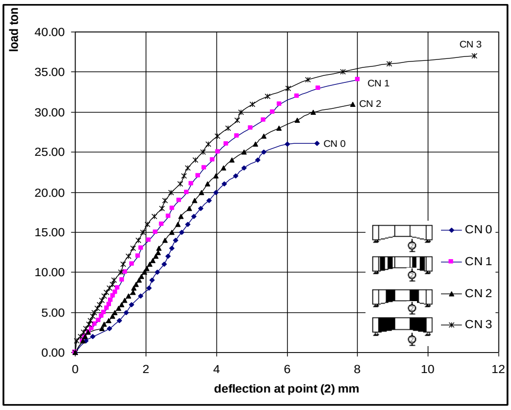


Fig. (6) :Load deflection curves for beams CN.0", "CN.1","CN.2","CN.3" from series (C = 550 kg/cm^2)

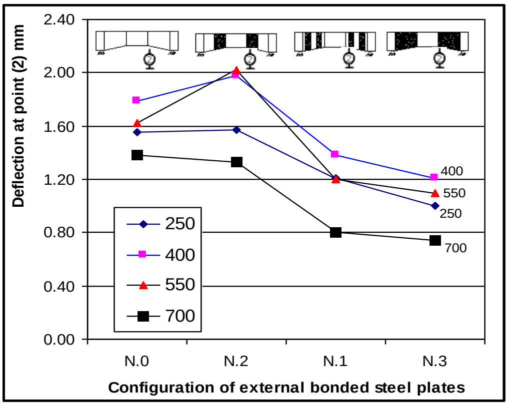


Fig. (7): Relation between deflection at point (2) at cracking level and configuration of external bonded steel plates for different series of beams.

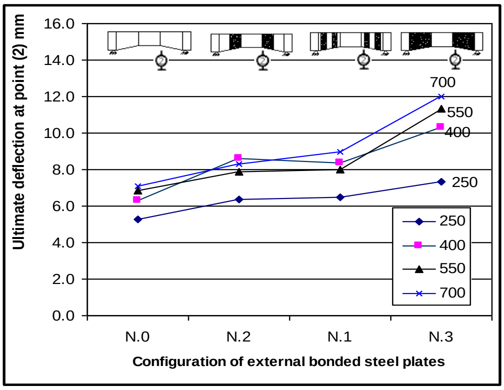


Fig. (8): Relation between ultimate deflection at point (2) and configuration of external bonded steel plates for different series of beams " N.0","N.1","N.2","N.3"

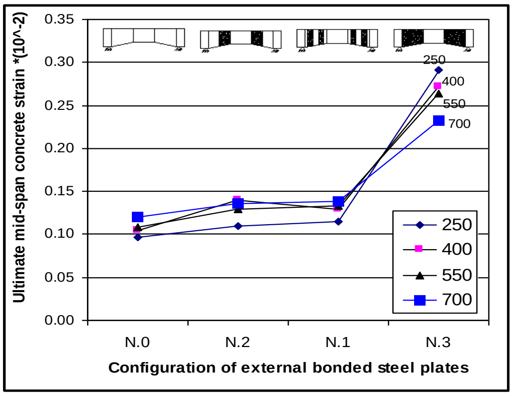


Fig. (9) : Relation between ultimate mid-span concrete strain and configuration of external bonded steel plates for different series of beams " N.0","N.1","N.2","N.3"

d- Ultimate Loads

The same trend was observed with respect to ultimate loads. The ultimate loads increase by increasing the ratio of area of side plate to area of haunched original beam, regarding the ultimate load for the strengthened beams showed 1.48, 1.411 and 1.53 times than that of the original beam for concrete (cube strength = 250 kg/cm^2) and 1.355, 1.314 and 1.48 for concrete (cube strength = 400 kg/cm^2) and 1.302, 1.20 and 1.42 for concrete (cube strength = 550 kg/cm^2) and 1.24, 1.207 and 1.32 for concrete (cube strength = 700 kg/cm^2)for case of beams having side plate the area of side plate to area of haunched original beam of 0.50, 0.469 and 1.00 respectively, as shown in Fig.(12). Based on experimental results a proposed equations for predicting relative ultimate loads (P ul str. / P ul ori.) was derived for beams having the same negative haunch (tan α = - 0.20) and reinforced steel bars as follow, as shown in Fig. (13).

P ul str.= P ul ori. [1.00+0.6550*(A str./A ori.)]
For concrete strength F c = 250 kg/cm^2
P ul str.= P ul ori. [1.00+0.5475*(A str./A ori.)]
For concrete strength F c = 400 kg/cm^2
P ul str.= P ul ori. [1.00+0.4523*(A str./A ori.)]
For concrete strength F c = 550 kg/cm^2
P ul str.= P ul ori. [1.00+0.3654*(A str./A ori.)]
For concrete strength F c = 700 kg/cm^2

Where
(A str./A ori.): The ratio of area of strengthened plate to area of haunched original beam.

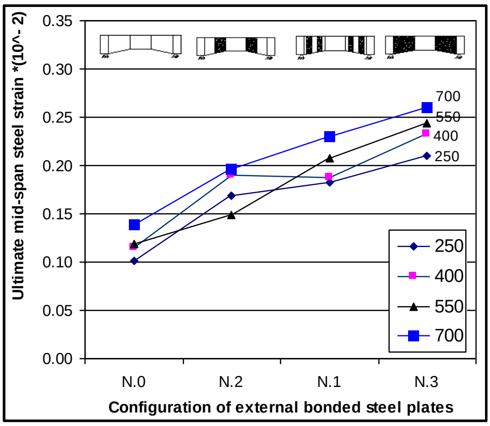


Fig. (10): Relation between ultimate mid-span steel strain and configuration of external bonded steel plates for different series of beams.

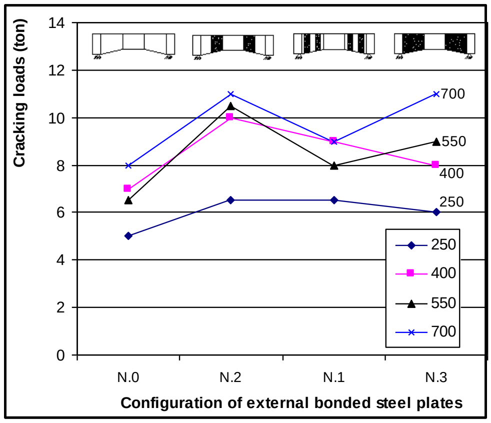


Fig. (11): Relation between the cracking load and configuration of external bonded steel plates for different series of beams " N.0","N.1","N.2","N.3"

e- Relative Beams Stiffness

By increasing the ratio of area of strengthened plates to area of haunched original beam and the position of bonded side plates the relative stiffness (K str./K ori.) increases, based on experimental results a suggested equations for relative stiffness (K str./K ori.) at cracking level for all grades of concrete was derived for beams having the same negative haunch (tan α = - 0.20) and reinforcement steel bars as follow, disregarding the grade of concrete , as shown in Fig.(14)

K str. = K ori. [1.00 + 1.0075 * (A str./A ori.)]

Where:
K str. = stiffness of strengthened beam.
K ori. = stiffness of original beam.

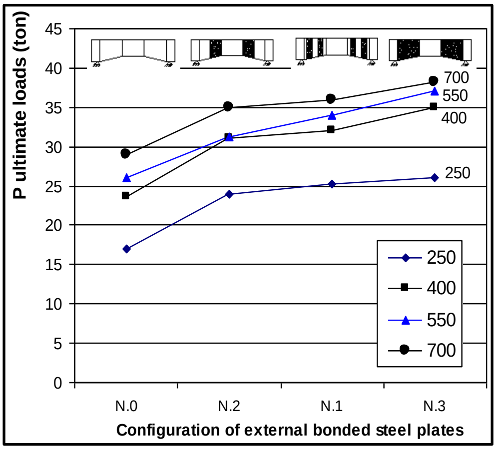


Fig. (12): Relation between ultimate load and configuration of external bonded steel plates for negative haunched beams" N 0","N 1","N 2","N 3" for different series.

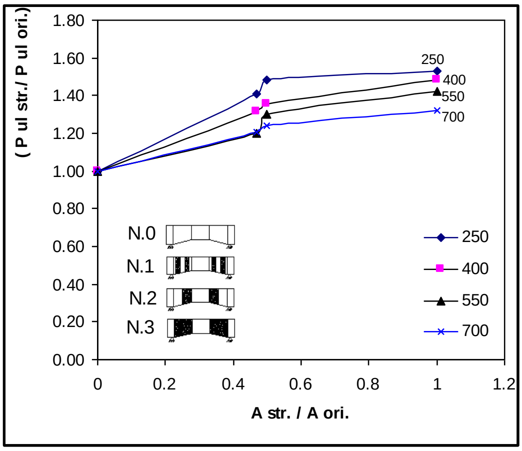


Fig. (13): Relation between relative ultimate load and (P ul str. / P ul ori.)and Area of strengthened plate to area of haunched original beams for negative haunched beams" N 0","N 1","N 2","N 3"from series (A,B,C,D = 250,400,550,700 kg/cm^2)

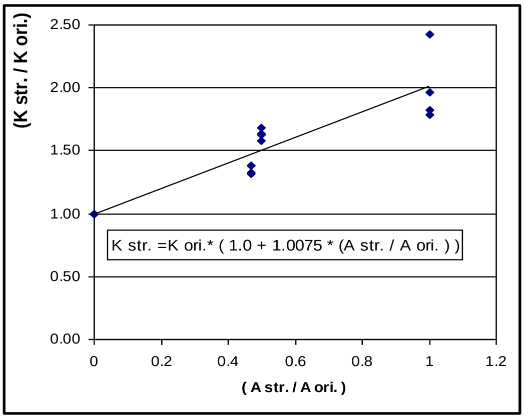


Fig. (14): Relation between relative stiffness (K str. / K ori.) at cracking level and area of strengthened plates to area of haunched of original beam (A str./A ori.)for all beams having negative haunch from series (A,B,C,D = 250,400,550,700 kg/cm^2)

