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EXPERIMENTAL STUDY ON BEHAVIOUR OF REINFORCED CONCRETE (RC) BEAMS WITH MECHANICAL SPLICES AS A REPLACEMENT OF LAP SPLICES FOR REINFORCEMENT STEEL

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Abstract: - The reinforced concrete is widely utilized in civil engineering industry globally. Construction of reinforced concrete (RC) structures are mainly required the use of concrete and reinforcement steel (rebar) to resist compression and tension respectively. Rebars are limited to Stock length and this limitation make it impossible to provide full length continuous bars in most RC structures. Therefor splicing of rebars become essential and which is done by various methods like lap splicing, weld splicing and mechanical splicing. Lap splicing has become the traditional method of connecting the rebars. Mechanical splices are commonly used to connecting two steel reinforcing bars. This paper represents the use of "Mechanical Coupler" splicing in HYSD (Fe-500) rebars with various splice specimens for UTM tensile test on each specimen and observed its strength and type of failure. This paper presents experimental test results of RC beams with Mechanical Splices and Lap Splices with Compare to Control Beams without any splices. The experimental tests so the effectiveness of mechanical splices over conventional splices like lap splice

Keywords: Lap splices, Mechanical splices, Reinforcement coupler, Reinforcement concrete, RC Beam test, tensile test.

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INTRODUCTION

Length of the reinforcing bar is limited by fabricating, transporting or storage capacity and normally supplied in standard stock length up to 12 m – 18 m. As a result, the length of steel bars could not ensure the integrity of throughout any sizeable structures. Therefore, splicing reinforcing bars is unavoidable. Fundamentally, splicing of any reinforcement steel bars done by mainly following four types of splice: lap splice, mechanical splice, welded splice and gas pressure welding splice (Figure 1).

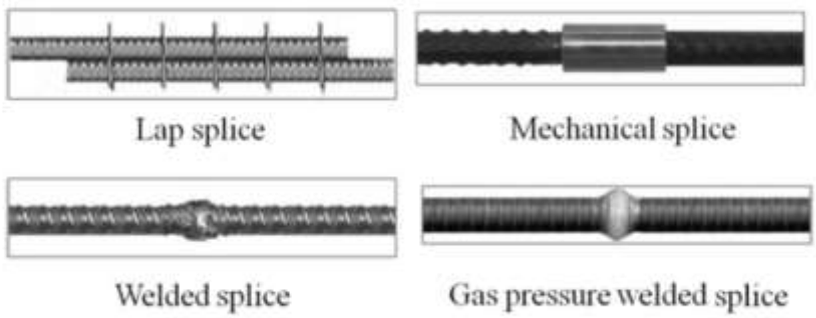

Figure 1: Splice of reinfocing bars

Among these four types of splice, Lap splicing one of the method which usually use for splicing in construction so that it is traditional way of connecting two steel reinforcing bars. Lap splice and welded splices have various imperfections such as poor quality of welds, increased labour cost, requires skilled labour inadequate length of laps, failure at joints, etc. In most of the RC structures, some reinforcement bars must be spliced. The required length of bars may be longer than the standard length of bars. Lapped joints are not an appropriate means of connecting reinforcement bars always. The utilization of lap splicing needs extra steel in terms of installation and design. Lapped joints are not that effective mean of splicing since it has various disadvantages such as greater congestion, time consuming and also lap splices are not considered reliable under cyclic loading and they are not effective for larger spans and have many “hidden” costs and it does not provide load path continuity, independent of the condition of concrete. Mechanical splices i.e. the coupler system is used to connect two bars in field quickly and easily. Hence mechanical splices such as threaded couplers can be very effective since they ease the design parameters, easy in installation and also reduce the amount of reinforcement required.

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Mechanical couplers are used for connecting HYSD bars. Generally, couplers are manufactured from mild steel, but in some cases alloys of different metals can also be used. Like EN8D material is used for making couplers having high carbon contents and high strength. The material should be such that couplers meet the minimum strength requirement (125% of yield strength of rebar). A very important aspect of coupler selection is selection of material and specification. Every manufacturer gives his own specifications regarding coupler selection. [12]. Broadly, Mechanical couplers can be classified in the following two main categories threaded and non-threaded couplers. Threaded couplers are sub-categorized into taper and parallel threaded couplers [11]. As per IS-16172:2014 (Annex-A Pg. no.4) Different Mechanical Splicing Systems based on: Threaded Coupler and Coupling Sleeve. Threaded Couplers: Tapered Threaded, Parallel Threaded & Upset Parallel Threaded Couplers [10].

