Behavior of R.C. T-Beams Strengthened with Glued Steel Plate.

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ABSTRACT

The paper discusses the experimental research carried out at Sheffield University (1) by the author. The main aim of this paper is to study the structural behaviors of T-beams strengthened by glued steel plates anchored at the ends withL-shaped plates to prevent the premature debonding failure. Further, the relative performance of external plates was compared with equivalent internal reinforcement designed to achieve the same ultimate strength. Results are presented for 24 T-beams; the variables studied were concrete strength (20-50Mpa), plate thickness (1.6-6mm) and double or single plate layers.

The results are discussed and demonstrated a reduction in bar strains, central deflections and crack widths was between "30% and 53%" at service load. The theoretical ultimate load of the composite section was achieved for beams with single and double plated and the maximum increase in strength was 41%. Tests results on beams with 25% to 72% of their main reinforcement replaced by steel plates showed that at service load a reduction in bar strains, central deflections and crack widths were between "54% and 66%".

سلوكية العتبات الخرسانية المسلحة بمقطع T المدعمة بالصفائح الفولاذية الملصقة

الخلاصة

يتناول هذا البحثالدراسة السلوكية الانشائية للعتبات بمقطع T المدعمة في أسفلها بالصفائح الفولاذية الملصقة والمثبتة في نهاياتها بصفائح بشكل L لمنع فشل النزع والتي أجريت الدراسة العملية عليها في جامعة شفيلد (1)من قبل الباحث. يضاف الى ذلك فقد تم مقارنة الأداء لعتبات استبدل حديد تسليحها بصفائح فولاذية صممت لتعطي نفس المقاومة القصوى. أن النتائج المطروحة تمثل فحوصات 24 عتبة والمتغريات التي درست هي قوة مقاومة الخرسانة (20 الى 50ن/ملم^2) , وسمك الصفائح الفولاذية (1.6 الى 6ملم) , واستخدام طبقة و عدة طبقات من الصفائح.

تم مناقشة النتائج واظهرت حصول انخفاض في قيمة انفعال حديد التسليح والانحراف الاعظم و عرض التشققات بمقدار تراوح بين 30% الى 53% تحت الاحمال الخدمية. تم تحقيق حساب قيمة الحمل الاقصى نظريا للمقطع المركب ذو الصفائح المفردة والمزدوجة وتم الحصول على اعلى نسبة في زيادة الحمل الاقصى بمقدار 41%. أظهرت نتائج الفحوصات للعتبات التي أستبدل نسبة 25% الى 72% من حديدها الرئيسي بصفائح

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الفولاذ أنخفاض في قيمة انفعال حديد التسليح والانحراف الاعظم و عرض التشققات بمقدار تراوح بين 54% الى 66% تحت الحمل الخدمي.

INTRODUCTION

The maintenance and changing circumstance of built structures may lead to the need for local strengthening and stiffening of existing structures to satisfy a higher ultimate load and/or more strict serviceability requirement. Over the past forty years there has been considerable interest in the use of epoxy resin adhesives to bond external steel plates onto concrete structures to increase their load capacity. The technique provides a larger contact area between the joined materials and allows them to act compositely. The operation has the advantage of being relatively simple in application, quick to carry out, economical; disruption on site is kept to a minimum and a minimum increase in member size.

Research into this technique was started at the University of Sheffield since 1977 but its increased use in practice has stimulated further work (1-5). Others (6-15) also had many contributions in this research field. The technique had many practical applications reported are concerned with bridges and multi-story buildings (16-21).

Experimental Programme

Details of the 24 T-beams together with the concrete control test results are presented in Table-1. The SBD epoxy resin was used in this investigation with constant glue layer thickness of 1.5mm. The beams were tested at 28 days curing age of concrete.

Three steel plate thicknesses 1.6, 3 and 6mm were employed for strengthening reinforced concrete T-beams of 20, 35 and 50Mpa compressive strength. The double steel plates were used in equivalent to the 6mm thick plate. Beams TB2-1, TB3-1 and TB4-1 had 25%, 50% and 72% of their main reinforcement replaced by steel plate respectively (characterize the repair of removed corroded bars), were designed to achieve the same ultimate strength as TB1-1.

Details of Beams

The T-beams were all identical in size; flange-450mm wide x 68mm thick, 150mm web width, 300mm overall depth and 2.8m overall length, as shown in Figure-1. All beams were tested under two points loads on a span of 2.4m, with shear span over effective depth ratio $a_v/d=3$. Stirrups, 8mm diameter high yield steel at 68mm centers, were provided in the shear span to prevent shear failure and 16mm diameter high yield steel bar was used as the main internal reinforcement. For each beam six 100mm cubs for compressive strength and three 100 x 100 x 50 mm prisms for modulus of rupture were sampled and tested at 28days.

Bonding Procedure

The plate's faces were abraded and the concrete surface abraded to remove laitance and expose the aggregates. The adhesive was applied to both concrete and plate surfaces. The joint thickness was controlled by a number of small hardened adhesive spacers. The plate was then erected and held in position by a uniformly distributed pressure obtained by a thick plywood plate clamped to the tested beam.Two L-shaped steel plates of 1.6mm thickness were utilized at plate ends to enable the composite section to enhance its full flexural strength, as shown in Figure-2.

Test Procedure

The beams were tested in a steel rig shown in Figure-3, a50ton Avery machine with hydraulic jack are to applying and controlling the load. Electrical pressure transducer connected to the hydraulic jack was used for measuring the applied load. The load was applied in increments of 25kN as approaching ultimate load becomes 10-5kN and the readings were taken. The first crack load, central deflection, support rotation, concrete and steel strains, crack width and ultimate load were measured by using mechanical and electrical instrumentations. The measuring instruments employed in the tests aredisplayed in Figure-3.

Materials Properties

(a)Epoxy: The epoxy resin used was under the name of SBD Epoxy plusPuttyby SBD Construction Products LTD, UK(22), consisting of three components; Resin, Hardener and Filler. Average properties of tested epoxy resin samples are: Compressive strength = 87.8 N/mm^2

Density = 1734 kg/m^3
Modulus of Elasticity = 10.4 kN/mm^2
Poisson's Ratio = 0.31
Tensile Strength = 15.4 N/mm^2
Flexural Strength = 40.8 N/mm^2

(b)Concrete: The concrete materials were crushed gravel, dried river sand and ordinary Portland cement. The concrete strengths for each grade of concrete for each beam are given in Table-1.

(c)Steel Plates: Mild steel plates of 1.6, 3 and 6mm thicknesses were used. The plate were sampled and tested according to BS-EN10002. The average properties for the tested plate samples are shown in Table (A):

Table (A): Properties of Steel Plates

Plate Thickness (mm)	ElasticModulus (kN/mm^2)	Yield Stress (N/mm^2)	Yield Strain X 10^{-6}	Ultimate Stress (N/mm^2)
1.6	200	261	1600	374
3	200	237	2100	344
6	200	229	1500	378

(d)Bar Reinforcement: High yield deformed bars were used for the internal reinforcement. The rebar were sampled and tested according to BS4449. The average properties for the tested bar samples are sown in Table (B):

Table (B): Properties of Steel Reinforcement

Bar Size (mm)	Elastic Modulus (kN/mm^2)	0.2%Proof Stress (N/mm^2)	Strain at Proof Stress X10^{-6}	Ultimate Stress(N/mm^2)
8	200	510	4600	606
12	200	500	4500	600

16	200	530	4700	635

Test Results and Discussions

Modes of Failure and Ultimate Strength

Test results and strength characteristics of the beams are presented in Table-2. Three methods (23-25) were used to compute the theoretical ultimate load. The mean ratio of experimental to theoretical ultimate load of the BS and ACI codes is 1.10.This verifies that within the present test result the ultimate strength of plated T-beams could be satisfactory predicted using these methods.

(a)T-beams of concrete M35 and M50 strengthened with 1.6x120mm and 3x120mm plates having a steel ratio maximum of 51.3% of the balanced steel ratio, all failed in flexure, see Figure-4.The concrete compressive strain attains values over 0.0035 causing the flange to crush and bar and plate strains both reached over yielding values before failure. If the load retained after the flange crushed and then released, a local plate bond failure occurred in the constant moment zone below the point of crushing flange. Beams of M20 concrete with 1.6x120mm and 3x120mm plates, however ithas a steel ratio 128% of the balanced (theoretically over reinforced), bar and plate strains both reached yielding before failure so it considered flexural failure. The maximum increase in ultimate load over that of unplated beams are 18%, 41% and 35% for plated T-beams of concrete type M20, M35 and M50 respectively. It appears that the use of L-shaped end plates introduces a great improvement in increasing the ultimate load. Still it is suggested that the balanced steel ratio should be the upper limit of the amount of steel plate to be bonded to the beam, as demonstrated in Figure-6.

(b) Beam TB1-5.1 was tested without L-shaped end plates and failed in debonding similarly was the failure of beam TB1-5.2 despite the use of two clips at ends of the plate. This suggest that the influence of L-shaped end plates in preventing debonding is due to its aid in increasing the end plate bond surface and not due to its ability to prevent the plate from lifting off.

(c)T-beams strengthened with 6x120mm plate having ratio of plate/thickness less than 40 failed by plate debonding, see Figure-5, very close to the theoretical ultimate load. Nevertheless plated beams of concrete type M35 and M50 are under reinforced. Diagonal cracks occurred first at the ends plates, and then it propagated around the L-shaped plates, as load increases, at failure load, it suddenly deboned at one end of beam and spread to beam center. At failure the plates reached their upper yield strains, but the bars did not achieve its proof strains.The alterative solution is by reducing the thickness of plate at ends. It is recommended to use two layers of 3mm thick plates, second layer was stopped before the end, narrower and bonded with L-shaped end plates. In these beams the composite section achieved the full theoretical ultimate load ata typical end plate debonding failure.