(3-1-2) Effect of Thickness of Bonded Side Steel Plate on:

a- Crack Pattern and Mode of Failure

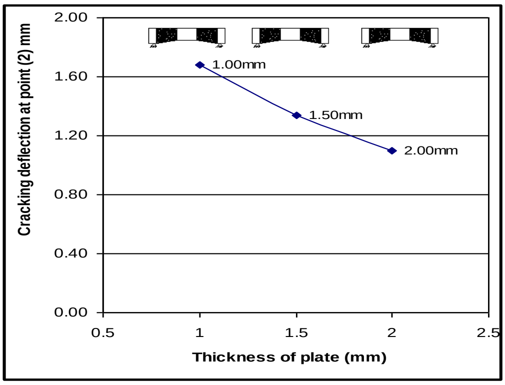
By increasing the thickness of steel plate from (1.00 to 2.00 mm) the number of cracks decreases at the same level of loading. The mode of failure changed from shear for unstrengthened beam to flexural failure for all beams with complete side plate on haunch at shear zone for any thickness of side plate. , as shown in Figs.(15 and 16).

Fig. (15): Crack pattern of beam "EN.1"with thickness of steel plate (1.50 mm)

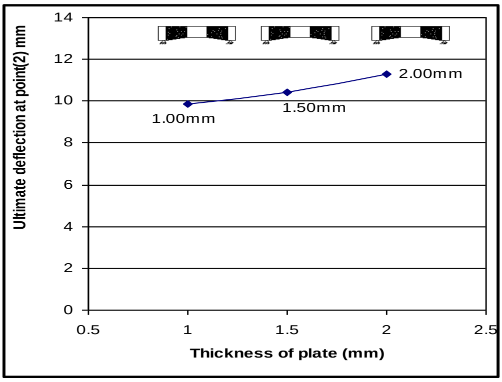
Fig. (16): Crack pattern of beam "EN.2"with thickness of steel plate (1.00 mm)

b- Maximum Deformation: (Deflection, Concrete and Steel Strain)

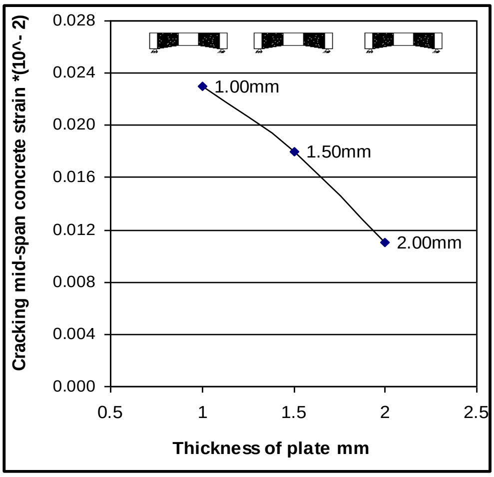
By increasing the thickness of steel plate the maximum deflection, mid-span concrete and steel reinforced bars strain decreases at any loading level before failure level. However at the final failure level the maximum deflection, mid-span concrete and steel reinforced bars strain increases by increasing the thicknesses of strengthened steel side plates as shown in Figs. (17 to 22).



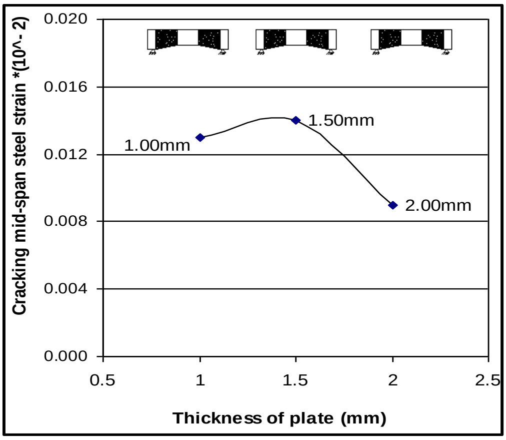
Fig(17): Relation between deflection at cracking level at point (2) and change in thickness of plate for negative haunched for beams"CN.3","EN.1","EN2" from series (CN and EN = 550 kg/cm^2)



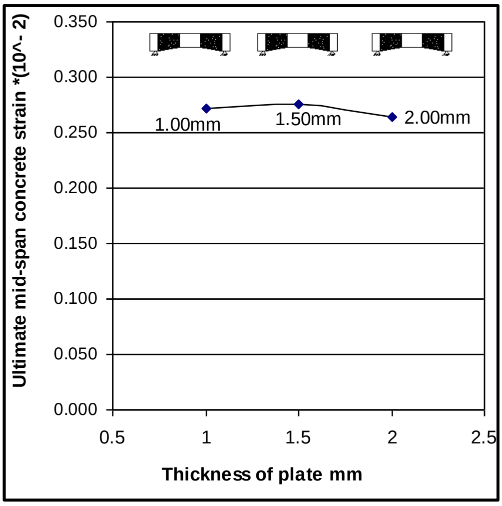
Fig(18): Relation between ultimate deflection at point (2) and change in thickness of plate for negative haunched for beams"CN.3","EN.1","EN2" from series (CN and EN = 550 kg/cm^2)



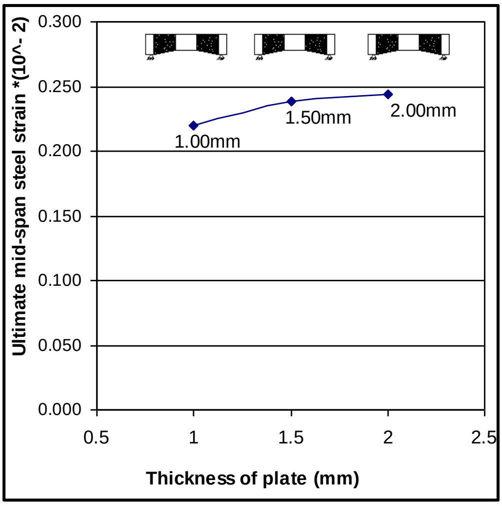
Fig(19): Relation between mid-span concrete strain at cracking level and change in thickness of plate for negative haunched for beams "CN.3", "EN.1","EN2" from series (CN and EN = 550 kg/cm^2)



Fig(20): Relation between mid-span steel strain at cracking level and change in thickness of plate for negative haunched for beams"CN.3","EN.1","EN2" from series (CN and EN = 550 kg/cm^2)



Fig(21): Relation between ultimate mid-span concrete strain and change in thickness of plate for negative haunched for beams"CN.3","EN.1","EN2" from series (CN and EN = 550 kg/cm^2)



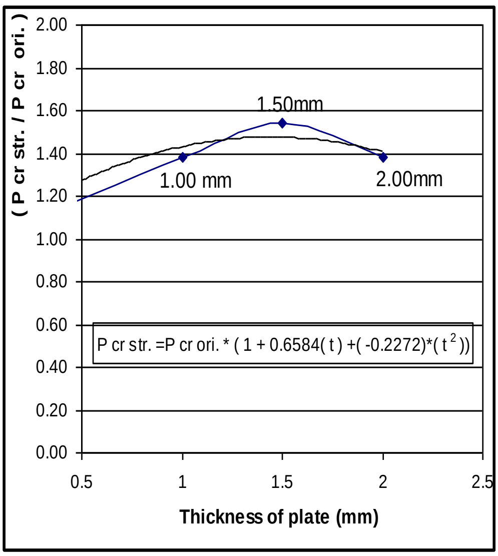
Fig(22): Relation between ultimate mid-span steel strain and change in thickness of plate for negative haunched for beams"CN.3","EN.1","EN2" from series (CN and EN = 550 kg/cm^2)

c- Cracking and Ultimate Loads

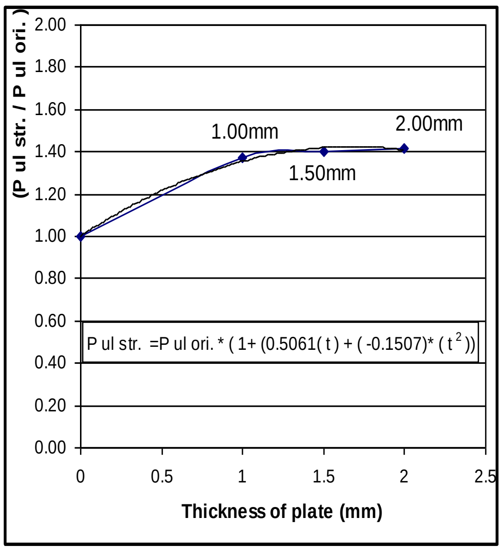
By increasing the thickness of steel side plate the cracking load is the same but the ultimate load increased. When considering the cracking load, the strengthened beams showed 1.384, 1.538 and 1.384 times more than that of the original beam for beams having steel plate thickness of 1.00, 1.50 and 2.00 mm respectively. Also when considering the ultimate load for the same latter beams showed 1.371, 1.398 and 1.42 times more than that of the original beam respectively. Based on experimental results a suggested equations for relative cracking (P cr str./P cr ori.) and ultimate load (P ul str./P ul ori.) was derived for beams having the same negative haunch (tan α = - 0.20) , reinforcement steel bars(μ=2.57 %) ,grade of concrete (cube strength = 550 kg/cm^2), position and arrangements "for plates bonded on both sides of shear zone of beams" as follows, see Figs.(23 and 24).

$$P_{cr\ str.} = P_{cr\ ori.}\ [1.00 + 0.6581 * (t) + (-0.2272) * (t)^2\ ]$$
$$P_{ul\ str.} = P_{ul\ ori.}\ [1.00 + 0.5061 * (t) + (-0.1507) * (t)^2\ ]$$

Where:
t = Thickness of steel plate in (mm)



Fig(23): Relation between relative cracking load and change in thickness of plate for negative haunched for beams"CN.0","CN.3","EN.1"and"EN2" from series (CN and EN = 550 kg/cm^2)



Fig(24): Relation between relative ultimate load and change in thickness of plate for negative haunched for beams"CN.0","CN.3","EN.1"and"EN2" from series (CN and EN = 550 kg/cm^2)

d- Relative Beams Stiffness

By increasing the thickness of steel side plate the relative stiffness (K str./K ori.) increases. Based on experimental results a suggested equations for relative stiffness (K str./K ori.) at cracking level was derived for beams having the same negative haunch (tan α = - 0.20) , reinforcement steel bars (μ=2.57 %), grade of concrete (cube strength = 550 kg/cm^2), position and arrangements "for plates bonded on both sides of shear zone of beams" as follow, as shown in Figs.(25) .

