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Effect of Mode of Continuity of Tension Reinforcement Bars on Flexural Strength of R.C. Beam

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Abstract **– The research investigation was carried out to determine the effect of different modes of continuity of tension reinforcement bars on the flexural strength of reinforced concrete beams. Nine (9) full size beams (2150 mm × 250 mm × 180 mm) were cast with 2 numbers of 16 mm diameter high yield bars in tension and 10 mm diameter high yield stirrups at 100 mm centres at the shear spans. Three (3) beams each were cast with full length bars (reference), lap-spliced bars and butt-welded reinforcement bars in tension. Twenty-seven (27) 150 mm cubes were also cast to monitor concrete strength. The beams and cubes were cured for twenty-eight (28) days and tested in flexure under four points bending system and in compression respectively. The test results showed that full length bars, lap-spliced and butt-welded bars had an average moment capacity of 25.54 kN·m, 19.16 kN·m and 10.64 kN·m respectively. Lap-spliced beam gave a higher moment of resistance compared to the beams with butt welded steel reinforcing bars. The average midspan deflection of butt welded reinforcement was smaller than that of in the beam with lap spliced type of continuity. It was concluded that continuity using lap spliced bars in tension is more effective and efficient than butt welded continuity. 58.34 %, 25.00 % of the moment capacity of beams with full length reinforcement was lost by using butt weld, without a coupler, and lap spliced bars, respectively.**

Keywords **– Butt welded, flexure, full length, lap-spliced, moment capacity.**

I. Introduction

Reinforced concrete is a composite material made of concrete and reinforcement. Concrete is strong in compression but very weak in tension hence the inclusion of steel reinforcement in tension zone. In bridge beam construction with reinforced concrete, the span of the bridge is sometimes between 20–25 m, but the standard length of high yield reinforcement is 12 m. The question of continuity of reinforcement then arose. Nine (9) full size beams (2150 mm × 250 mm × 180 mm) were cast in all, three (3) beams each with full length tension bars (reference), butt welded and lapped splice steel bars. Nine (9) 150 mm cubes were also cast to monitor the strength of the concrete (see Table V). Practical engineering questions regarding the best way of achieving continuity of the reinforcement bars and the reduction in strength due to continuity are what this paper was set out to answer. The investigation was therefore an attempt to find out the best and most efficient and effective way of achieving the continuity of the reinforcing bars. Two options, namely, lap-spliced and butt weld were compared with the reference option (with full bars).

Lap–splicing is a commonly accepted mode of achieving continuity with recommendations made in the code for compression and tension lap splicing for continuity. Another mode of achieving continuity of the reinforcement is by the use of a coupler, original coupler or the skill to use it is not readily available so full butt welding of the reinforcement is sometimes adopted. The two modes were compared with a reference mode, in which full bars were used to reinforce the beam.

Lap-splicing of the reinforcing bars tends to lead to congestion of reinforcement especially if the splicing of the reinforcing bars is at the same location. It is therefore recommended that the laps should be staggered and be away from the section of high stresses. The minimum lap length is recommended to be not less than the greater of 15 diameters or 300mm for bars depending on the grade of concrete and the type of reinforcement the ultimate bond length, anchorage bond length and lap length as a multiple of the bar size is given in [1].

For Butt welds in tension, the only acceptable form of full strength butt joint for a bar in tension is only by a mechanical coupler satisfying some specified conditions. These couplers are expensive and not easy to come by. The local benders, therefore, still indulge in using ordinary butt weld to achieve reinforcement continuity. This investigation would show an approximate percentage loss in strength or moment capacity if this (butt welding) method is adopted. It is desirable and worthwhile to know the effective continuity method of reinforcement in the tension zone of reinforced concrete beam and the approximate percentage loss in strength when either of the continuity method is used.

A. Significance of the Work

- An effective and efficient way of achieving continuity of reinforcement in RC beam was identified.
- Approximate, percentage loss in strength due to the use of lapped splice or butt weld in tension, in the absence of a coupler, was determined.

B. Review of Some Previous Works

Various investigations have been carried out on flexural strength of reinforced concrete beams some are reported herein. Twelve (12) RC beams made of phyllite coarse aggregate (a by-product of underground gold mining activity) were tested to failure under four points test to investigate their flexural behaviour. Collapse of the beams occurred mostly through either flexural shear failure and/or diagonal-tension failure. The failure loads averaged approximately 115 % of the theoretical failure loads. The study showed that the beams developed early shear cracks and higher flexural crack width than allowable at service loads [2]. The flexural strength of 12 beams with a mix ratio 1 : 1.5 : 3 and water cement ratio of 0.4 were cast and field cured for two days and tested at the curing age of 28 days. The study showed that excellent control of flexural strength specimen is required to prevent unwarranted variability in the test results [3]. Factors affecting flexural tensile strength of concrete were studied with different concrete mixes which were tested at 7, 28 and 56 days with the specimen under different confinement, and without manipulating conditions of concrete. The result showed that the flexural strength increases when the compressive strength and age of concrete increase and that increase in flexural strength is lower than the corresponding increase in the compressive strength at the same age of concrete [4].