(d) Beams with their main reinforcement partially (only up to 50%) replaced by glued plates achieved the full composite action and the theoretical ultimate load was reached. It can be suggested that, the ultimate strength of the composite section of those beams would be very much improved if the plate debonding could be prevented.

Cracking

The first crack load for all plated beams started at the level of bar reinforcement. This might be caused by the restraining effect of glue layer and steel plate at the concrete cover. This and the increasing in the stiffness of plated beams caused the delay of the appearance of the cracks. These effects had greater value as the concrete strength reduces. The experimental and theoretical first crack loads are shown in Table-2.

The crack widths at level of bar reinforcement at each load stage and the crack spacing near ultimate load were measured. The experimental results demonstrate that the crack widths of plated beams were reduced up to 50% of the values of control beams. The crack widths were predicted at service and 1.5 service loads by applying three methods (23,24&26) are shown in Table-3. In all beams, the average crack widths at service and 1.5 service loads are below the 200 micrometer, the limit recommended by BSI moderate environment. Within the present test results the BS8110 code gave the better predictions of crack widths at service load. In general, the variation in the plate thickness has little effect on crack spacing. However, the crack spacing of plated T-beams increased by 39% over that of unplated beams.

The relationship between the mean crack widths in constant bending moment region at the level of bar reinforcement, and the applied load are listed in Table-3. Ingeneral, the crack widths decreased with increase the plate thickness, and the use of multi layers plate showed slight reduction over that of single plate. Furthermore it appears that the concrete strength has no great influence on the crack width of plated T-beams.

Deflections

The theoretical and experimental central deflections are presented in Table-4. Three methods(24, 26&27) were used to calculate the central deflection. Within present tests, Beeby(27) formula gave better predictions of deflections. The mean ratio of experimental to Beeby's predicted values are 0.98. The experimental results illustrated that central deflection of plated T-beams were reduced up to 70% of the values of control beams. Likewise, the deflections of beams their reinforcement partial replaced by glued plate were reduced up to 46%. This is due to the fact that the stiffness of the beams increased by adding glued plates to their soffits. It is clear that this effect is higher by using thicker plate. The load deflection curves are shown in Figures-7 to 10, give the same conclusion. The sudden drops in some curves are for beams failed in plate debonding. In general, the ductility of these beams is slightly reduced with increase the plate thickness. The stiffness of plated beams increased with increasing the concrete strength, as shown in Figure11&12.

Concrete Compressive Strain

The load concrete compressive strain curves are shown in Figures-13 to 18. It is clear that the concrete strain decreased as the plat thickness increased and concrete strength increased. The maximum ultimate concrete compressive strains recoded were 4400, 5000 and 4300 microstrains for concrete types M20, M35 and M50 respectively for beams failed in flexure, higher than values suggested by the codes. However, these beams failed at load greater than the ultimate load corresponding to the codes. The strains of beams failed prematurely were below the codes values.

Steel Strains

The theoretical calculation of steel strains using the elastic theory at service and 1.5 service loads presented in Table-5 , illustrate a good agreement with the experimental results.

(a)Bar Strains: The load-bar strains curves are shown in Figures-19 to 22, revealed bar strains were reduced as the plate thickness increased and the ductility of the beams were slightly reduced as well. The bar strains recorded for plated beams failed in flexure, were well ahead in the plastic zone. Bar strains of M20 concrete type beams strengthened with 3 & 6mm plates, in Figure-20did not reach the proof strains at debonding failure, reflecting the over reinforced behavior of the beams.

(b)Plate Strains: The load central steel plate strains are shown in Figures-23 to 26 that of multi layers plates are for outside plate. The general behavior was similar as for bar strains, confirming the full composite action achievement. The central plate strains recorded at ultimate load was higher than the yield strain, and the general behavior was similar as for bar strains, confirming the full composite action achievement.

Conclusions

(i)T-beams strengthened with 1.6, 3 and 6mm steel plates, show a corresponding reduction in concrete, bar and plate strains, central deflection and crack width. The maximum reduction in strains, central deflection and crack width, at service load was 53%, 30% and 50% respectively.

(ii) The maximum increase in strength by the addition of externally bonded steel plates was 41%, without exceeding the balanced steel ratio. The theoretical ultimate load capacity of single and double plated beams of the composite section was achieved by using the L-shaped end plates.

(iii)The actual action of L-shaped end plates in preventing debonding is due to increase the bond area rather than its ability to prevent the plate from lifting off by force.

(iv)The general level of interface bond stresses in plated beams was significantly increased as the steel plate thickness was increased by two to three folds.

(v)The prediction of the ultimate strength and the crack width at 1.5 service load of plated beams using the BS8110 and ACI codes methods was satisfactory. Meanwhile, Beeby's method of evaluating the central deflection was the finest.

(vi)Beams of up to 72% of main reinforcement replaced by steel plates show significant reductions in deflections, crack widths and concrete and bar strains for loads up to 1.5 service load. At service load the maximum reduction in bar strain, central deflection and crack width was 66%, 54% and 59% respectively.

Table-1: Details of Experimental Program

Beam No.	Conc. Type	Bars	Plate Dimensions(mm) (Thick x Width)	End Plate Details	Lab. f_{cu}(M)	Stand. f_{cu}(Mpa)	f_r (Mpa)
TB1-1	M35	4Y16	----	----	36.4	43.8	3.5
TB1-2	M35	4Y16	Glue layer only	----	36.6	--	--
TB1-3	M35	4Y16	1.6x120	LSEP	37.8	--	3.8
TB1-4	M35	4Y16	3x120	LSEP	35.7	43.2	3.4
TB1-5	M35	4Y16	6x120	LSEP	36.7	38.8	3.5
TB1-5.1	M35	4Y16	6x120	No LSEP	38.1	40.1	--
TB1-5.2	M35	4Y16	6x120	Clip end plate	35.6	37.3	3.6
TB1-5DP	M35	4Y16	3x148+3x90	LSEP each plate	35.2	46.5	3.4
TB1-5DP2	M35	4Y16	3x148+1.6x148	LSEP each plate	34.1	45.2	3.6
TB1-6	M20	4Y16	----	-----	18.1	21.4	2.3
TB1-7	M20	4Y16	1.6x120	LSEP	19.6	25.6	2.6
TB1-8	M20	4Y16	3x120	LSEP	18.0	20.4	2.8
TB1-9	M20	4Y16	6x120	LSEP	17.0	25.8	2.7
TB1-9DP	M20	4Y16	3x148+3x90	LSEP each plate	19.5	27.3	3.0
TB1-10	M50	4Y16	----	-----	46.0	51.0	3.6
TB1-11	M50	4Y16	1.6x120	LSEP	46.2	--	--
TB1-12	M50	4Y16	3x120	LSEP	45.7	55.3	4.1
TB1-13	M50	4Y16	6x120	LSEP	49.0	--	3.9
TB1-13DP	M50	4Y16	3x148+3x90	LSEP each plate	49.8	56.4	4.0
TB2-1	M35	3Y16	3x120	LSEP	39.8	46.5	4.0
TB3-1	M35	2Y16	6x135	LSEP	38.2	45.4	4.0
TB4-1	M35	2Y12	10x115	LSEP	37.9	--	--
TB3-1DP	M35	2Y16	3x148+3x120	LSEP each plate	36.6	46.5	3.2
TB3-1TP	M35	2Y12	3x148+3x125+ 3x100	LSEP each plate	41.2	45.0	3.6

LSEP= L-Shaped End Plate
f_r= Modulus of rupture of concrete.
Stand.f_{cu}=Concrete cube strength, fog room curing.
Lab.f_{cu}=Concrete cube strength, laboratory curing.
DP= Double Steel Plates.
TP= Triple Steel Plates.

Table-2: Strength Characteristics of T-Beams

Beam No.	First Crack Load (kN)		Experimental and Theoretical Ultimate Load (kN)							Mode of Failue
	Exp.	Theo.	Exp.	BS8110	ACI	Parab. Str.Block	Exp/Theo Ratio			
							BS8110	ACI	Parab. Str.Blo	
TB1-1	36	34	277	261	263	262	1.06	1.05	1.06	Flexure
TB1-2	43	34	290	261	263	262	1.11	1.10	1.11	Flexure
TB1-3	60	50	311	292	296	295	1.07	1.05	1.05	Flexure
TB1-4	75	50	357	315	319	317	1.13	1.12	1.13	Flexure
TB1-5	80	58	380	364	370	368	1.04	1.03	1.03	Flexure
TB1-5.1	104	58	290	364	370	368	0.80	0.78	0.79	P.D.
TB1-5.2	100	58	294	364	370	368	0.81	0.80	0.80	P.D.
TB1-5DP	97	56	390	354	359	358	1.10	1.09	1.09	P.D.
TB1-5DP2	95	60	360	351	356	355	1.03	1.01	1.01	P.D.
TB1-6	33	29	254	243	244	-	1.05	1.05	-	Flexure
TB1-7	75	37	290	262	263	-	1.11	1.11	-	Flexure
TB1-8	75	44	300	273	275	-	1.10	1.09	-	Flexure
TB1-9	90	52	295	296	298	-	1.00	0.99	-	P.D.
TB1-9DP	95	56	280	287	288	-	0.98	0.97	-	P.D.
TB1-10	35	34	290	268	271	270	1.08	1.07	1.07	Flexure
TB1-11	75	52	333	301	306	304	1.11	1.09	1.10	Flexure
TB1-12	75	64	350	325	330	328	1.07	1.06	1.07	Flexure
TB1-13	85	64	370	378	385	382	0.98	0.96	0.97	P.D.
TB1-13DP	85	62	390	367	374	371	1.06	1.04	1.05	Flexure
TB2-1	50	48	295	260	260	261	1.13	1.13	1.13	Flexure
TB3-1	75	62	250	262	266	264	0.95	0.94	0.95	P.D.
TB4-1	109	67	230	260	263	261	0.89	0.88	0.88	P.D.
TB3-1DP	70	49	263	260	262	262	1.01	1.00	1.00	P.D.
TB4-1TP	75	60	230	263	265	264	0.88	0.87	0.87	P.D.
The Mean of Ratio for flexural failure beams							1.12	1.08	1.08	