K str. = K ori. [1.00 + 0.4739 * (t)]

Where:
K str. = stiffness of strengthened beam.
K ori. = stiffness of original beam.
t = thickness of steel side plate in (mm).

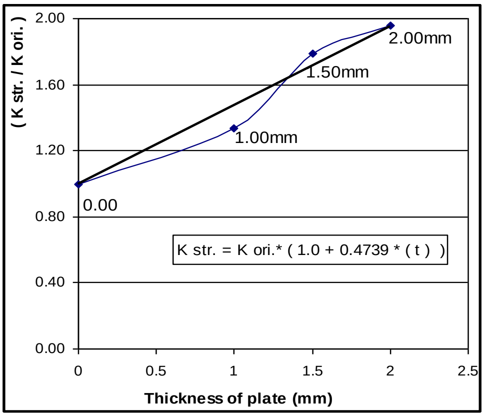


Fig. (25): Relation between relative stiffness (K str./K ori.) at cracking level and thickness of strengthened plates for beams having negative haunch "CN.0","CN.3","EN.1","EN2" from series (C and E = 550 kg/cm^2)

(3-1-3) Effect of the Grade of Concrete on:

a- Crack Pattern and Mode of Failure

By increasing the strength of concrete from (250 to 700 kg/cm^2) the number of cracks decreases at the same level of loading, but the mode of failure is the same for strengthened and unstrengthened beams for all grades of concrete.

b- Maximum Deformation: (Deflection, Concrete and Steel Strain)

By increasing the grade of concrete the maximum deflection, mid-span concrete and steel reinforced bars strain decreases at any loading level before failure level. However at the final failure level the maximum deflection, mid-span concrete and steel reinforced bars strain increases by increasing the grade of concrete. But the measured maximum mid-span concrete strain at failure point for strengthened beams with complete side plate on haunch at shear zone to begin crushing of concrete at compression zone decreases by increasing the grade of concrete, as shown in Figs. (26 to 29).

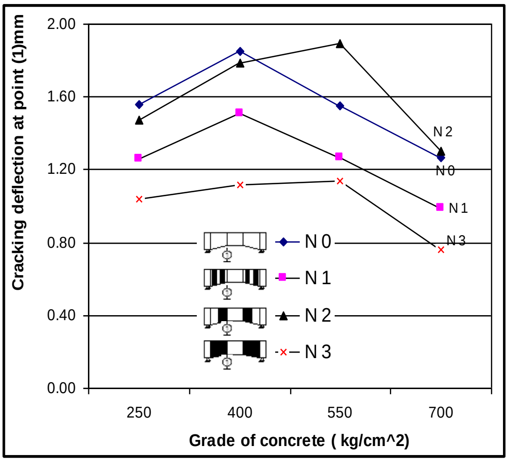


Fig. (26): Relation between cracking deflection at point (1) and change in the grade of concrete for negative haunched beams from series (AN, BN, CN and DN = 250,400,550,700 kg/cm^2)

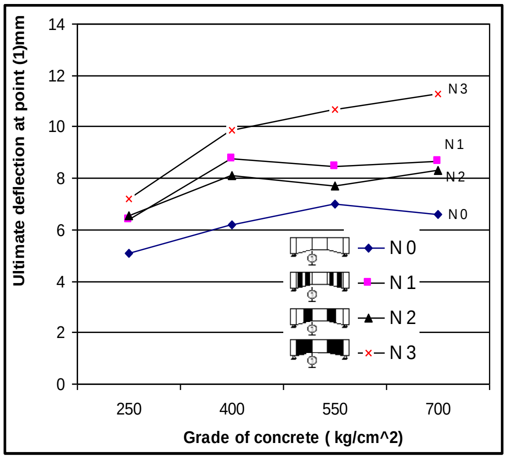


Fig. (27): Relation between ultimate deflection at point (1) and change in the grade of concrete for negative haunched beams from series (AN, BN, CN and DN = 250,400,550,700 kg/cm^2)

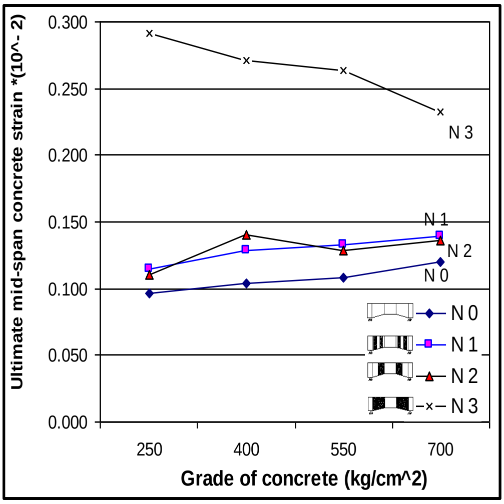


Fig. (28): Relation between ultimate mid-span concrete strain and change in the grade of concrete for negative haunched beams from series (A,B,C,D = 250,400,550,700 kg/cm^2)

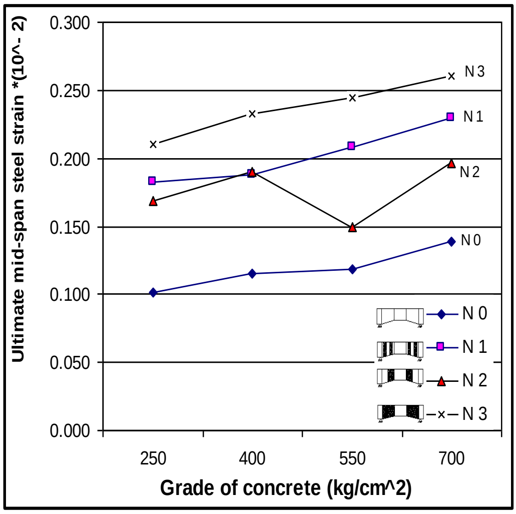


Fig. (29): Relation between ultimate mid-span steel strain and change in the grade of concrete for negative haunched beams from series (A,B,C,D = 250,400,550,700 kg/cm^2)

c- Cracking and Ultimate Loads

By increasing the strength of concrete both of cracking and ultimate load increases. When considering the increasing of relative ultimate load between high strength concrete to reinforced normal strength concrete beams decreases when increasing the grade of concrete for strengthened beams to unstrengthened beams, as shown in Figs. (12 and 13).

d- Beams Stiffness and Toughnes

By increasing the grade of concrete strength both of stiffness reference (K) and toughness increases, as shown in Figs. (30 and 31).

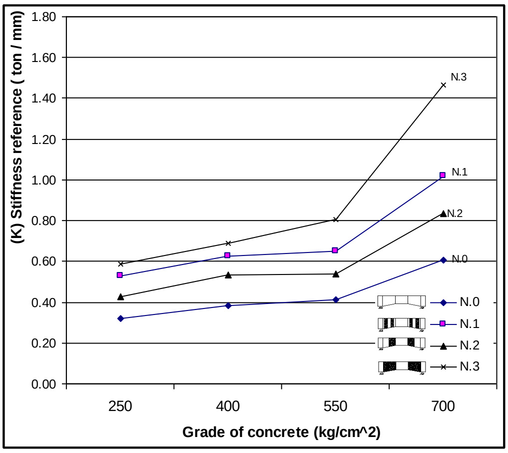


Fig. (30): Relation between stiffness (K) and grade of concrete for negative haunched beams" N .0","N .1","N .2","N .3"for different series

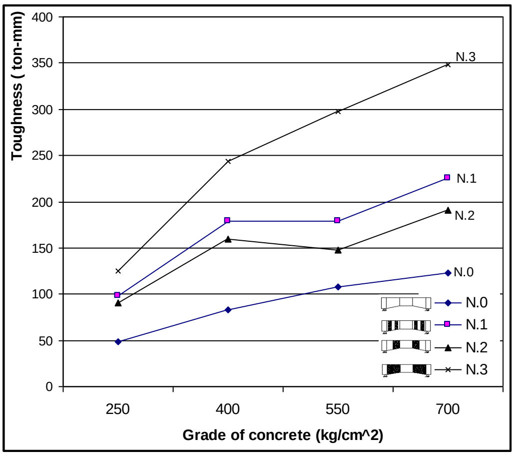


Fig. (31): Relation between toughness and grade of concrete for negative haunched beams" N .0","N .1","N .2","N .3 for different series

(3-2) Beams Having Positive Haunch (tan α = + 0.20)

(3-2.1) Effect of Width, Arrangements and Position of Bonded Side Steel Plates on:

a- Crack Pattern and Mode of Failure

For all strengthened beams it was observed that the major crack is initiated from the bottom concrete surface in big depth (tension zone) and propagated upwards towards the top surface (compression zone) between the two point of load application as shown in Figs. (33, 34 and 35), but for unstrengthened beam "AP.0"the major crack is initiated at one of the two supports at bottom concrete surface and propagated upwards towards the point of load application, as shown in Fig.(32) . This behavior is ascribable to the high shear capacity for zones including bonded side plates. The mode of failure was of shear type for unstrengthened beam and strengthened beams having area side plate to area of haunched original beam of 0.46 bonded at small depth on haunch but it changed to shear compression for strengthened beams having area side plate to area of haunched original beam ratio higher than of 0.50.

b- Maximum Deformation: (Deflection, Concrete and Steel Strain)

For all grades of concrete, it was obvious that for beams having positive haunch, in general, The effect of area side plates to area of haunched original beam and the position of bonded side plates on maximum deflection, mid-span concrete and steel reinforced bars strain decreases at any loading level before failure level by increasing the area of side plates to area of haunched original beam and change the position of it. However at the final failure level the maximum deflection, mid-span concrete and steel reinforced bars strain increases, as shown in Figs.(36to 42). This is ascribable to the corresponding increase of both the stiffness and shear capacity for beams as a result of increasing the area, arrangements and position of strengthened side plates on shear zone.