Mechanical splices are commonly used in reinforced concrete structures. According to an ACI 439.3R-07, there are four basic categories of mechanical splices: compression-only mechanical splices; tension-compression mechanical splices; dowel bar mechanical splices; and mechanical lap splices. Of these, tension-compression mechanical splices are the most popular because they resist both tensile and compressive forces. In this paper, a thread coupler utilized, which fall into the tension-compression category. The behaviour of the RC structure is examined by carrying out tensile tests of the mechanical splice (tarped thread couplers) along with various splices itself and loading tests on RC beams along with Mechanical splices, Lap splices and no splices proved.

Experimental Program

First, the characteristics of various splices with same bar of 1 m length was clarified by carrying out tensile tests. Next, RC beams constructed with mechanical splices and lap splices; along with no splices beams were prepared and tested under monolithic loading. Mechanical Splices and Lap Splices were proved in these beam specimens. The results obtained from these tests include load-displacement curves, ductility, crack width, crack pattern, and beam failure mode.

The materials, test setup, and instrumentation used for both tensile tests and beams tests are described in the following

Materials

The standard HYSD (Fe-500) steel bar used in the tests was D-10 bar (HYSD bar with a diameter of 10 mm) with ribs. The yield and ultimate strength of the bar were 500 N/mm^2 and 545 N/mm^2, respectively.

Mechanical splices were assembled using a coupler with tarped thread similar in rebars tarped thread, allowing the two steel bars to be inserted mechanically. The dimensions of the coupler are 9 mm inner diameter, 20 mm outer diameter and 40 mm length of coupler. The couplers were made of mild steel.

The grade of concrete mix was M:25. Concrete was made with 53 grade of OPC cement with sand and 20 mm coarse aggregate.

Tensile Tests

Total 12 different specimens of 10 mm were subjected to tensile tests; the four types of specimen prepared and each splice type consist three specimens. Four types of specimens: Without splices, lapped splices, mechanical splices and welded splices. Tensile load was applied monotonically by a universal testing machine (UTM capacity = 600 kN) until the steel bar ruptured or slipped out of the coupler. Steel bar and coupler strains were measured using strain gauges. Elongation between two points measured by manually and extensometer is also used. Details of the tensile test of all specimens are Table 1.