P.D.=Plate Debond

Table(3): Crack Widths Investigations

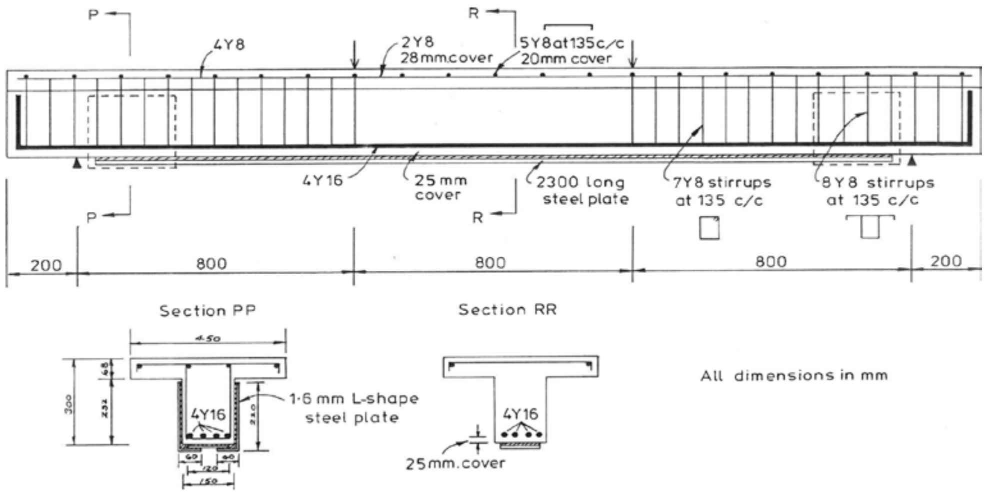
Beam No.	**Service Load (kN)**	**Exp. Av. Crack Width (microns)**		**Theoretical Crack width Calculation (microns)**						**Average Crack Spacing near Ultimate Load (mm)**
		Service Load (S.L.)	1.5 Service Load	BS8110		ACI		CEB-FIP		
				S.L.	1.5 S.L.	S.L.	1.5 S.L.	S.L.	1.5 S.L.	
TB1-1	135	76	156	77	117	114	169	155	243	67
TB1-2	135	90	183	77	117	1142	169	155	243	80
TB1-3	155	66	120	67	100	99	144	123	187	80
TB1-4	165	57	134	59	92	87	132	101	161	100
TB1-5	190	58	113	48	72	72	105	76	115	100
TB1-5DP	190	53	100	49	73	73	106	77	116	100
TB1-6	110	58	108	59	87	89	128	116	177	57
TB1-7	120	40	93	47	78	71	113	83	143	80
TB1-8	125	37	94	38	64	58	93	63	109	73
TB1-9	130	29	74	28	53	44	76	42	82	89
TB1-9DP	130	26	73	28	53	45	77	43	83	80
TB1-10	145	111	183	83	116	122	168	167	240	67
TB1-11	160	77	143	69	99	102	144	127	186	80
TB1-12	175	77	150	63	92	92	132	107	160	100
TB1-13	200	58	110	58	80	76	114	81	126	89
TB1-13DP	200	53	127	58	80	77	115	82	127	89
TB2-1	135	59	130	55	85	84	125	102	161	100
TB3-1	135	38	70	38	60	60	90	65	103	80
TB4-1	135	31	57	30	48	50	74	50	81	100
TB3-1DP	135	37	83	38	59	61	91	66	104	133
TB4-1TP	135	34	60	31	49	51	75	51	82	133

Table(4): Central Deflection Investigation

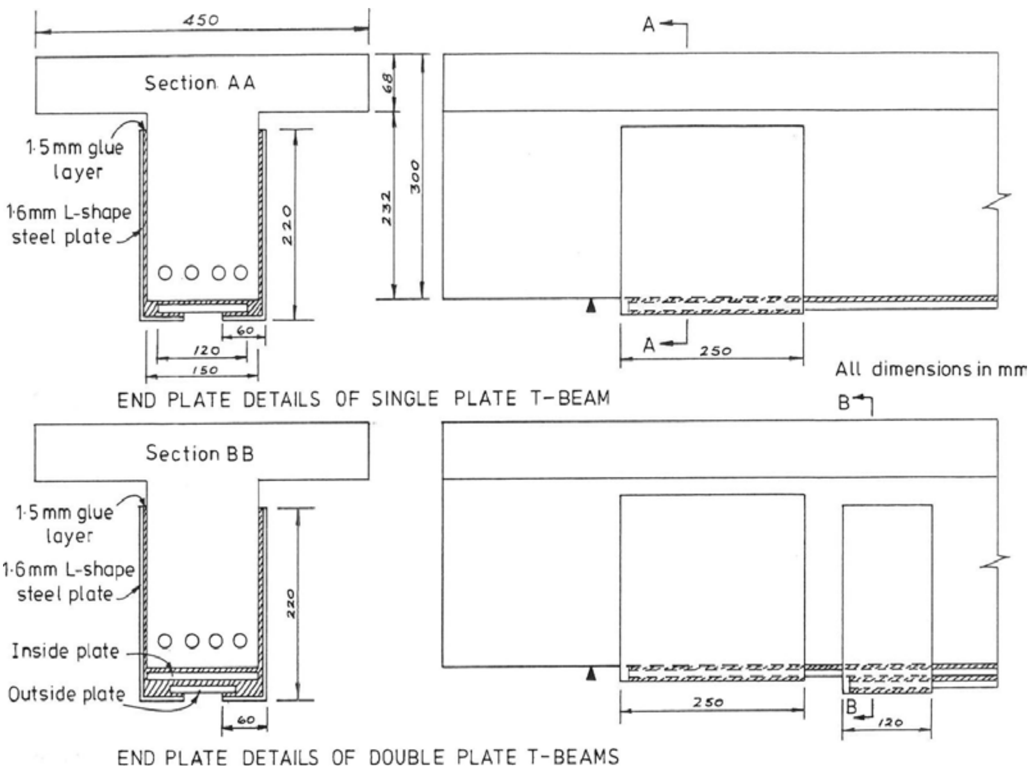
Beam No.	Service Load (kN)	Experimental Deflection (mm)			Calculated Deflection (mm)					
					ACI		CEB-FIP		Beeby	
		S.L.	1.5 S.L.	Ultimate Load	S.L.	1.5 S.L.	S.L.	1.5 S.L.	S.L.	1.5 S.L.
TB1-1	135	6.43	10.36	60.0	4.31	6.47	4.89	7.72	7.49	11.99
TB1-2	135	6.87	10.47	52.0	4.31	6.47	4.89	7.72	7.49	11.99
TB1-3	155	6.45	10.10	46.8	3.90	5.77	4.31	6.73	6.47	10.32
TB1-4	165	6.13	10.53	50.0	3.59	5.51	4.08	6.61	6.05	10.06
TB1-5	190	5.62	9.23	35.0	3.27	4.72	3.76	5.75	5.51	8.63
TB1-5DP	190	5.33	8.93	29.0	3.24	4.73	3.75	5.74	5.50	8.62
TB1-6	110	5.44	8.18	50.0	3.56	5.12	4.13	6.19	6.32	9.60
TB1-7	120	4.75	8.51	35.5	2.94	4.77	3.29	5.70	4.84	8.63
TB1-8	125	4.96	8.53	32.1	2.51	4.09	2.77	4.84	3.99	7.25
TB1-9	130	3.78	6.98	15.5	2.06	3.68	2.29	4.44	3.18	6.52
TB1-9DP	130	3.72	6.86	13.2	2.06	3.68	2.29	4.44	3.18	6.52
TB1-10	145	7.09	10.10	50.0	4.49	6.27	5.11	7.43	7.89	11.58
TB1-11	160	6.07	9.40	55.0	3.86	5.56	4.24	6.42	6.37	9.83
TB1-12	175	6.89	10.73	42.3	3.59	5.27	3.90	6.05	5.76	9.17
TB1-13	200	5.00	8.62	12.8	3.25	4.93	3.72	5.94	5.53	9.04
TB1-13DP	200	6.15	10.50	30.7	3.25	4.93	3.72	5.94	5.53	9.04
TB2-1	135	4.95	8.58	51.0	3.22	4.95	3.45	5.63	5.26	8.03
TB3-1	135	3.42	5.60	8.7	2.46	3.79	2.65	3.60	3.75	6.42
TB4-1	135	2.97	5.90	7.9	2.11	3.25	2.28	3.74	3.14	5.43
TB3-1DP	135	4.26	6.93	13.0	3.04	4.64	2.74	4.43	4.65	7.90
TB4-1TP	135	3.85	6.05	9.6	2.57	4.00	2.38	3.85	3.93	6.76

Table(5): Steel Strain at Service & 1.5 Service Loads

Beam No.	Reinforcing Bar Strain x 10^{-6}				Steel Plate Strain x 10^{-6}			
	Service Load		1.5 Service Load		Service Load		1.5 Service Load	
	Exper.	Theor.	Exper.	Theor.	Exper.	Theor.	Exper.	Theor.
TB1-1	1460	1388	2470	2053	-----	-----	-----	-----
TB1-2	1545	1388	2520	2053	-----	-----	-----	-----
TB1-3	1271	1213	2168	1761	1578	1444	2801	2097
TB1-4	1110	1068	2130	1618	1417	1284	2608	1945
TB1-5	860	876	1740	1267	1224	1076	2286	1557
TB1-5DP	900	895	1536	1295	1102	1114	2106	1613
TB1-6	1145	1090	1720	1557	-----	-----	-----	-----
TB1-7	852	871	1574	1386	1063	1047	1900	1665
TB1-8	745	719	1365	1144	907	873	1750	1388
TB1-9	537	544	981	946	676	677	1256	1178
TB1-9DP	430	546	777	949	648	690	1264	1200
TB1-10	1585	1479	2540	2039	-----	------	-----	-----
TB1-11	1333	1246	2185	1752	1728	1477	2704	2077
TB1-12	1407	1126	2314	1611	1723	1347	2850	1926
TB1-13	890	935	1590	1403	1152	1140	2144	1709
TB1-13DP	907	938	1814	1407	1183	1159	2284	1738
TB2-1	1166	1026	2055	1520	1385	1226	2737	1815
TB3-1	648	742	1129	1100	869	903	1497	1338
TB4-1	685	618	1221	916	838	757	1497	1121
TB3-1DP	745	744	1000	1101	988	918	1798	1359
TB4-1TP	500	632	907	935	697	793	1118	1174



Figure(1) T- Beam Reinforcements.