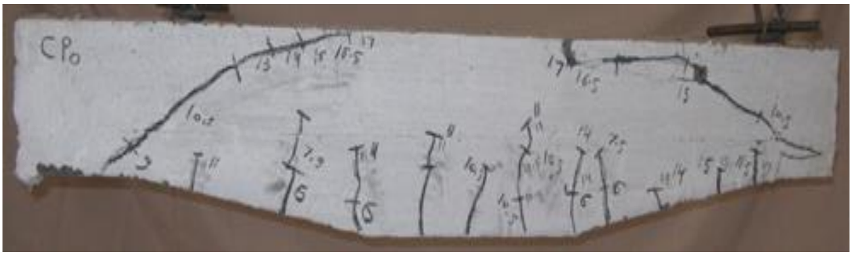


Fig. (32): Crack pattern of beam "CP.0".

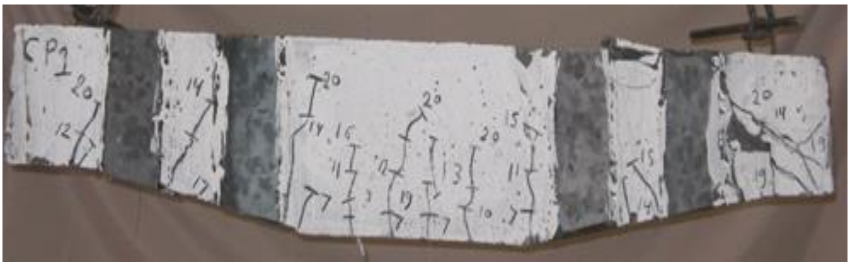


Fig. (33): Crack pattern of beam "CP.1"with thickness of steel plate (2.00 mm)

Fig. (34): Crack pattern of beam "CP.2"with thickness of steel plate (2.00 mm)

Fig. (35): Crack pattern of beam "CP.3"with thickness of steel plate (2.00 mm)

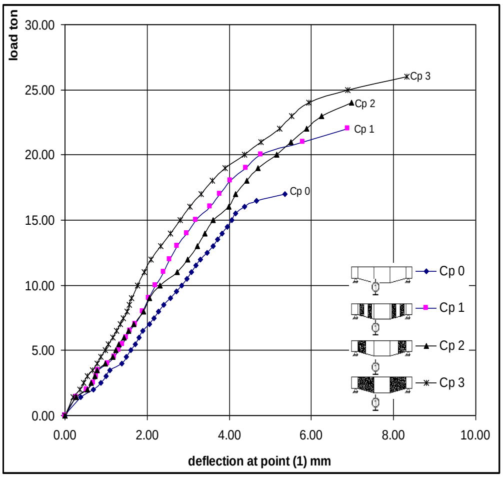


Fig. (36) :Load deflection curves for beams " CP.0","CP.1","CP.2","CP.3" from series (C = 550 kg/cm^2)

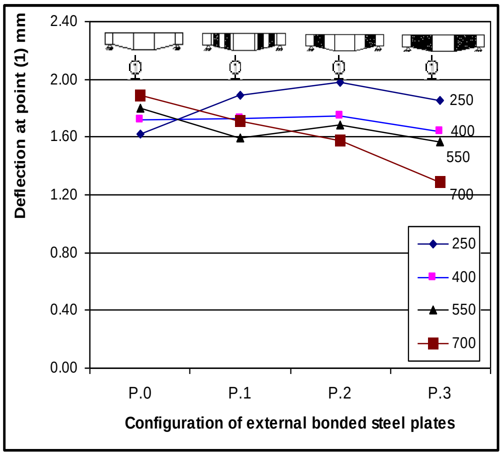


Fig. (37): Relation between deflection at point (1) at cracking level and configuration of external bonded steel plates for different series of beams" P.0","P.1","P.2","P.3"

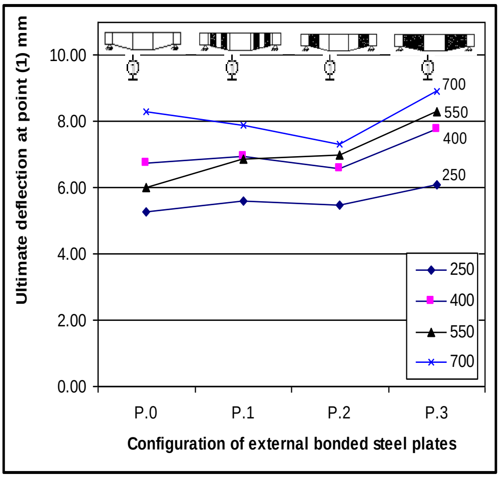


Fig. (38): Relation between ultimate deflection at point (1) and configuration of external bonded steel plates for different series of beams " P.0","P.1","P.2","P.3"

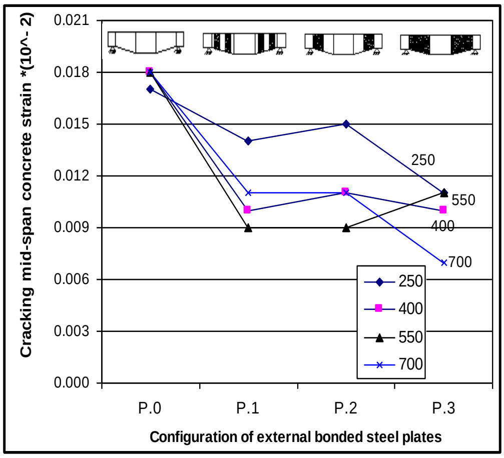


Fig. (39): Relation between mid-span concrete strain at cracking level and configuration of external bonded steel plates for different series of beams" P.0","P.1","P.2","P.3"

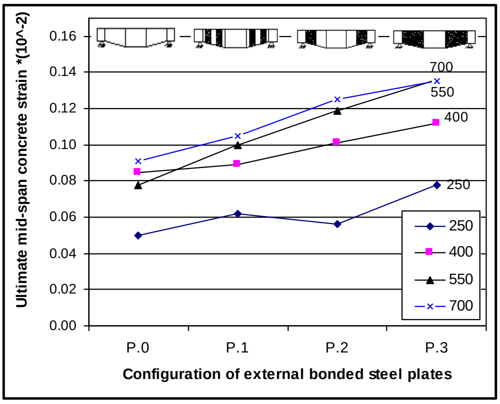


Fig. (40): Relation between ultimate mid-span concrete strain and configuration of external bonded steel plates for different series of beams " P.0","P.1","P.2","P.3"

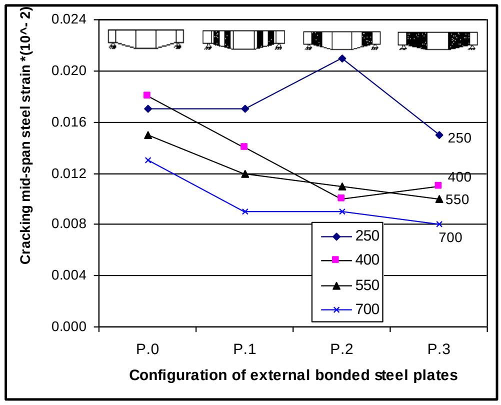


Fig. (41): Relation between mid-span steel strain at cracking level and configuration of external bonded steel plates for different series of beams" P.0","P.1","P.2","P.3"

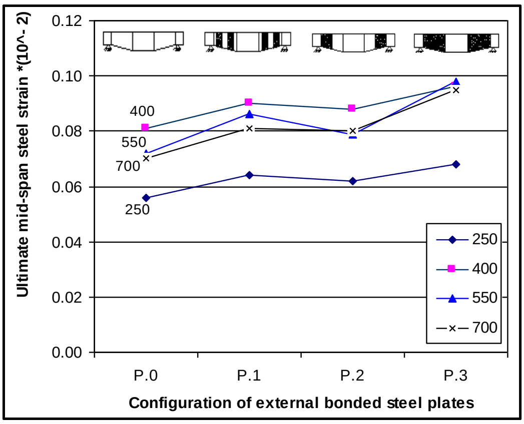


Fig. (42): Relation between ultimate mid-span steel strain and configuration of external bonded steel plates for different series of beams " P.0","P.1","P.2","P.3".

c- Cracking Loads

The cracking loads increase by increasing the ratio of area of side plate to area of haunched original beam, regarding the cracking load for the strengthened beams showed 1.375, 1.50 and 1.75 times than that of the original beam for concrete (cube strength = 250 kg/cm^2) and 1.20, 1.30 and 1.60 for concrete (cube strength = 400 kg/cm^2) and 1.10, 1.17 and 1.42 for concrete (cube strength = 550 kg/cm^2) and1. 1.14, 1.14 and 1.285 for concrete (cube strength = 700 kg/cm^2) for case of beams having side plate the area strengthened plate to area haunches original beam of 0.50, 0.46 and 1.00 respectively, as shown in Fig.(43).

d- Ultimate Loads

General, the ultimate loads increases by increasing the ratio of area of side plate to area of haunched original beam. The ultimate load for the strengthened beams showed 1.386, 1.287 and 1.505times than that of the original beam for concrete (cube strength = 250 kg/cm^2) and 1.212, 1.333 and 1.412for concrete (cube strength = 400 kg/cm^2) and 1.292, 1.415 and 1.543 for concrete (cube strength = 550 kg/cm^2) and 1.16, 1.25 and 1.375 for concrete (cube strength = 700 kg/cm^2)for case of beams having area of side plate to area of haunched original beam of 0.50, 0.46 and 1.00 respectively, as shown in Fig.(44).