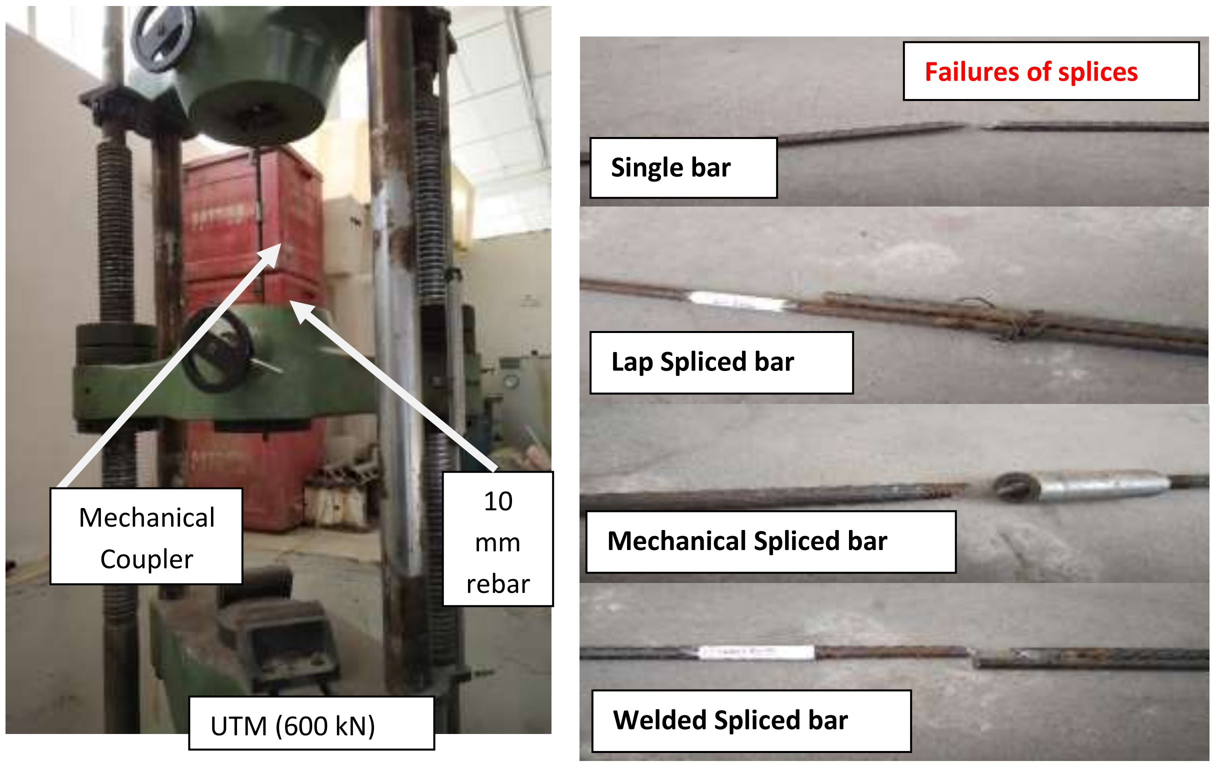

Figure 2: Tensile Test setup and test result failures of various spliced (#10) bars

Table 1: Tensile test results for 10 mm rebar with various splices

Specimens	**Normal Bars**			**Lapped Bars**			**Coupled Bars**			**Welded Bars**		
Identity of Specimens	10d-**A1**	10d-**A2**	10d-**A3**	10d-**B1**	10d-**B2**	10d-**B3**	10d-**C1**	10d-**C2**	10d-**C3**	10d-**D1**	10d-**D2**	10d-**D3**
Nominal Diameter (mm)	10	10	10	10	10	10	10	10	10	10	10	10
Average Effective Cross-Sectional Area of test Specimen (mm^2)	78.5	78.5	78.5	78.5	78.5	78.5	78.5	78.5	78.5	78.5	78.5	78.5

Unit weight per meter (kg/m)	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Gauge Length (mm)	50	50	50	50	50	50	50	50	50	50	50	50
Yield Stress Obtained (N/mm^2)	502	526	542	19	13	16	568	542	602	556	529	539
Yield Stress as per IS 1786: 2008 (N/mm^2)	> 500											
Average of Yield Stress (N/mm^2)	524			16			570			542		
Ultimate Stress Obtained (N/mm^2)	553	613	596	59	59	58	679	606	675	673	593	586
Ultimate Stress as per IS 1786: 2008 (N/mm^2)	> 545											
Average of Yield Stress (N/mm^2)	588			59			654			618		
Percentage Elongation (%)	10	15	16	20	20	20	0	0	0	44	40	20

Beam Tests Setup

To clarify the influence of mechanical splices along with lap splices and no splices in RC members, 9 RC beams specimens were prepared, cast and then testing was carried out at, Government Engineering College, Modasa, Gujrat, INDIA.

All 9 RC beam specimens are divided into three types of groups along with Type-A: No splices used, Type-B: Lap splices used and Type-C: Mechanical splices used. So, that each three types of specimens have three beams. All beams were 1500 mm (1.5 m or 5 ft) in length with a span of 1200 mm (1.2 m or 4 ft) and a rectangular cross section of 200 mm x 230 mm (0.20 m x 0.23 m or 8 in. x 9 in.). Figure 2 gives details of the test beam dimensions and the test setup. For all beam specimens, four longitudinal 10 mm HYSD (Fe-500) steel rebars were used (two bars at top and two bars bottom) and 8 mm HYSD (Fe-500) steel rebars were used as the stirrups at 100 mm (0.10 m or 4 in.) c/c spacing. In Type-A group, all three specimens A1, A2 and A3 are design without use of splices. In Type-B group, all three specimens B1, B2 and B3 are design with use of lap splices at mid location of beam in two bottom bars only. Similarly, In Type-C group, all three specimens C1, C2 and C3 are design with use of mechanical splices at mid location of beam in two bottom bars only.