Figure(2): End Plate Details for Single and Double Plated T-Beams.

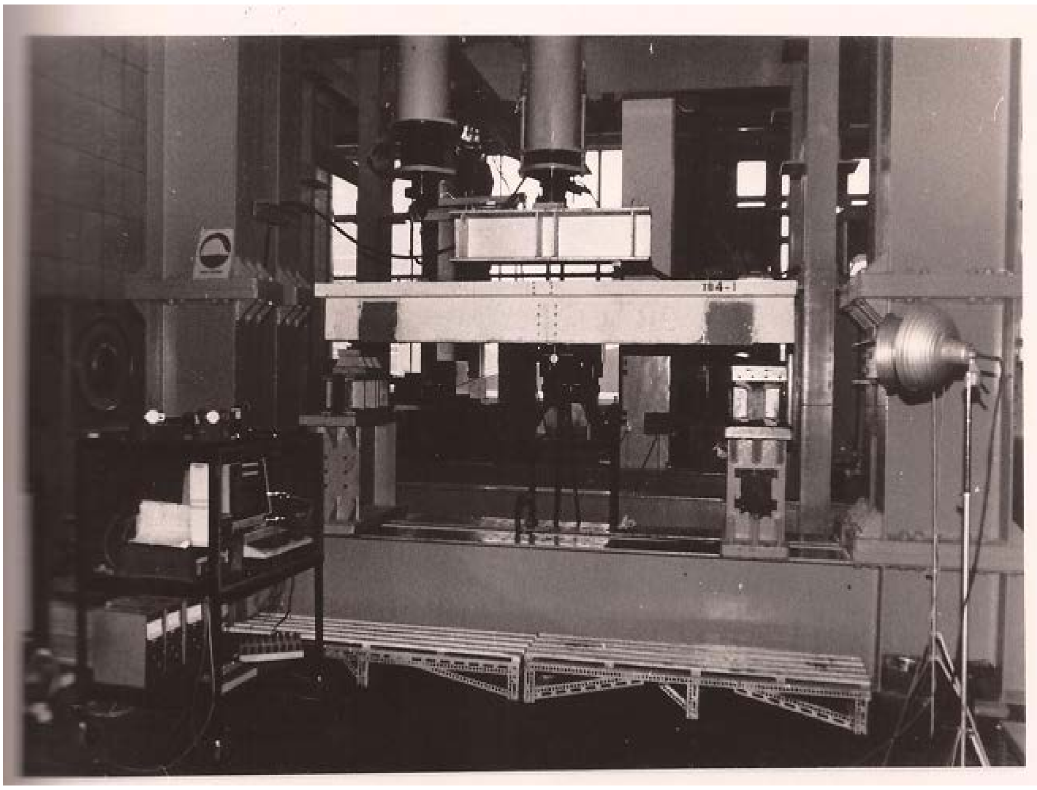
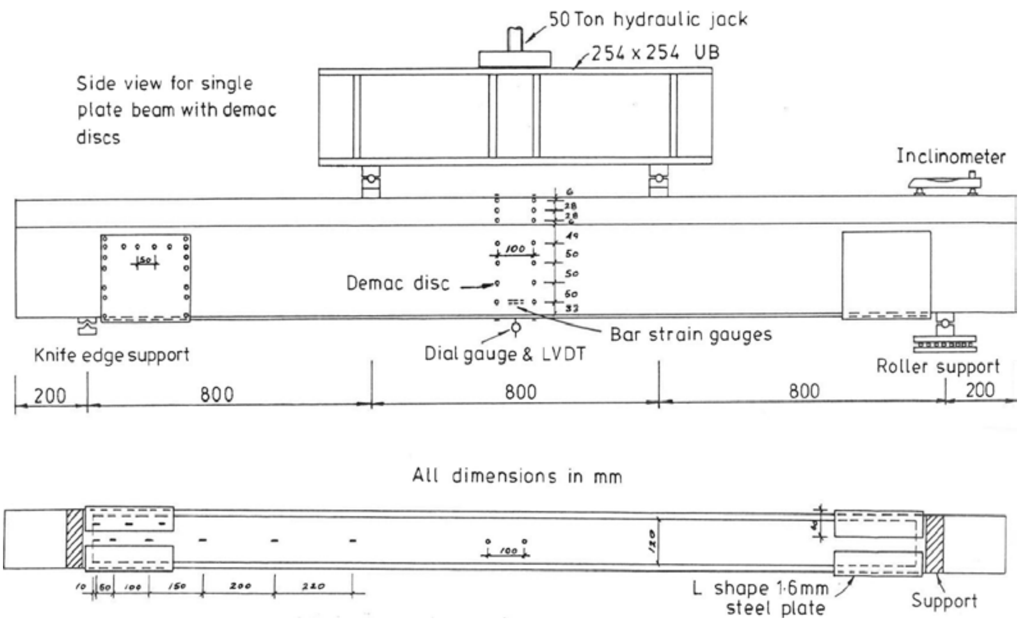
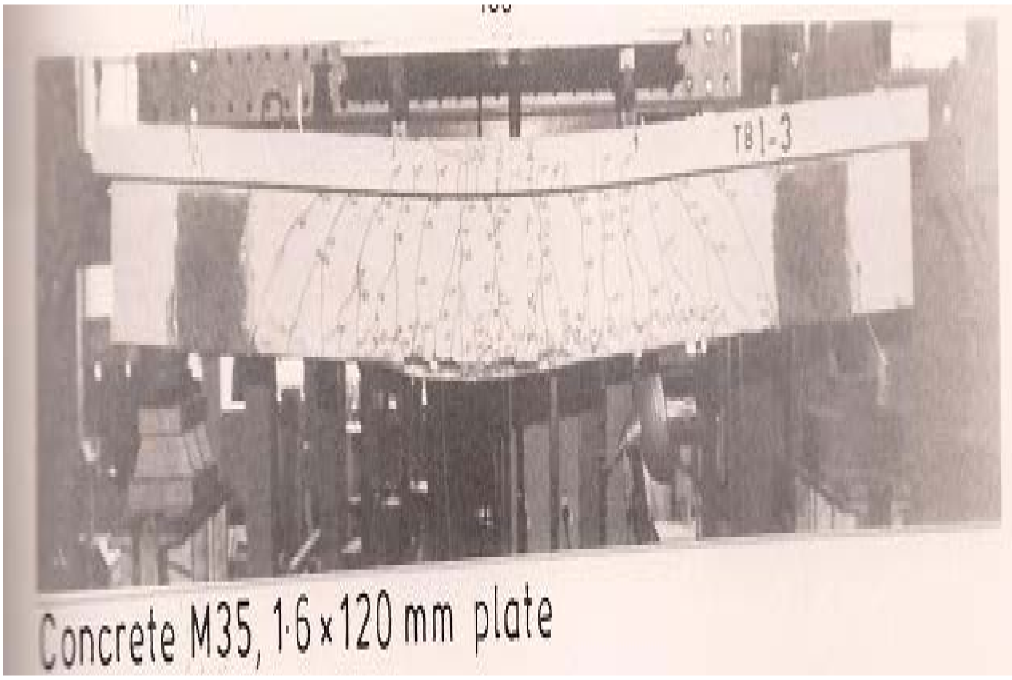
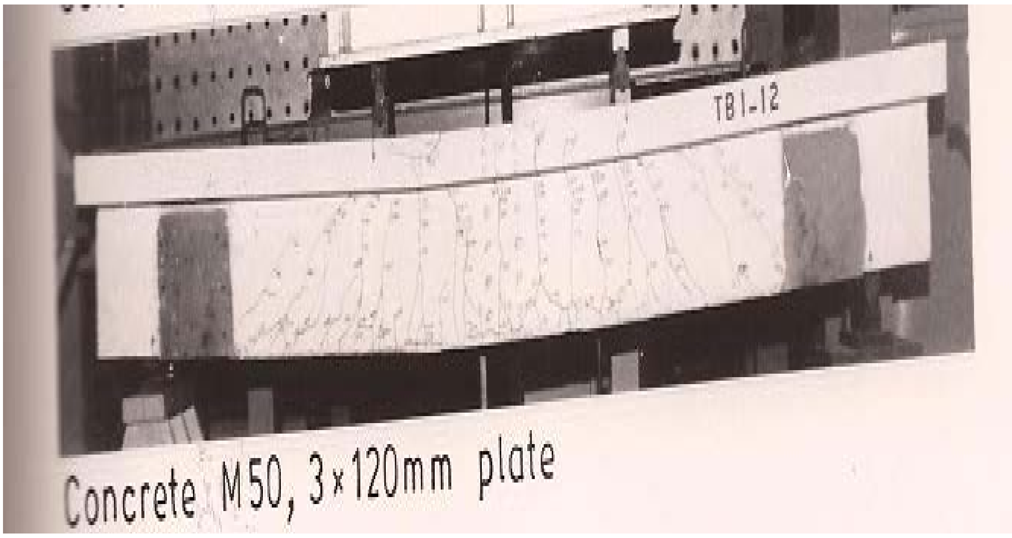