Based on the obtained experimental results a suggested equations for predicting relative ultimate loads (P ul str. / P ul ori.) was derived for beams having the same positive haunch (tan α = + 0.20) and reinforced steel bars as follow, as shown in Fig. (45).

P ul str. = P ul ori. [1.00 + 0.5665 * (A str./A ori.)]
For concrete strength F c = 250 kg/cm^2
P ul str. = P ul ori. [1.00 + 0.4589 * (A str./A ori.)]
For concrete strength F c = 400 kg/cm^2
P ul str. = P ul ori. [1.00 + 0.6019 * (A str./A ori.)]
For concrete strength F c = 550 kg/cm^2
P ul str. = P ul ori. [1.00 + 0.3893 * (A str./A ori.)]
For concrete strength F c = 700 kg/cm^2

Where
(A str./A ori.): The ratio of area of strengthened plate to area of haunched original beam.

e – Beams Stiffness

By increasing the ratio of area of side plates to area of haunched original beam and the position of bonded side plates the relative stiffness of beams (K str./K ori.) increases. Based on experimental results a suggested equations for relative stiffness (K str./K ori.) at cracking level for all grade of concrete was derived for beams having the same positive haunch (tan α = + 0.20) and main steel bars as follow, as shown in Fig.(46).

K str. = K ori. [1.00 + 0.5758 * (A str./A ori.)]

Where:
K str. = stiffness of strengthened beam.
K ori. = stiffness of original beam.

(3-2-2) Effect of Thickness of Bonded Side Steel Plate on:

a- Crack Pattern and Mode of Failure

By increasing the thickness of steel plate from (1.00 to 2.00 mm) the number of cracks decreases at the same level of loading, Also the height of vertical crack at tension zone decreases by increasing the thickness (1.00, 1.50, 2.00 mm) respectively. The mode of failure changed from shear type for unstrengthened beam to shear compression one for all beams with complete side plate on haunch at shear zone for any thickness of side plate, as shown in Figs.(47 and 48).

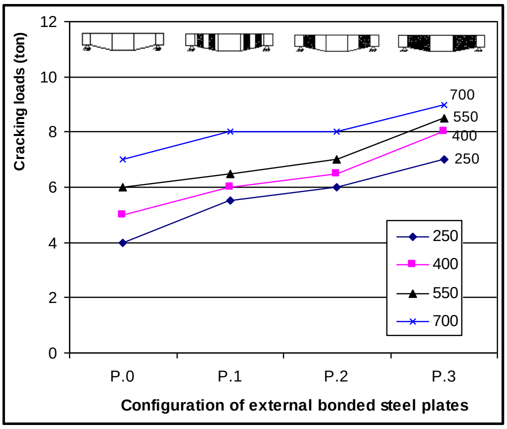


Fig. (43): Relation between cracking load and configuration of external bonded steel plates for positive haunched beams" P. 0","P.1","P.2","P.3"for different series.

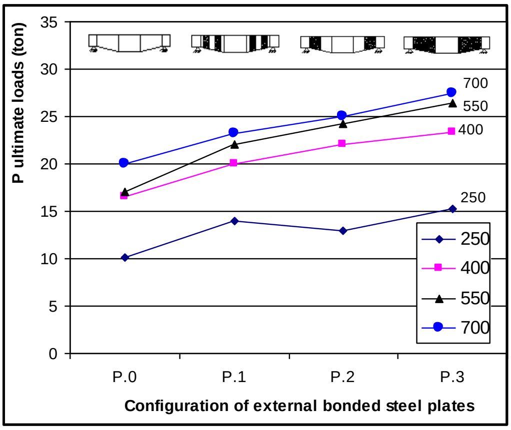


Fig. (44): Relation between ultimate load and configuration of external bonded steel plates for positive haunched beams" P. 0","P.1","P.2","P.3"for different series.

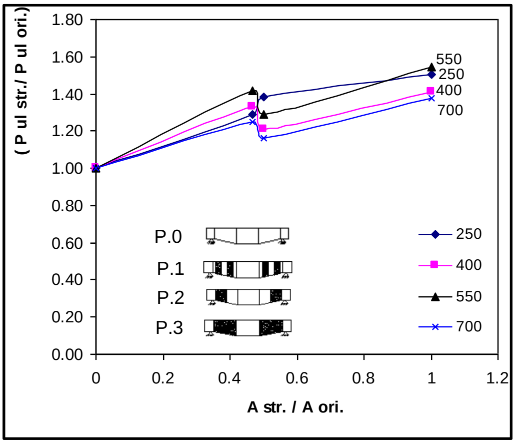


Fig. (45): Relation between relative ultimate load and Area of side plate to area of haunched original beams for positive haunched beams" P. 0" ,"P.1","P.2","P.3"for different series.

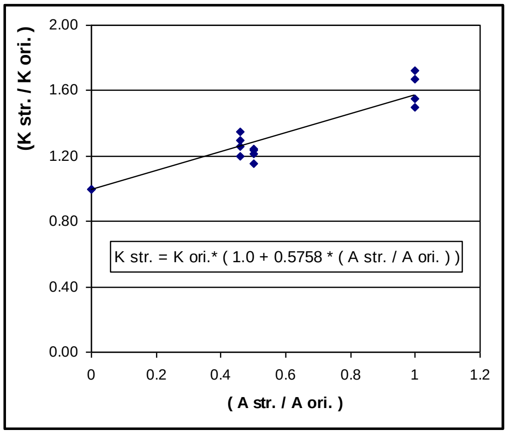


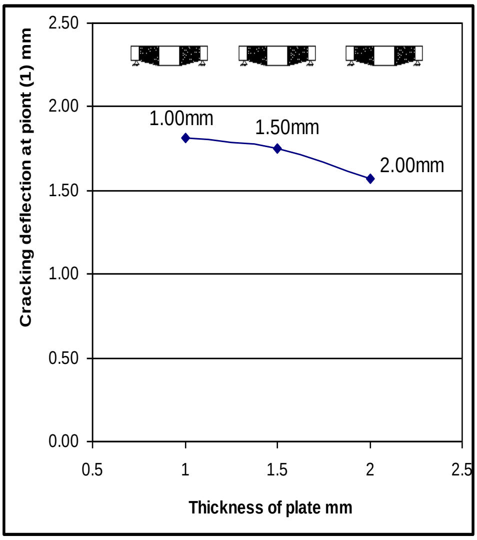
Fig. (46): Relation between relative stiffness at cracking level and area of side plates to area of haunched of original beam for all beams having positive haunch for different series.

Fig. (47): Crack pattern of beam "EP.1"with thickness of steel plate (1.50 mm)

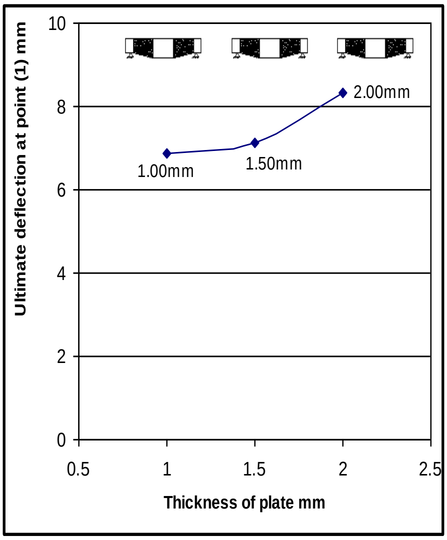
Fig. (48): Crack pattern of beam "EP.2"with thickness of steel plate (1.00 mm)

b- Maximum Deformation: (Deflection, Concrete and Steel Strain)

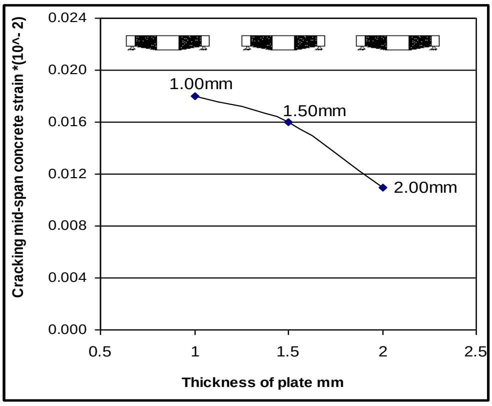
By increasing the thickness of steel plate the maximum deflection, mid-span concrete and steel reinforced bars strain decreases at any loading level before failure level. However at the final failure level the maximum deflection, mid-span concrete and steel reinforced bars strain increases by increasing the thicknesses of strengthened steel side plates as shown in Figs. (49 to54).