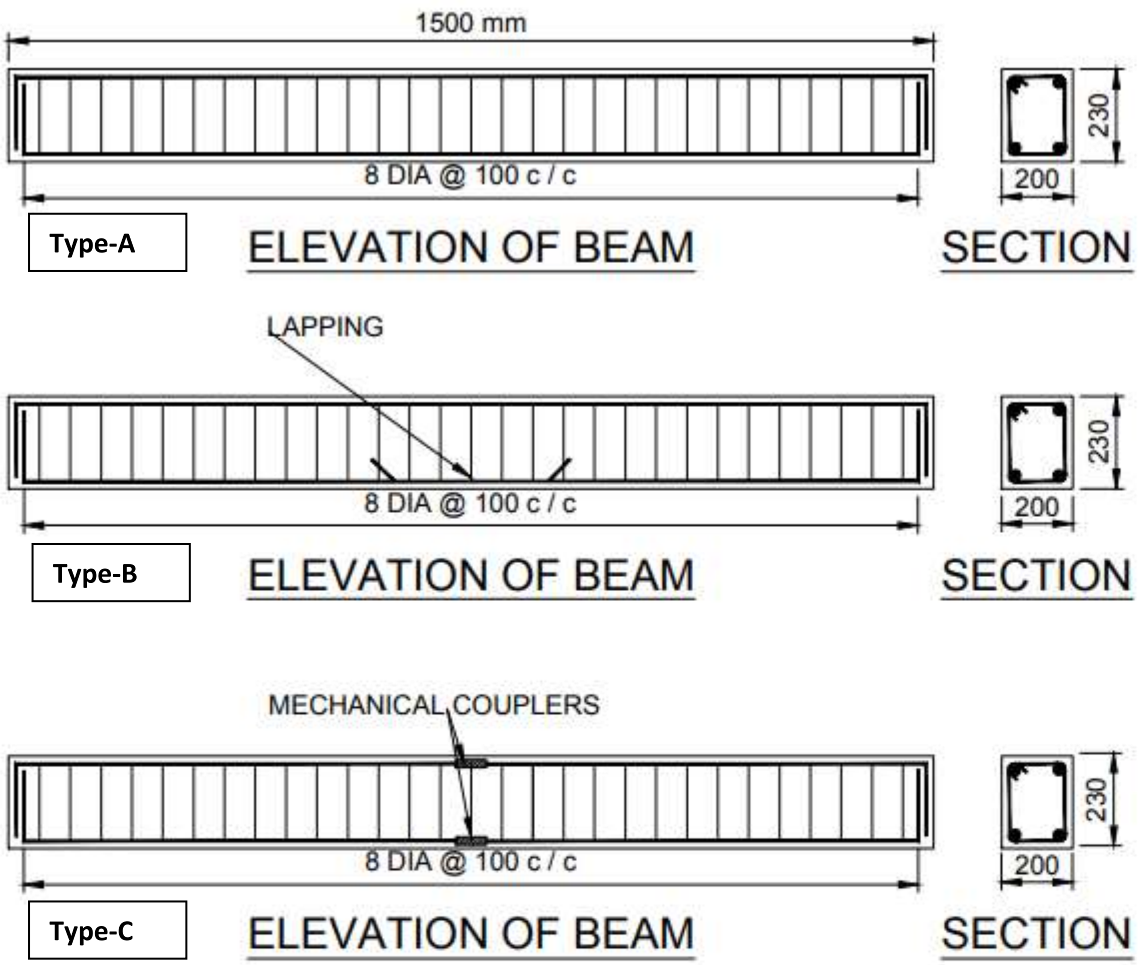

Figure 3: Various type of Specimens

All beams were subjected to monolithic loading, by using of 25-ton (250 kN) capacity hydraulic jacks. The specimen was oriented as described below, and then tested until failure by displacement control. The beam testing setup is shown in Fig. 10. The beams were kept horizontal and both ends of the RC beams were simply supported at heights of 450 mm (0.45 m or 1.5 ft) form the finish floor level. To facilitate the application of monolithic load on top side of the RC beam, the hydraulic jacks were connected to the strong steel frame with mechanical fasteners and the RC beam was loaded as shown in the figure 2.