Figure-3(a): Testing Rig

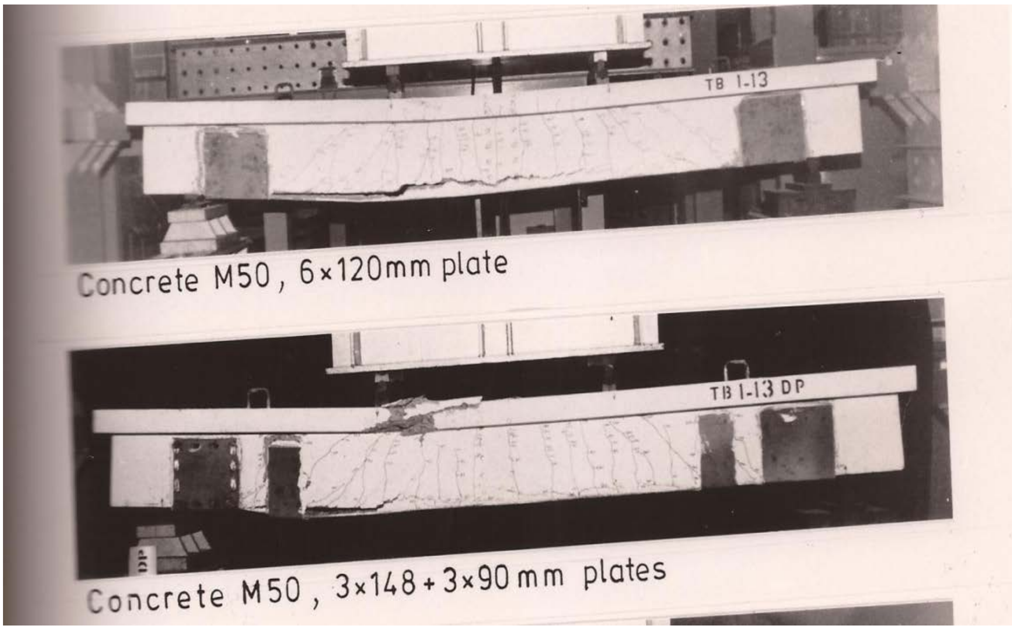


Bottom view of single plate T-beam with strain gauges and demac discs locations.Figure-3(b): Instrumentations of Beams.

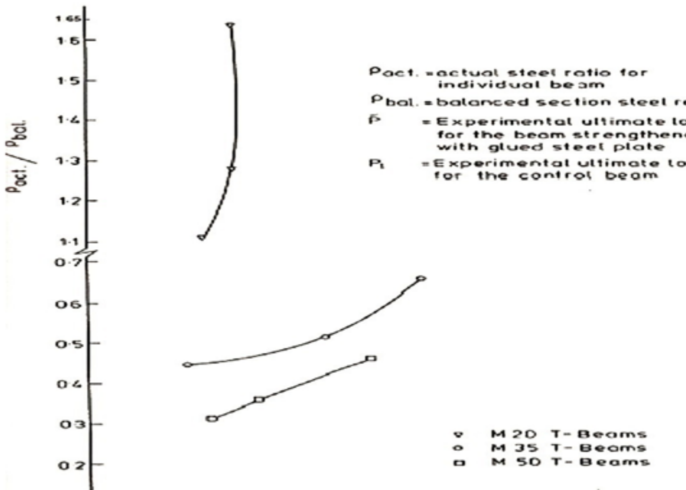




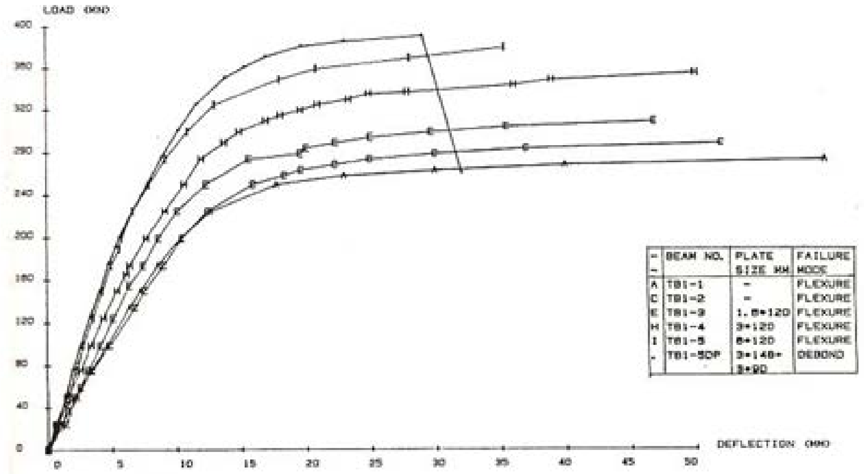
Figure(4): Typical Flexural Failure for Plated Beams



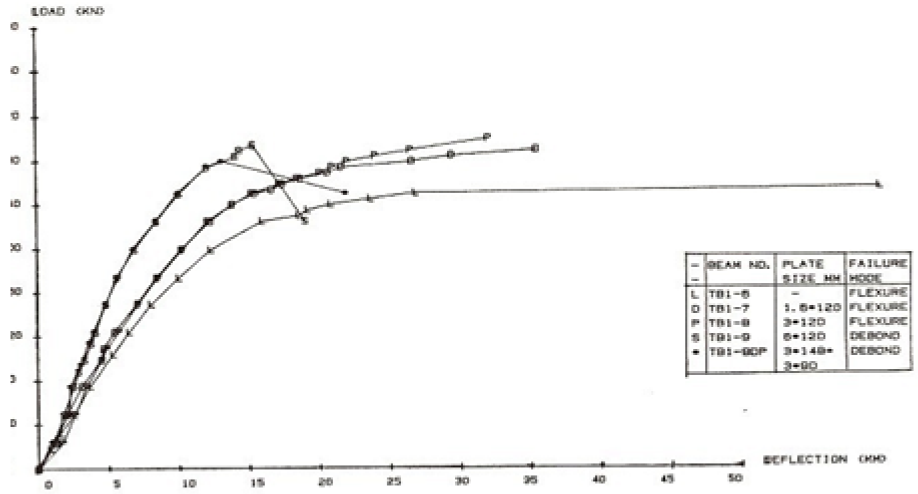
Figure(5): Typical Debond Failure of Plated Beams



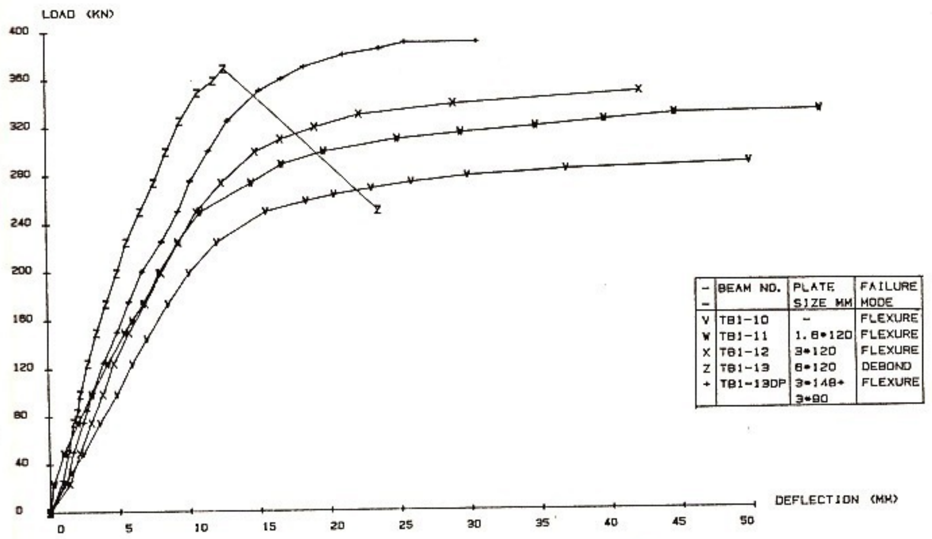
Figure(6): Relationships between Steel Ratio and the Increase in Ultimate Load



Figure(7) load deflection curves for T- beams of concrete type M35



Figure(8) load deflection curves for T- beams of concrete type M20



Figure(9) load deflection curves for T- beams of concrete type M50

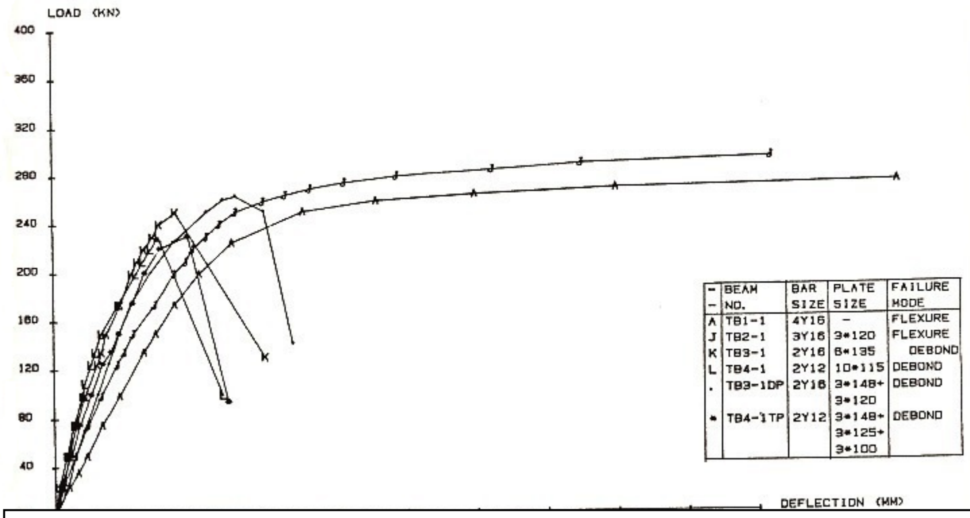


Figure (10) : load – Deflection Curves for T-Beams Their Mainreinforcement partially by plates