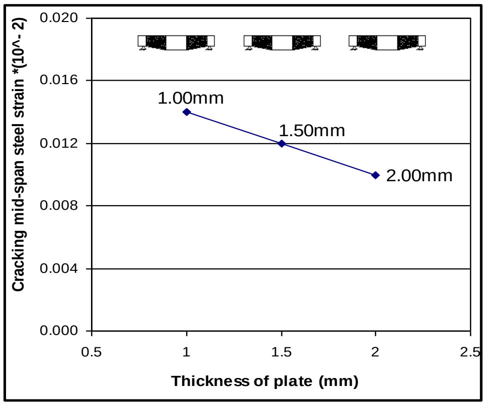
Fig(49): Relation between deflection at cracking level at point (1) and change in thickness of plate for positive haunched for beams"CP.3","EP.1","EP.2" from series (CP and EP = 550 kg/cm^2)



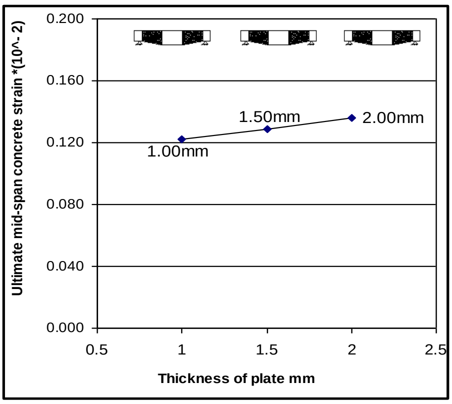
Fig(50): Relation between ultimate deflection at point (1) and change in thickness of plate for positive haunched for beams"CP.3","EP.1","EP.2" from series (CP and EP = 550 kg/cm^2)



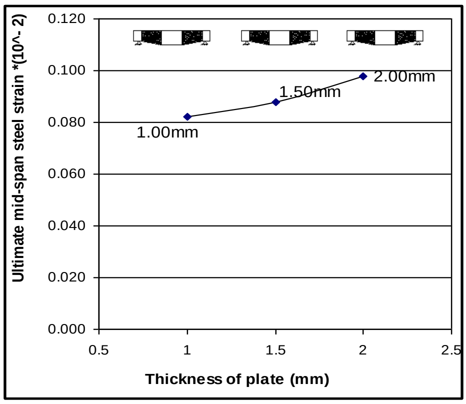
Fig(51): Relation between mid-span concrete strain at cracking level and change in thickness of plate for positive haunched for beams"CP.3","EP.1","EP.2" from series (CP and EP = 550 kg/cm^2)



Fig(52): Relation between mid-span steel strain at cracking level and change in thickness of plate for positive haunched for beams"CP.3","EP.1","EP.2" from series (CP and EP = 550 kg/cm^2)



Fig(53): Relation between ultimate mid-span concrete strain and change in thickness of plate for positive haunched for beams"CP.3","EP.1","EP.2" from series (CP and EP = 550 kg/cm^2).



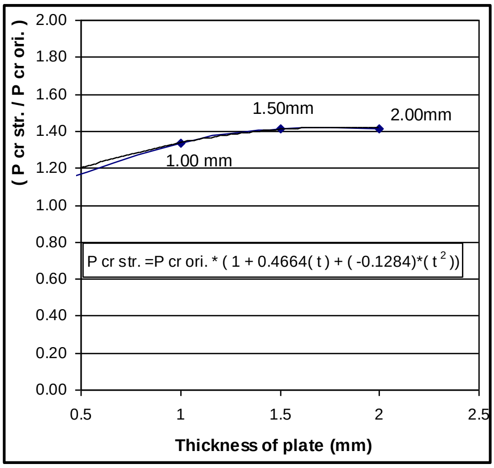
Fig(54): Relation between ultimate mid-span steel strain and change in thickness of plate for positive haunched for beams"CP.3","EP.1","EP.2" from series (CP and EP = 550 kg/cm^2).

c- Cracking and Ultimate Loads

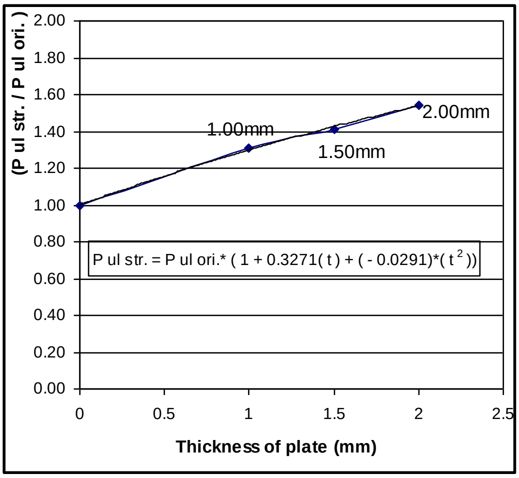
By increasing the thickness of steel side plate, both of cracking and ultimate loads increase. When considering the cracking load, the strengthened beams showed 1.333, 1.417 and 1.417times than that of the original beam for beams having steel plate thickness of 1.00, 1.50 and 2.00 mm respectively. Also when considering the ultimate load the same latter beams showed 1.31, 1.41 and 1.544 times than that of the original beam respectively. Based on experimental results a suggested equations for relative cracking (P cr str. /P cr ori.) and ultimate load (P ul str. / P ul ori.) was derived for beams having the same negative haunch (tan α = - 0.20), reinforced steel bars, degree of strength concrete, position and arrangements "for plates bonded on both sides of shear zone of beams" as follow, as shown in Figs. (55 and 56).

P cr str.= P cr ori. [1.00 + 0.4664 * (t) + (- 0.1284) * (t)^2]
P ul str.= P ul ori. [1.00 + 0.3271 * (t) + (- 0.0291) * (t)^2]

Where:
t = thickness of steel plate in (mm).



Fig(55): Relation between relative cracking load and Change in thickness of plate for positive haunched for beams"CP.0","CP.3","EP.1"and"EP.2"from series (CP and EP = 550 kg/cm^2)



Fig(56): Relation between relative ultimate load and Change in thickness of plate for positive haunched for beams"CP.0","CP.3","EP.1"and"EP.2"from series (CP and EP = 550 kg/cm^2)

d- Beams Stiffness

By increasing the thickness of steel side plate the relative stiffness (K str./K ori.) increases. Based on experimental results a suggested equations for relative stiffness (K str./K ori.) at cracking level was derived for beams having the same positive haunch (tan α = + 0.20), reinforcement steel bars, grade of concrete, position and arrangements "for plates bonded on both sides of shear zone of beams" as follows, see Fig.(57).

K str. = K ori. [1.00 + 0.3352 * (t)]
Where:

K str. = stiffness of strengthened beam.
K ori. = stiffness of original beam.
t = thickness of steel side plate in (mm).

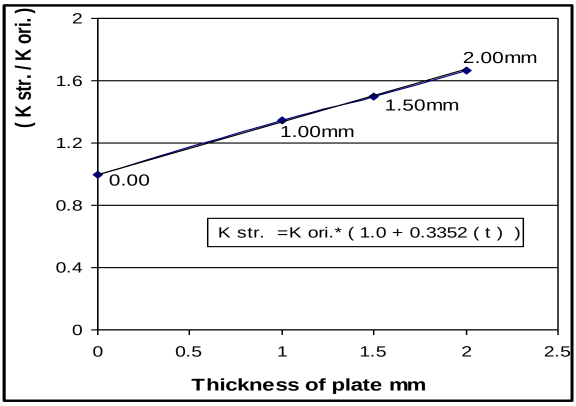


Fig. (57): Relation between relative stiffness (K s/K o) at cracking level and thickness of strengthened plates for beams having positive haunch "CP.0","CP.3","EP.1","EP.2" from series (CP and EP = 550 kg/cm^2)

(3-2-3) Effect the Grade of Concrete on:

a- Crack Pattern and Mode of Failure

By increasing the strength of concrete from (250 to 700 kg/cm^2) the number of cracks decreases at the same level of loading, but the mode of failure is the same for strengthened and unstrengthened beams for all grades of concrete.

b- Maximum Deformation: (Deflection, Concrete and Steel Strain)

By increasing the grade of concrete, the maximum deflection, mid-span concrete and steel strain decrease at any loading level before failure level. However at the final failure level the maximum deflection, mid-span concrete and steel reinforced bars strain increase by increasing the grade of concrete. But the steel bars strain at failure point is the same level values for high strength concrete beams but big for that of the reinforced normal strength concrete beams, as shown in Figs.(58 to61).