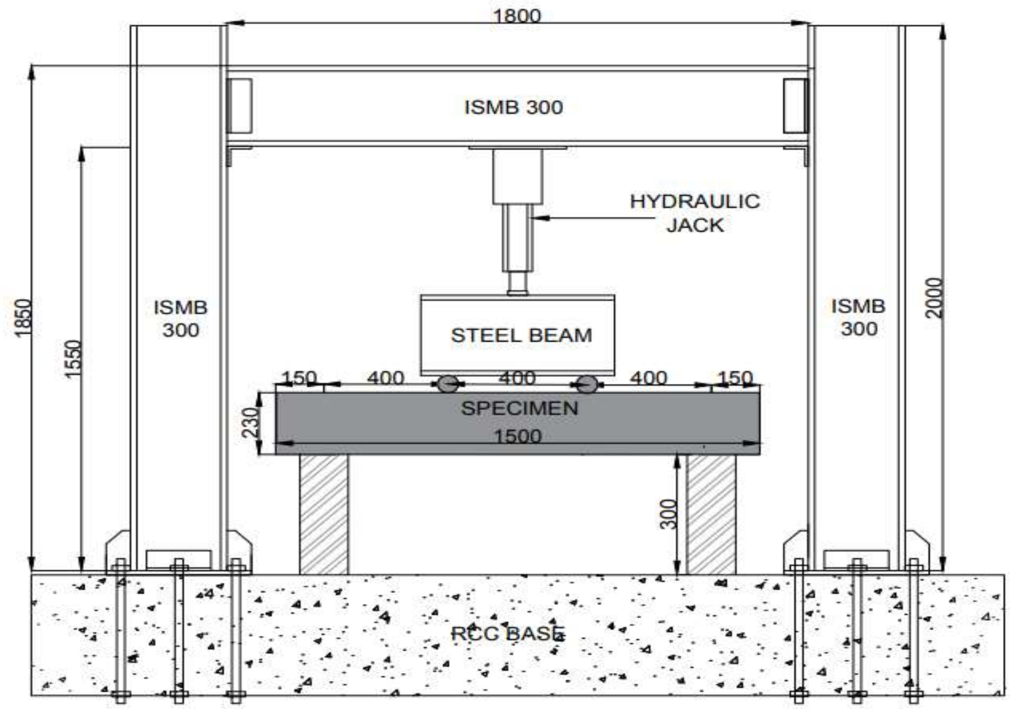

Figure 4: Schematic diagram of Test Setup

Figure 5: Filed arrangement of test setup

Obtained Result

In this test, Obtained following results: Yield load and yield displacement; Ultimate load and ultimate displacement; Ductility index and Stiffness. Table 2 shows the beam test results.

Table 2 Beam test results of Specimens

(Yield load & displacement, Ultimate load & displacement, Ductility and Stiffness)

Specimen Type	Beams	Yield Load in kN (P_y)	Yield displacement in mm (Δy)	Ultimate load in kN (P_u)	Ultimate displacement in mm (Δu)	Displacement Ductility Factor or index μ=Δu/Δy	Stiffness kN/mm $k=P_u/\Delta y$
Type A (No Splices)	A1	102.44	10.15	139.63	30.00	2.96	13.76
	A2	100.11	10.40	141.49	32.00	3.08	13.60
	A3	97.74	10.20	140.56	28.00	2.75	13.78
Type B (Lap Splices)	B1	89.36	11.30	133.11	24.00	2.12	11.78
	B2	84.71	10.85	120.08	19.00	1.75	11.07
	B3	92.15	9.00	137.77	25.00	2.78	15.31
Type C (Mechanical Splices)	C1	100.53	9.15	144.28	15.00	1.64	15.77
	C2	94.02	10.20	152.66	18.00	1.76	14.97
	C3	103.33	10.25	148.55	20.00	1.95	14.49