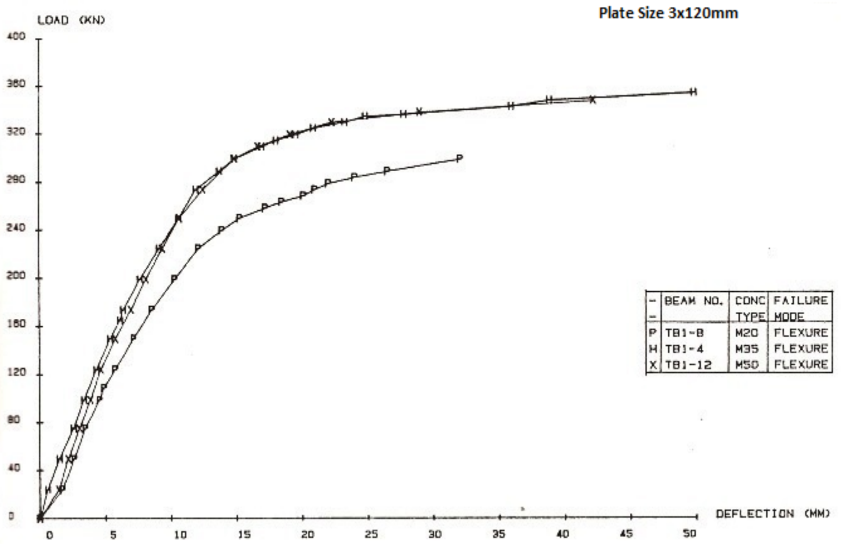


Figure (11):load-Deflection Curves for Plated TBeams of Different ConcreteTypes with Plate 3*120

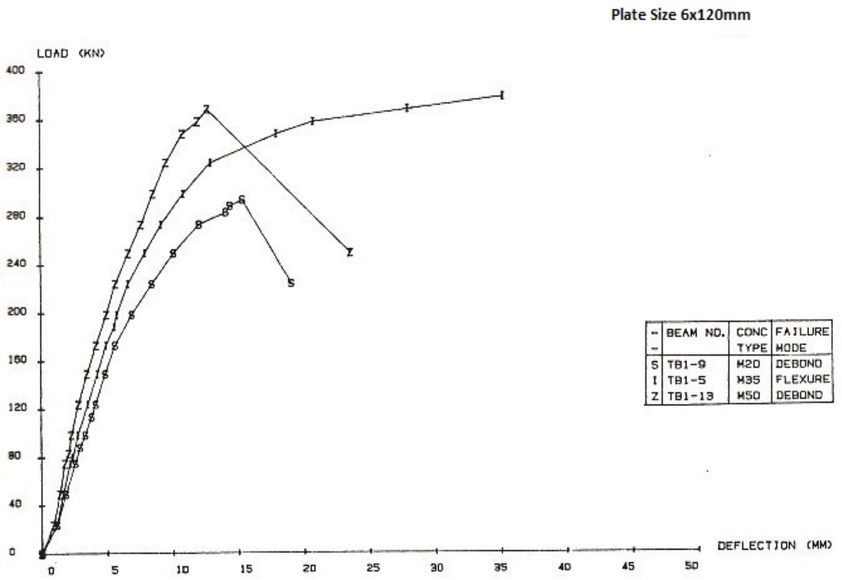


Figure-12: Load-Deflection Curves for Plated T-Beams of Different Concrete Types with Plate 6x120

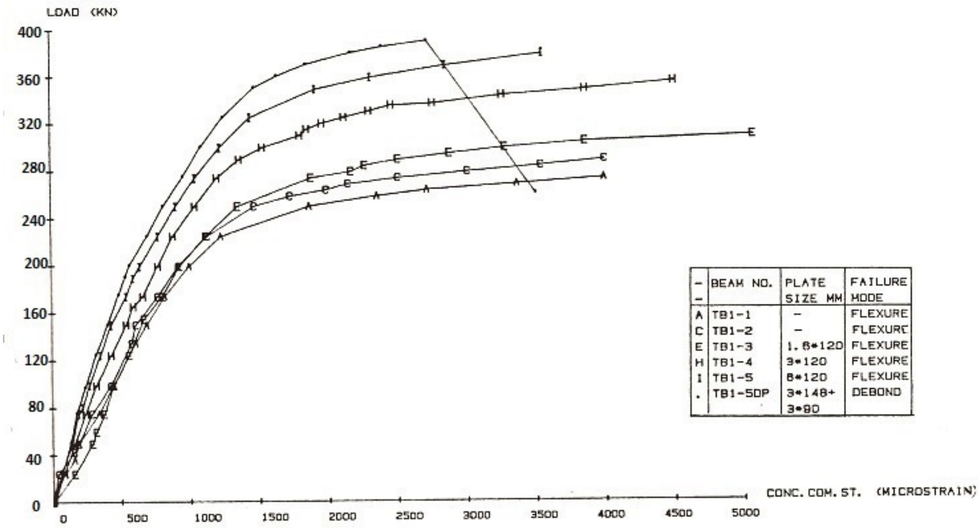


Figure-13: Load-Concrete Compressive Strength Curves for T-Beams of Concrete Type M35

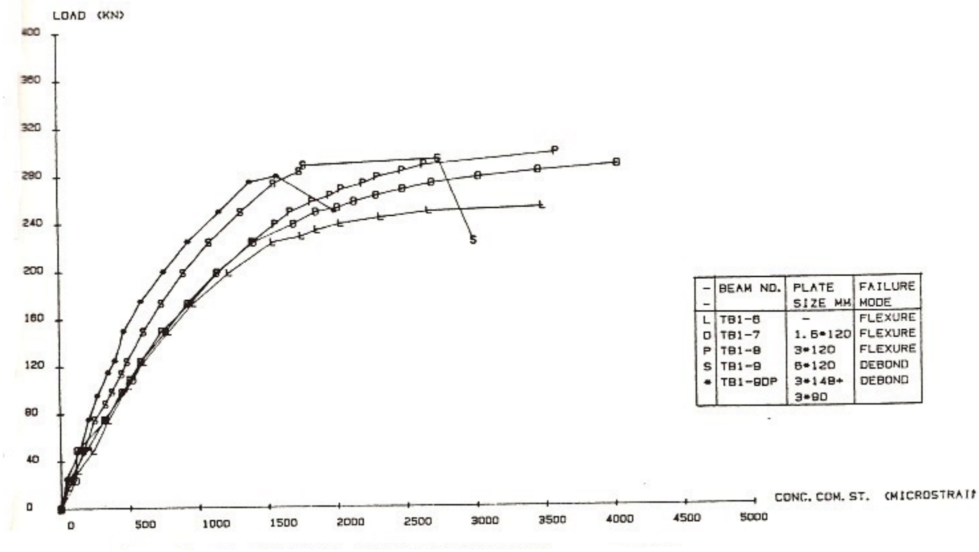


Figure-14: Load-Concrete Compressive Strength Curves for T-Beams of Concrete Type M20