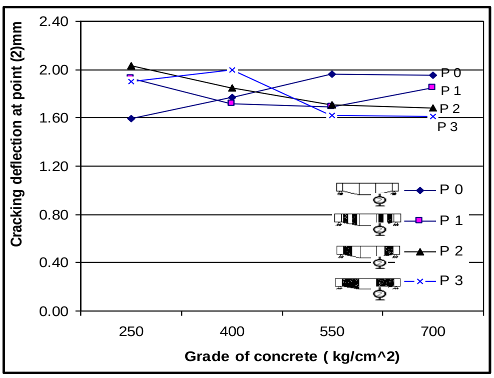


Fig. (58): Relation between cracking deflection at point (2) and change in the grade of concrete for positive haunched beams" P.0","P.1","P.2","P.3" for different series

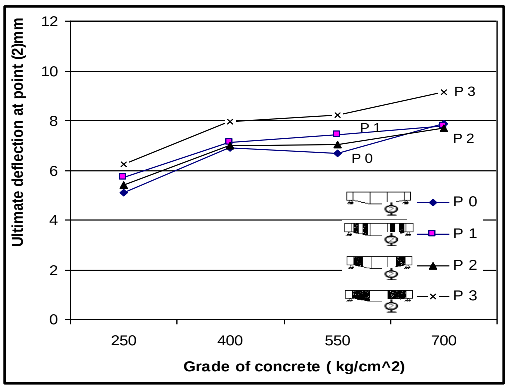


Fig. (59): Relation between ultimate deflection at point (2) and change in the grade of concrete for positive haunched beams" P.0","P.1","P.2","P.3" for different series

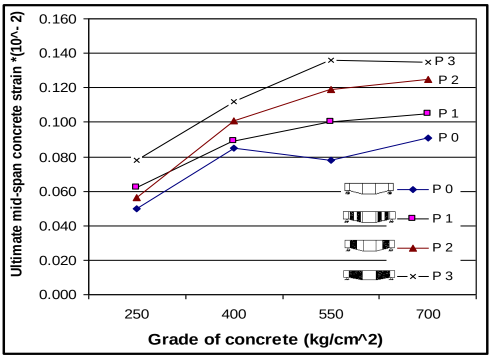


Fig. (60): Relation between ultimate mid-span concrete strain and change in the grade of concrete for positive haunched beams" P. 0","P.1","P. 2","P. 3" for different series

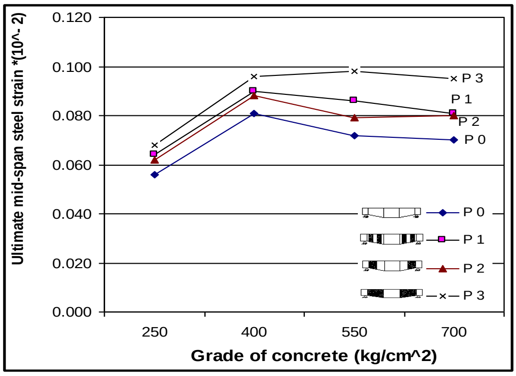


Fig. (61): Relation between ultimate mid-span steel strain and change in the grade of concrete for positive haunched beams" P.0","P.1","P.2","P.3"for different series

c- Cracking and Ultimate Loads

By increasing the strength of concrete both of cracking and ultimate load increases. When considering the increasing of relative ultimate load between high strength concrete to normal reinforcement concrete beams is decreases when increasing the grade of concrete for strengthened beams to unstrengthened beams, as shown in Figs. (44 and 45).

d- Beams Stiffness and Toughness

By increasing the grade of concrete strength both of stiffness reference (K) and toughness increases, as shown in Figs. (62 and 63).

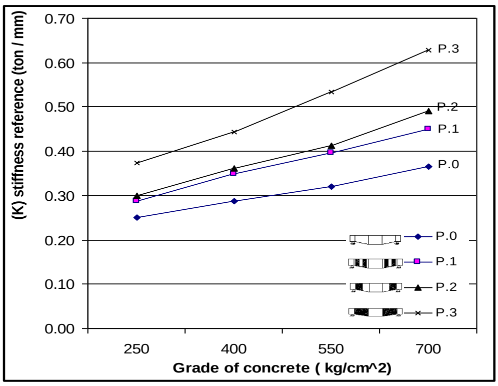


Fig. (62): Relation between stiffness (K) and grade of concrete for positive haunched beams" P .0","P .1","P .2","P .3"for different series

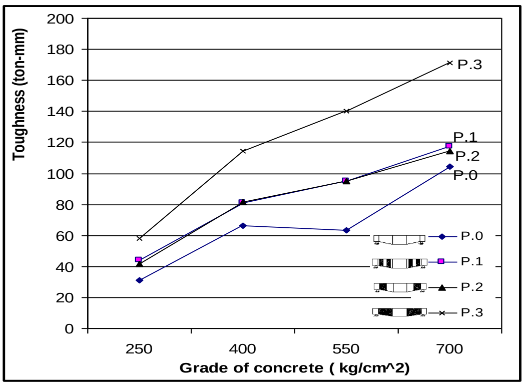


Fig. (63): Relation between toughness and grade of concrete for positive haunched beams" P .0","P .1","P .2","P .3" from series (AP, BP, CP and DP = 250,400,550,700 kg/cm^2)

(3-3) Effect of Haunch Inclination (α) on:

a- Crack Pattern and Mode of Failure

By changing the haunch inclination (α) from positive to negative the number of both shear and flexure cracks decreases at the same level of loading, The mode of failure was the same for all unstrengthened having negative and positive haunched beams as shear failure. But for strengthened negative haunched beams changed from shear failure to shear compression failure and flexure failure with crushing of concrete at mid-span for case of beams having side plate the area of side plate to area of haunched original beam of 0.46, 0.50 and 1.00 respectively. But strengthened positive haunched beams changed from shear failure to shear compression failure with crushing of concrete at the bearing support for the same area of side plate respectively. This is ascribable behavior is due to the increase of both stiffness and shear capacity of the beams having negative haunch with big depth at support.

b- Maximum Deformation: (Deflection, Concrete and Steel Strain)

By changing the haunch inclination (α) from positive to negative the maximum deflection decreases at any level of loading, but the corresponding measured of concrete compression and steel bars strain increases at any loading level, for all grade of concrete beams, as shown in Figs.(64 to 66). This is ascribable this behavior is due to the increase of both stiffness and shear capacity of the beams having negative haunch with big depth at support.

c- Cracking and Ultimate Loads

For change the haunch inclination (α) from positive to negative the both of cracking and ultimate load increases, as shown in Figs.(67 and 68).

d- Beams Stiffness

By change the haunch inclination (α) from positive to negative the stiffness of beams (K) increases. as shown in Fig.(69)

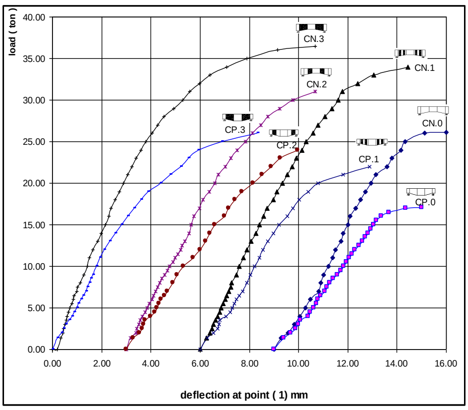


Fig. (64): Load deflection curves at point (1) for beams having positive and negative haunch from series (C = 550 kg/cm^2)

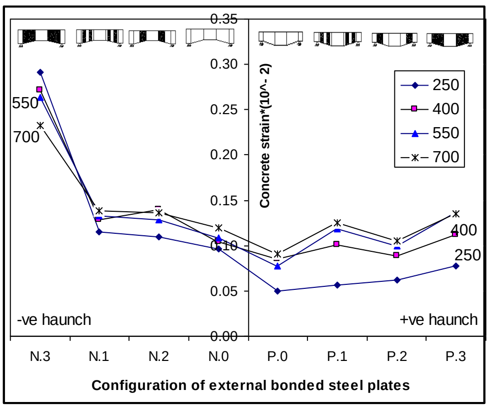


Fig. (65): Relation between ultimate mid-span concrete strain and change in slope for beams with negative and positive haunch from series (A, B, C and D = 250,400,550,700 kg/cm^2)

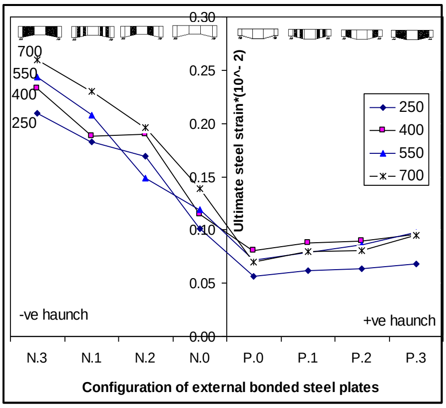


Fig. (66): Relation between ultimate mid-span steel strain and change in slope for beams with negative and positive haunch from series (A, B, C and D = 250,400,550,700 kg/cm^2)

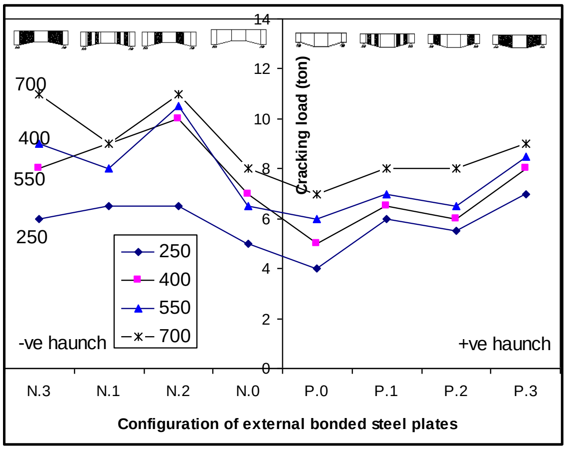


Fig. (67): Relation between cracking load and change in slope for beams negative and positive haunched from series (A, B, C and D = 250,400,550,700 kg/cm^2)

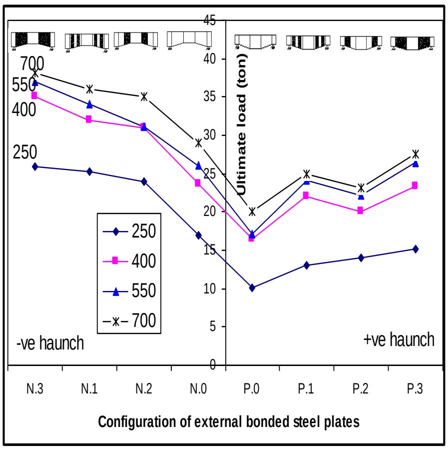


Fig. (68): Relation between ultimate load and change in slope for beams negative and positive haunched from series (A, B, C and D = 250,400,550,700 kg/cm^2)