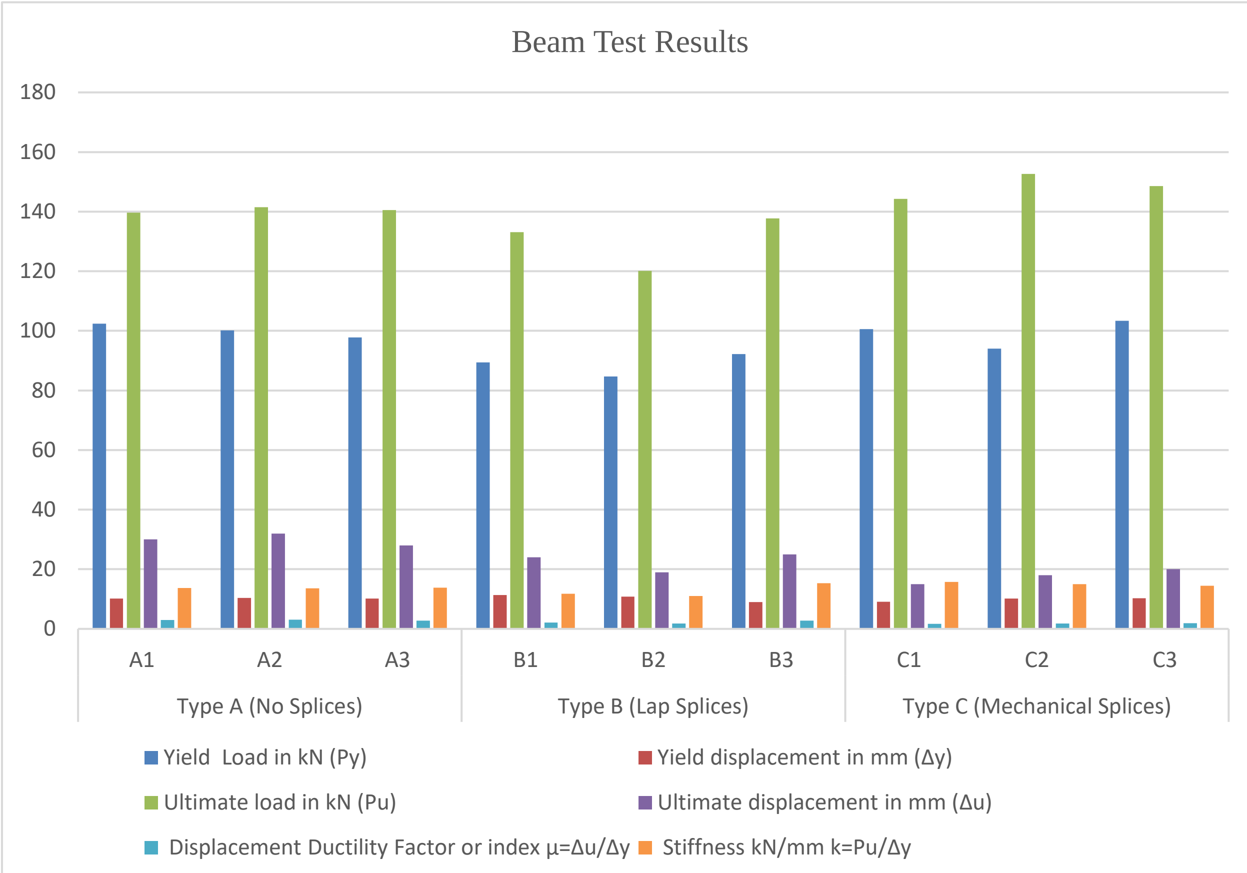

Figure 6: Observed results of Beam tests

(Yield load & displacement, Ultimate load & displacement, Ductility and Stiffness)