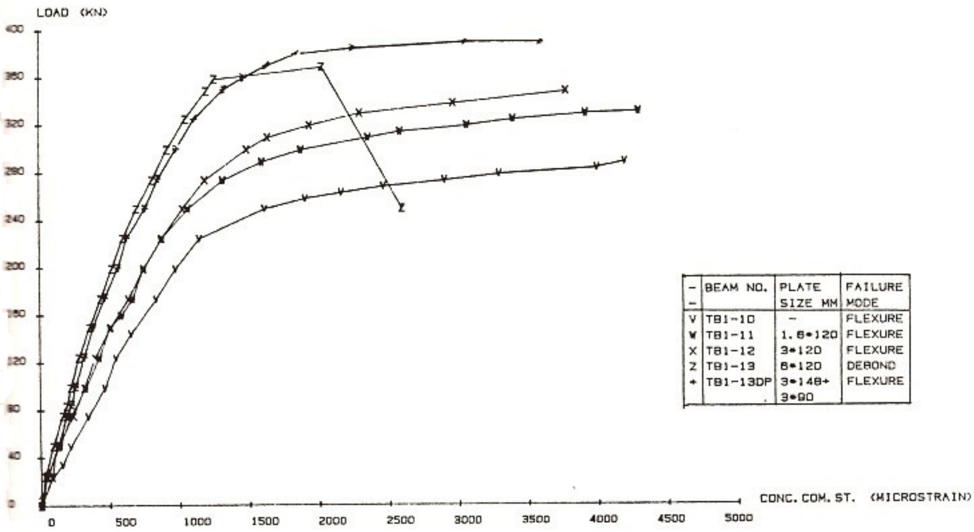


Figure-15: Load-Concrete Compressive Strength for T-Beams of Concrete Type M50

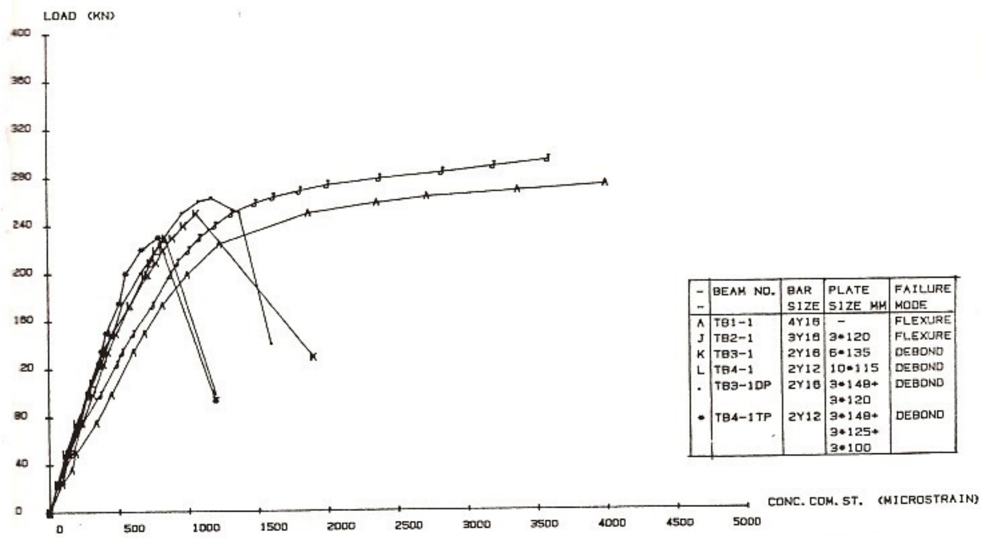


Figure-16: Load-Concrete Compressive Strength for T-Beams Their Mainreinforcement Partially Replaced by Plates

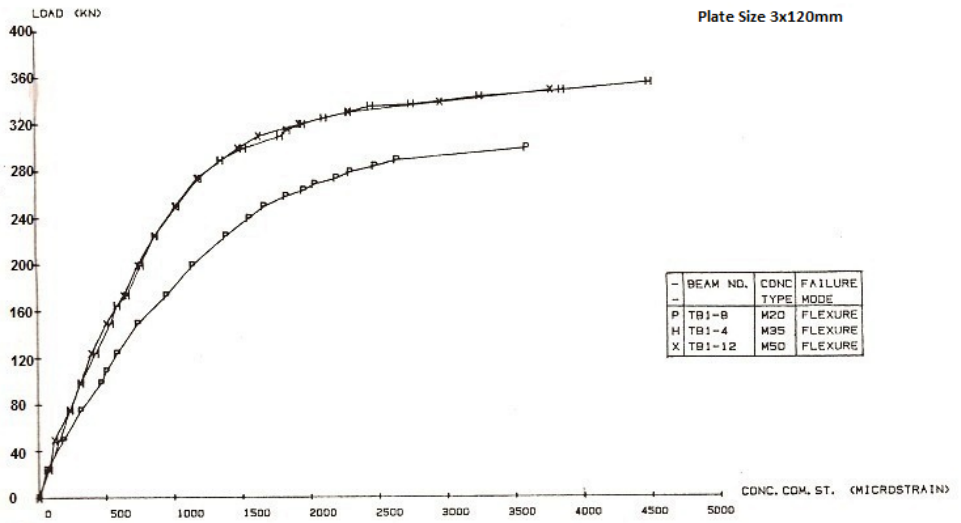


Figure-17:Load-Concrete Compressive Strength Curves for T-Beams of Different Concrete Types with Plate Size 3x120

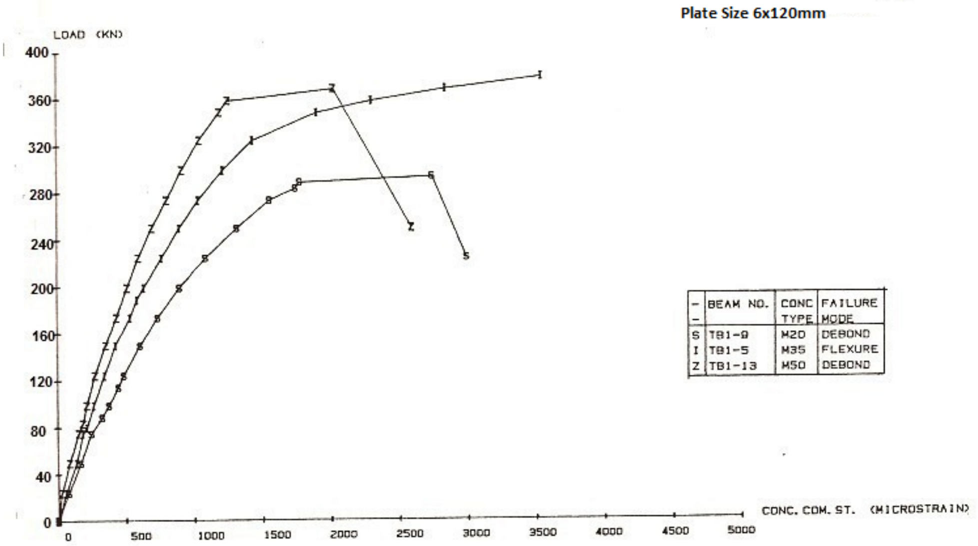


Figure-18:Load-Concrete Compressive Strength Curves for T-Beams of Different Concrete Types with Plate Size 6x120