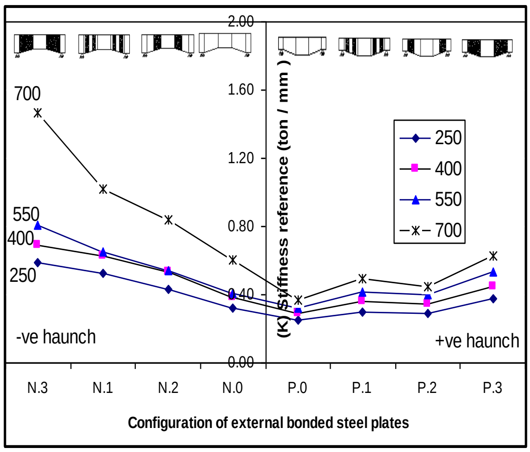


Fig. (69): Relation between stiffness (K) and change in slope for beams negative and positive haunched from series (A, B, C and D = 250,400,550,700 kg/cm^2)

4- CONCLUSIONS

Based on the results of the experiments carried out on high strength reinforcement concrete beams strengthened with bonded steel side plates, the following conclusions can be drawn:

Beams Having Negative Haunch (tan α = - 0.20)

1- The mode of failure was shear failure for all unstrengthened having negative haunched beams. But for strengthened beams, the mode of failure changed from shear to shear compression and flexure failure with crushing of concrete at mid-span for case of beams having area of steel side plate to area of haunched original beam of about 0.46, 0.50 and 1.00 respectively.

2- By increasing the thickness of steel side plate from (1.00 to 2.00 mm) the number of cracks decreases at the same level of loading. The mode of failure changed from shear failure for unstrengthened beam to flexural failure for all beams with complete side plate on haunch at shear zone for any thickness of steel side plate.

3- By increasing the thickness of steel side plate the cracking load is the same but the ultimate load increases. The cracking load of strengthened beams "EN.1 ","EN.2" and "CN.3" having steel side plate of thickness 1.00, 1.50 and 2.00 mm respectively showed 1.384, 1.538 and 1.384 times more than that of the original beam "CN.0". The ultimate load for the same latter beams showed 1.371, 1.398 and 1.42 times more than that of the original beam respectively.

4- A general equation to determine the ultimate loads for beams strengthened by using steel side plate of relative area (A str./A ori.) and different thickness of side plate, as a main variables as follows ;

P ul str.= P ul ori. [1.00 + C 1+ C 2]

Where:
C 1 = [0.6550 * (A str./A ori.)] … for concrete strength F c = 250 kg/cm^2
C 1 = [0.5475 * (A str. /A ori.)] … for concrete strength F c = 400 kg/cm^2
C 1 = [0.4523 * (A str. /A ori.)] … for concrete strength F c = 550 kg/cm^2
C 1 = [0.3654 * (A str. /A ori.)] … for concrete strength F c = 700 kg/cm^2
C 2 = [0.5061 * (thickness "mm") + (- 0.1507) * $(\text{thickness "mm"})^2$]
P ul str. , P ul ori. = ultimate load carrying capacity for both strengthened and original beams.
(A str. /A ori.): the ratio of area of side plate to area of haunched original beam.

5- The failure of strengthened beam with area of side plate to area of haunched original beam = 0.46, which bonded at the small depth was more sudden.

Beams Having Positive Haunch (tan α = + 0.20)

6- The mode of failure was shear failure for all unstrengthened having positive haunch beams. But for strengthened beams, the mode of failure changed from shear to shear compression and shear compression failure with crushing of concrete at the bearing support for the beams having area steel side plate to area of haunched original beam of about 0.46, 0.50 and 1.00 respectively.

7- By increasing the thickness of steel side plate the both of cracking and ultimate loads increase. The cracking load of strengthened beams "EP.1 ","EP.2" and "CP.3" having steel plate of thickness 1.00, 1.50 and 2.00 mm respectively showed 1.333, 1.417 and 1.417 times more than that of the original beam "CP.0". The ultimate load for the same latter beams showed 1.31, 1.41 and 1.544 times more than that of the original beam respectively.

8- A general equation to determine the ultimate loads for beams strengthened by using steel side plate of relative area (A str./A ori.) and different thickness of side plate, as a main variables as follows ;

P ul str.= P ul ori. [1.00 + C 1+ C 2]

Where:

C 1 = [0.5665 * (A str./A ori.)] …… for concrete strength F c = 250 kg/cm^2

C 1 = [0.4589 * (A str. /A ori.)] …… for concrete strength F c = 400 kg/cm^2

C 1 = [0.6019 * (A str. /A ori.)] …… for concrete strength F c = 550 kg/cm^2

C 1 = [0.3893 * (A str. /A ori.)] …… for concrete strength F c = 700 kg/cm^2

C 2 = [0.3271 * (thickness "mm") + (- 0.0291) * (thickness "mm") ^{2}]

Effect of Haunch Inclination (α)

9- For change the haunch inclination (α) from positive to negative the number of shear and flexure cracks decreases at the same level of loading. But cracking and ultimate loads increase.

10- With all grades of concrete, by changing the haunch inclination (α) from positive to negative, the maximum deflection decreases at any level of loading, but the corresponding measured concrete and steel bars strain increase.

11- Generally, the effectiveness of strengthening increases by increasing the area of strengthening steel side plates, its position on haunch and its thickness, but decreases relatively by increasing the grade of concrete strength.

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السلوك الاستاتيكى للكمرات الخرسانية المسلحة عالية المقاومة و ذات الشطف والمقواة باستخدام الواح الصلب الخارجية الملصوقة بالايبوكسي

من المعروف ان بعض عناصر المنشأت الخرسانية القائمة مثل الكمرات قد تحتاج الى تدعيم او تقوية لزيادة مقاومتها وتحسين ادائها الانشائي. لقد اصبحت تقنية تدعيم تلك الكمرات باستخدام الواح الصاج المعدنية مثبته خارجيا بماده الايبوكسى من الطرق شائعة الاستخدام لما لها من مميزات كثيرة. لقد قام

العديد من الباحثين بدراسة سلوك الكمرات الخرسانية ذات المقاومه العادية والمقواة بهذة التقنية والمعرضة لاجهادات انحناء او اجهادات قص وكثيرا منهم استفاضوا فى دراسة وتحليل الكمرات ذات الشطف الراسى ولكن كلها على خرسانة ذات مقاومة عادية. ولكن طبقا للمعلومات المتاحة فان سلوك الكمرات الخرسانية العالية المقاومة ذات الشطف الراسي والمقواة بهذة التقنية والمعرضة لاجهادات قص مازالت تحتاج الى الكثير من الدراسة. لذا فان الهدف من هذا البحث هو دراسة سلوك القص للكمرات الخرسانية العالية المقاومة ذات الشطف الراسى و المقواة باستخدام الواح من الصلب والملصوقة خارجيا بمادة الايبوكسي. هذا وقد اجريت التجارب على ستة وثلاثون كمرة ذات نسبة حديد تسليح ثابت ولا تحتوى على تسليح جذعى(حديد مكسح) وذات عدد للكانات ثابت , وكانت المتغيرات التى تمت دراستها هى:

تغير مكان وعرض ومساحة اللوح المعدنى فى منطقة القص (A str./A ori.) , تغير سمك اللوح المعدنى(t) , تغير مقاومة الخرسانة من خرسانة عادية المقاومة الى خرسانة عالية المقاومة (250 – 400 – 550 – 700 كجم/سم2), تغير ميل الشطف من الميل الموجب الى الميل السالب .

كما تم فى هذا البحث مقارنة مقاومة القص التى ساهمت بها الالواح المعدنية والتى تم الحصول عليها معمليا لهذة الكمرات بتلك المحسوبة طبقا للكود (ACI) ومن اهم النتائج التى تم استخلاصها ما يلى:–

- بزيادة عرض الصاج الجانبى(مساحة تغطيتة من الشطف) يزداد كل من حمل التشريخ والحمل الاقصى و على العكس بالنسبة لقيم سهم الانحناء و الانفعال .
- بزيادة عرض الصاج الجانبى ومساحة تغطيتة يتغير طراز الانهيار من انهيار قص الى انهيار نتيجة الانحناء وذلك فى الكمرات ذات الشطف السالب (ظا هـ = –0.20) ولكن يتحول من انهيار نتيجة القص الى انهيار نتيجة القص و الانحناء (انحناء قص) وذلك فى الكمرات ذات الشطف الموجب (ظا هـ = +0.20).
- بزيادة ميل الشطف (من الميل السالب الى الميل الموجب) يتحول طراز الانهيار للكمرة المقواه من انهيار نتيجة الانحناء الى انهيار نتيجة الانحناء والقص (انحناء قص) وكذلك تزداد قيم اقصى سهم للانحناء و الانفعال النسبى مع زيادة اقصى حمل نسبى .
- مع ثبات شكل التقوية و تغيير مقاومة الخرسانة من خرسانة عادية المقاومة الى خرسانة عالية المقاومة وجد ان نسبة الزيادة فى الاحمال تقل مع زيادة رتبة الخرسانة اى ان هذة التقنية لها حدود مع زيادة مقاومة الخرسانة .
- بزيادة سمك الصاج الجانبى يزداد كل من حمل التشريخ والحمل الاقصى و يقلل من قيم سهم الانحناء و الانفعال .
- تم استنباط معادلات للتنبؤ بالقيم التى تساهم بها هذة التقنية للتدعيم فى مقاومة القص لهذه الكمرات.