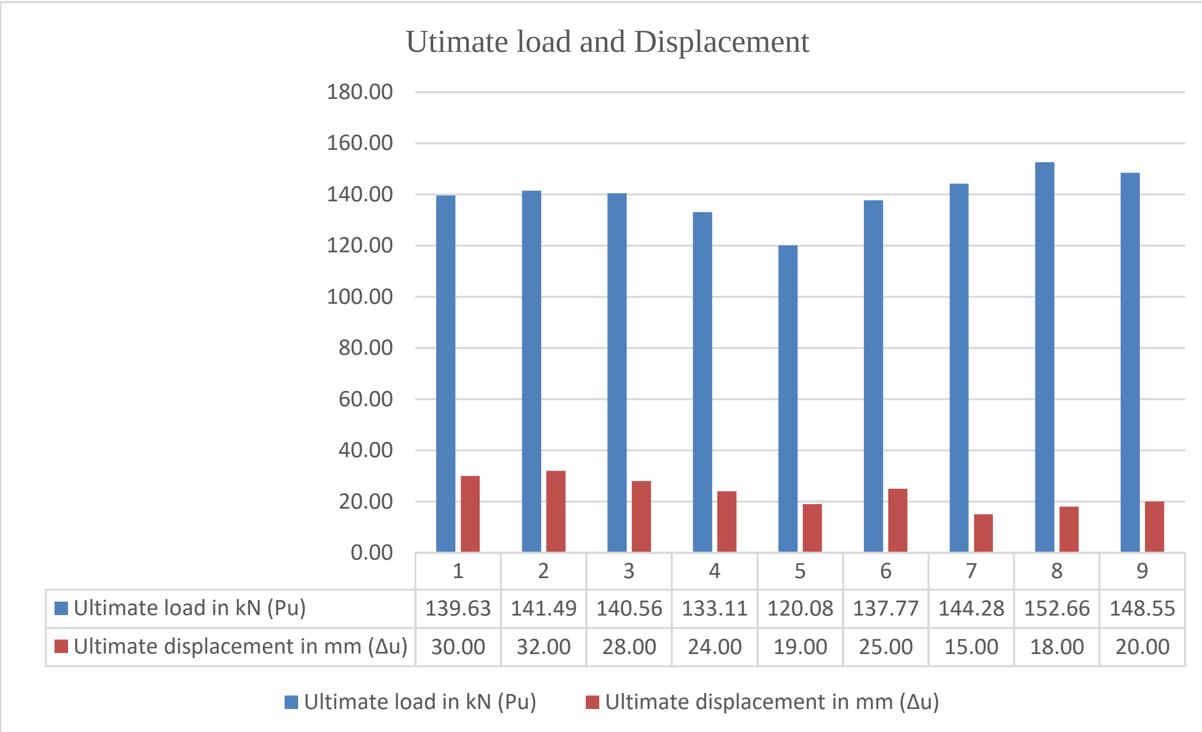

Figure 7: Load vs Displacement

Crack Pattern Study

The tested beam details of specimens A1, B1 and C1 are shown in Figure 8, respectively. Developed crack can be seen from Figure 6.1, all cracks have developed on the beam in all the specimens where the two points loads apply was formed at the top of the middle portion beams. Further, vertical or diagonal cracks have developed in the beam side area of the specimens. In the A1 specimen, vertical three cracks are developed one crack at mid of beam and two cracks at load applied. In the B1 specimen, two diagonal cracks are developed at near to loading point and lapping area. In the C1 specimen, only one vertical crack occurred and located at mid of beam where mechanical couplers provided. In Group-I, the specimen with mechanical splices (C1) shows the lesser cracks and much better control of crack capacity than the other specimens. So that, A1 and C1 are fails in Flexural failures and B1 fails in shear failures.

(A1) (B1) (C1)

Figure 8: Crack pattern of Group-1 (A1, B1, & C1)

The tested beam details of specimens A2, B2 and C2 are shown in Figure 9, respectively. Similarly, vertical or diagonal cracks have developed in the beam side area of the specimens. In the A2 specimen, three minor vertical but open cracks are developed one crack at mid of beam and two cracks at load applied. In the B2 specimen, two diagonal cracks are developed at near to loading point and lapping area. In the C2 specimen, only one vertical crack occurred and located at mid of beam where mechanical couplers provided. In Group-II, the specimen with mechanical splices (C2) shows the lesser cracks and much better control of crack capacity than the other specimens. Again, A2 and C2 are fails in Flexural failures and B2 fails in shear failures.