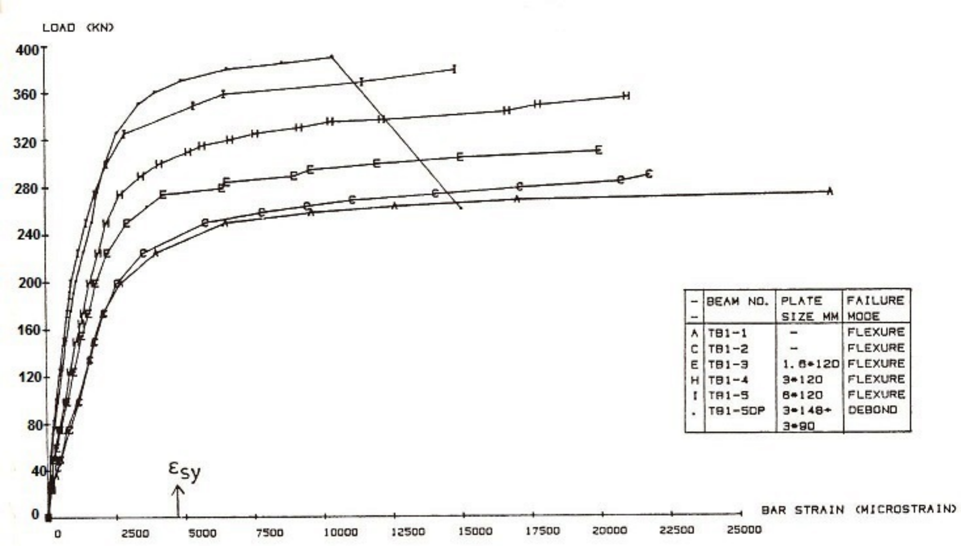


Figure-19: Load-Bar Strain Curves for T-Beams of Concrete Type M35

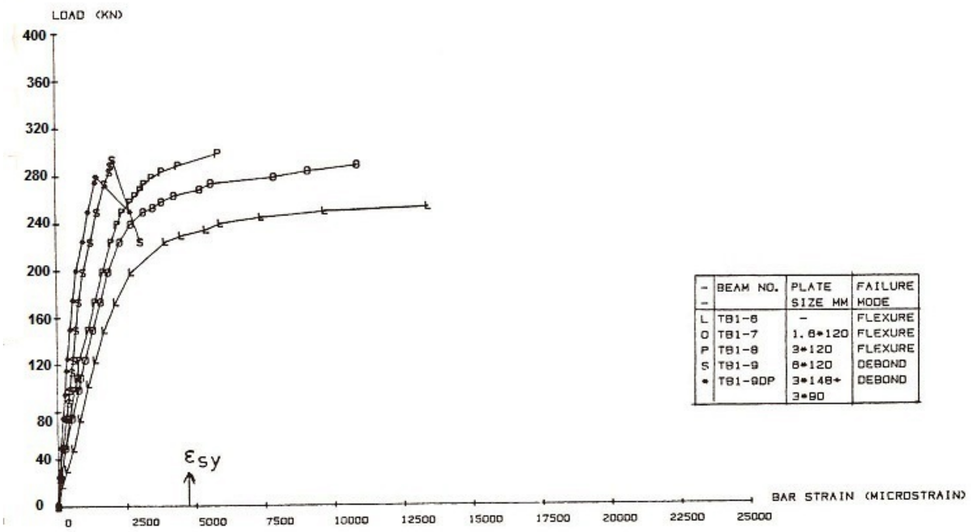


Figure-20: Load-Bar Strain Curves for T-Beams of Concrete Type M20

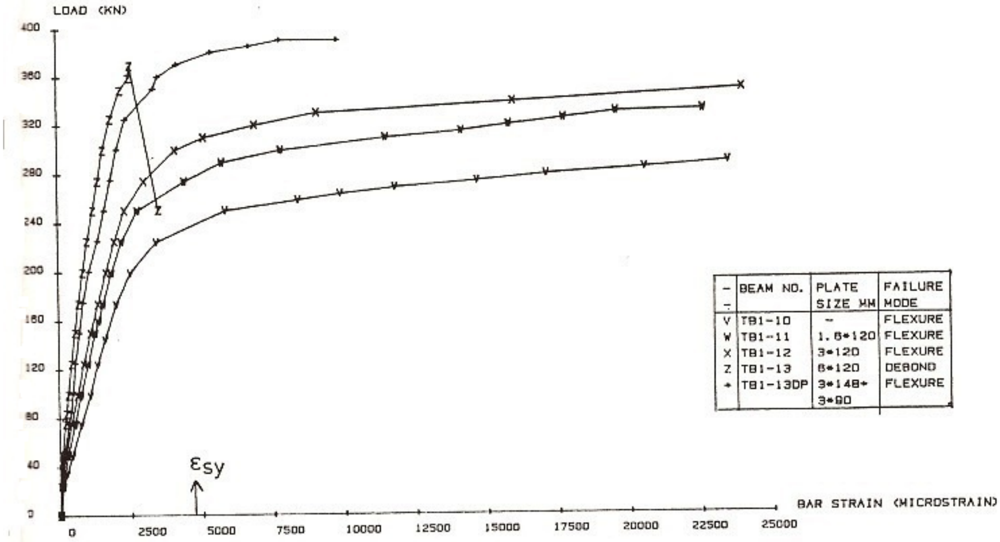


Figure-21: Load-Bar Strain Curves for T-Beams of Concrete Type M50

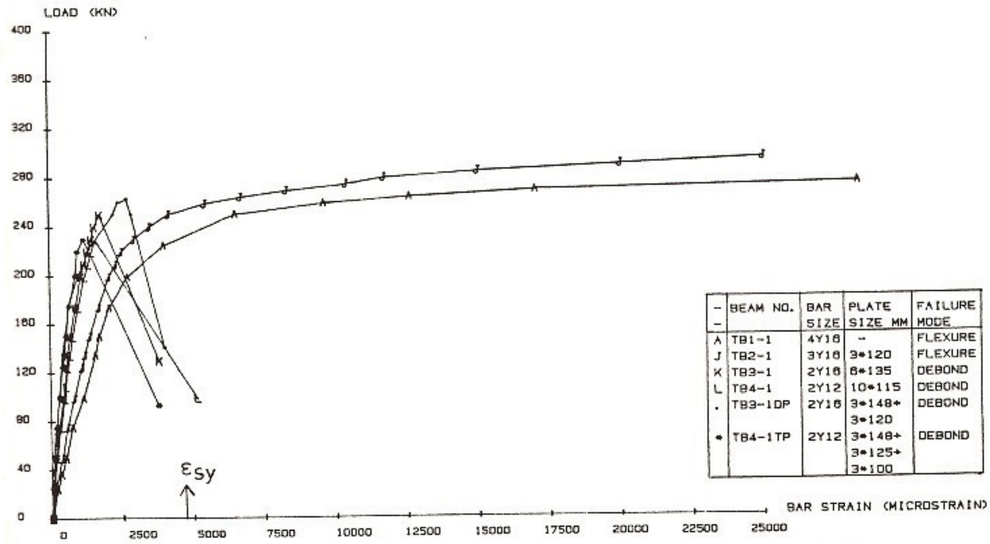


Figure-22: Load-Bar Strain Curves for T-Beams Their Mainreinforcement Partially Replaced by Plates

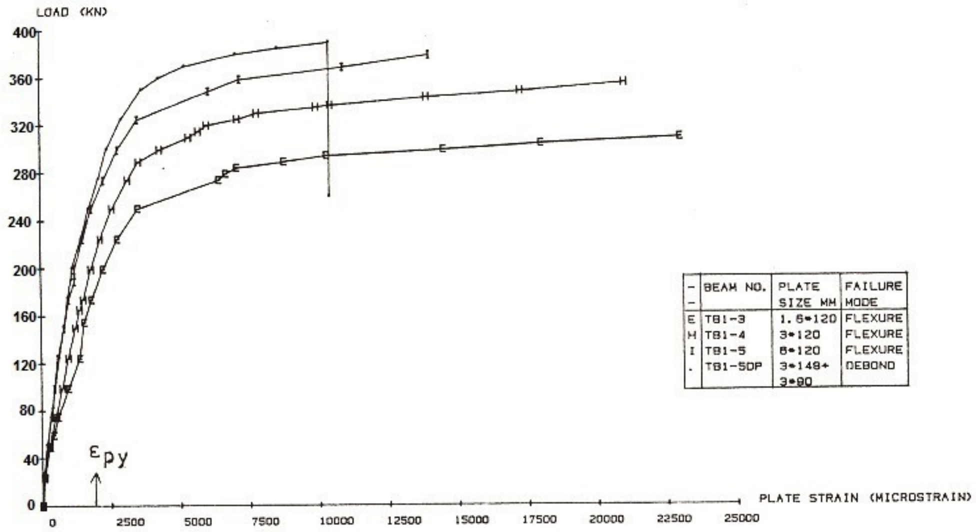


Figure-23: Load-Plate Strain Curves for T-Beams of Concrete Type M35

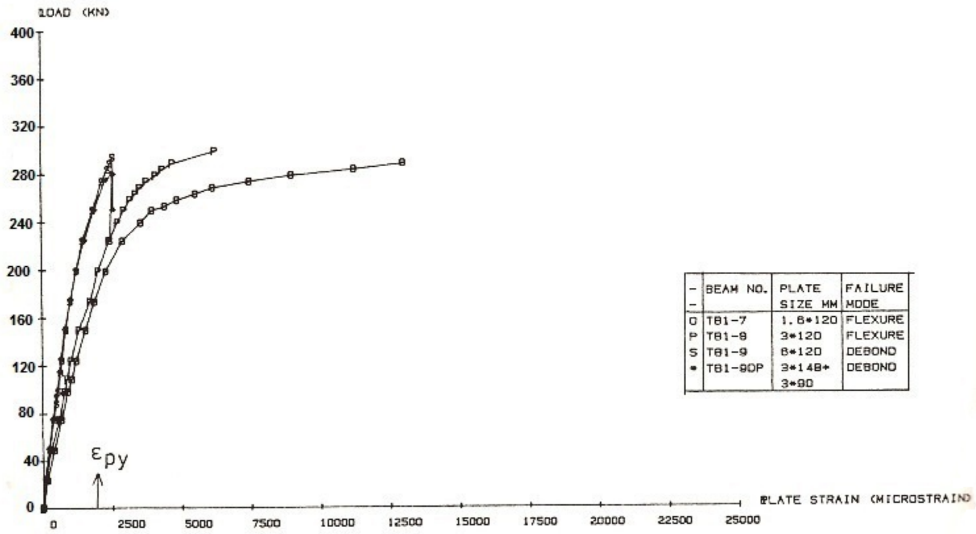


Figure-24: Load-Plate Strain Curves for T-Beams of Concrete Type M20

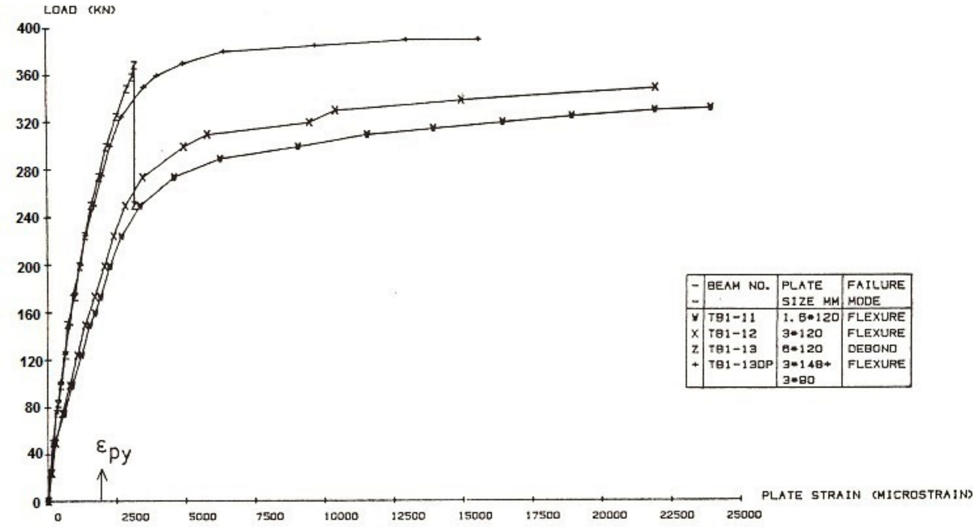


Figure-25: Load-Plate Strain Curves for T-Beams of Concrete Type M50

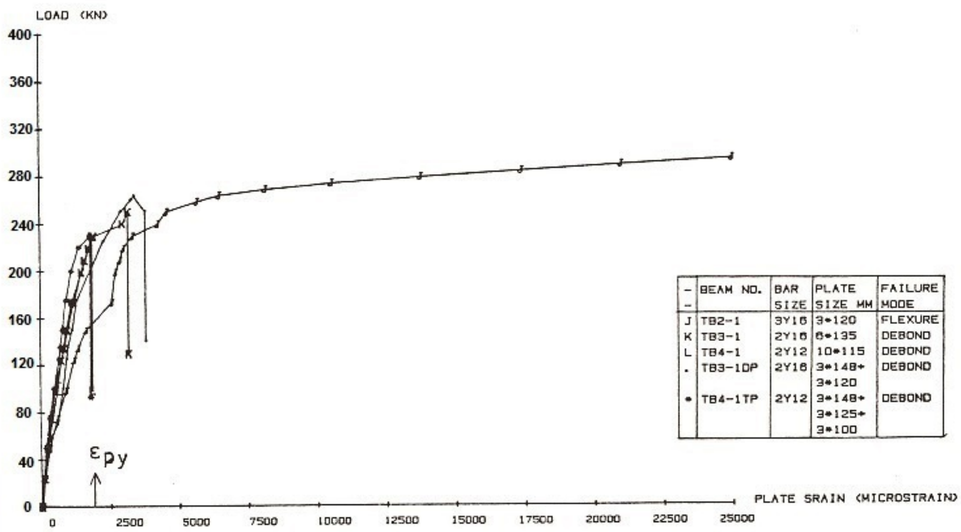


Figure-25: Load-Plate Strain Curves for T-Beams Their Mainreinforcement Partialy Replaced by Plates

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