(A2) (B2) (C2)

Figure 9: Crack pattern of Group-2 (A2, B2, & C2)

The tested beam details of specimens A3, B3 and C3 are shown in Figure 10. Similarly, vertical or diagonal cracks have developed in the beam side area of the specimens. In the A3 specimen, three major vertical cracks are developed one crack at mid of beam and two cracks at load applied. In the B3 specimen, two diagonal cracks are developed at near to loading point and lapping area, in which one is Mainor and other two is major open-wide cracks. In the C3 specimen, only one vertical crack occurred and located at mid of beam where mechanical couplers provided. In Group-III, the specimen with mechanical splices (C3) shows the lesser cracks and much better control of crack capacity than the other specimens. So that, A3 and C3 are fails in Flexural failures and B3 fails in shear failures.

(A3) (B3) (C3)

Figure 10: Crack pattern of Group-3 (A3, B3, & C3)

In this performance study towards cracks of all these specimens, the specimen C1 shows an excellent performance with few flexural cracks only at mid one. In all above groups, the A1, A2 and A3 specimens have no splices in bars are gives crack controls which act as control beam specimen which standard beams to compere the other specimens for it failures and crack analysis. B1, B2 and B3 specimens have lap splices in bottom two bars only which means tension steel only spliced so that the developed share crack in this specimen is diagonal to shear ties or stirrups of beams at loading location are a tensile stress. The specimens C1, C2 and C3 with mechanical splices shows a lesser crack pattern than other specimens using conventional splices details in Group-I and II & III without losing the strength, however, specimen C1, C2 and C3 with mechanical couplers at mid of beams only for bottom tensile bars, shows lesser cracks and much better control of crack capacity than other specimens. So that mechanical splicing gives good flexural strength and much closer to Control beam which having no splices, along the lap splice specimens.

CONCLUSION

The experiment work of different splices is carried out by tensile test of rebars with various splices and after that experiment test of RC beam specimen along with no splices, lap splices and mechanical splices are performed. These are present in this paper. Based on the experiment test results following conclusion are coming out,

- Use of Mechanical splices give continues load path in reinforced concrete and form the tensile test mechanical coupler gives good tensile strength as compere to single normal rebar strength.

- Tensile strength of Lap splices, Mechanical splices and welded splices are 0.10, 1.11 and 1.05, respectively along with single rebars tensile strength. So that, lap splices having very low tensile strength and in the rebars are fails in slippage due to breakage of banding wire at very low load which used for lapping. So that, lap splices having very low load caring capacity.

- Welded spice gives much better preformation than lapping and normal bar but it is less strength compere to coupler splices.

- Mechanical splices provide good strength and reduced steel congestion in RC structures and reduce steel use which give economic benefits.

- Especially threaded mechanical couplers are globally available and easy installation to application than lapping or welding, because coupler is easy available form factory, treaded rebars prepared at site and after that is only requited to installation at application of construction with in sort time period.

- For the beam test results, average ultimate load for Type-A, B and C are 140.56, 130.32 and 148.50 kN, respectively. Which shows mechanical splice having good load carrying capacity and lapping having very low capacity. Along with Type-A control beam, 0.93 and 1.06 efficiency of B and C respectively.

- Ductility index or factor of Type-A control beam has very good, then comes the Type-B lapping beam. But Type-C mechanical coupler have very low ductility as compered to A and B. So, we can say that the mechanical coupler reduced ductility of RC structure and mechanical coupler having bed behaviour in RC structures.

- Type-B Lapped beam has very low stiffness and Type-A control beam has more stiffness then it. But Type-C mechanical spliced having much good stiffness then A and B. So that, Type-C are good in Stiffness.

- In Type-A, developed cracks are vertical and within the loading area. In which open and wide cracks occurs and fails in flexure. So, Type-A control beam flexural failure. In Type-B, developed cracks are diagonal and shear cracks. So, fails in shear (shear failure) This behaviour or failure is not good and fails the section.

- In Type-C, cracks are occurred fast then above types, at mid of beam. Cracks are only occurring at end of the coupler in all beams. So that mechanical spliced beams are given flexural failures. Behaviours of RC beams with Mechanical splices are good very good stiffer and much load carrying capacity. Therefor, mechanical splice is most suitable for replacement of lap splices in terms of structure integrity and continues load path.

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