Experimental research on the flexural and tensile properties of concrete using lateritic sand and quarry dust as fine aggregate was carried out. The proportion of lateritic sand varied from 0 % to 100 % against quarry dust at intervals of 25 %, using 1 : 1.5 : 3 concrete mix and water/cement ratio of 6.5. Concrete samples were prepared, cured for 28 days and tested to destruction in order to determine their flexural and tensile strength properties. The results showed that the flexural strength was 3.28 N/mm^2 for 50 % laterite: 50 % quarry dust and 2.88 N/mm^2 for 25 % laterite: 75 % quarry dust. Similarly, tensile strengths were 2.91 N/mm^2 for 50 % laterite: 50 % quarry dust and 1.67 N/mm^2 for 25 % laterite: 75 % quarry dust. These results show that both flexural and tensile strengths increase with the increase in laterite content [5]. Experimental test on the behaviour of twelve (12) concrete beams with lap spliced reinforcement in tension was carried out, the main parameters include: shape of transverse reinforcement in the splice zone, length of lap splices, and spacing. The results show that there was a reduction in ductility for the specimen with the same value of the lap splice length as was recommended in the Egyptian code, without the use of transverse reinforcement at the splice zone, the change of the cut off ratio from 25 % to 100 % resulted in a reduction in ductility, while there was a drastic increase in ductility when transverse reinforcement was used [6].

From the above said, it may be concluded that not much has been done to analyse the flexural strength of concrete beams with different modes of tension reinforcement continuity. The attempt to investigate and compare the flexural of RC beams with extended tensile reinforcement using lap spliced and butt welding is worthwhile and desirable.

II. Materials and Methodology

A. Materials and Sample Preparation

Sieve analysis was carried out on the fine and coarse aggregates used in the investigation, see Tables I and II, and Figure 1.

TABLE I

SIEVE ANALYSIS RESULTS FOR FINE AGGREGATE

Sieve mesh size, mm	Weight retained (W_1 in gram)	Percentage, % retained (W_2 in gram)	Percentage, % passing (W_3 in gram)
10.00	6.60	0.55	99.45
5.00	18.60	1.56	97.89
2.36	55.30	4.62	93.27
1.18	243.60	20.37	72.90
0.60	475.20	39.74	33.16
0.30	302.20	25.27	7.89
0.15	81.80	6.84	1.08
0.075	8.60	0.73	0.33
Dust	–	0.33	0.00

TABLE II

SIEVE ANALYSIS RESULTS FOR COARSE AGGREGATE

Sieve mesh size, mm	Weight retained (W_1 in gram)	Percentage, % retained (W_2 in gram)	Percentage, % passing (W_3 in gram)
25.00	0.0	0.00	100.00
19.00	72.7	1.47	98.53
14.00	113.8	2.30	96.23
10.00	1161.0	23.41	72.82
5.00	3150.2	63.93	9.29
2.36	104.7	6.15	3.14
1.18	125.4	3.14	0.00

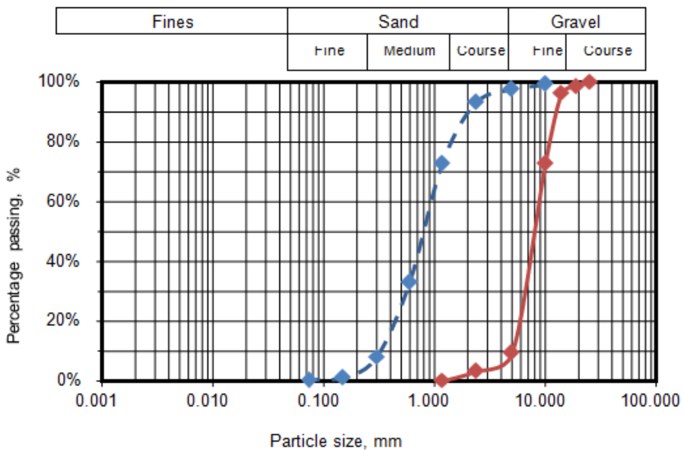

Fig. 1. Grain size analysis for fine and coarse aggregate.

The average yield strength was 398.4 N/mm^2 and 674 N/mm^2 for 16 mm and 10 mm respectively, (see Table III). The steel cage was made up of 2–16 mm and 10 mm diameter high yield steel bars as the main tension bars (lap spliced, and butt welded) at the midspan and stirrups at 100 mm centres in the shear spans to prevent shear failure of the beams, and two 10 mm in diameter bars as hangers. (see Figures 2 a, b and c).

TABLE III A

TENSILE TEST RESULTS

Bar size, mm	Yield				Ultimate				Elongation, %	Average elongation, %
	Load, kN	Average load, kN	Stress, N/mm²	Average stress, N/mm²	Load, kN	Average load, kN	Stress, N/mm²	Average stress, N/mm²		
Y10	40.50	47.38	590.54	674.34	57.46	63.56	731.59	809.31	20.75	17.30
	48.17		735.21		66.89		851.61		15.53	
	53.48		697.28		66.34		844.72		15.63	
Y16	101.39	106.26	405.33	398.38	118.31	116.98	588.40	581.82	29.71	31.63
	109.30		407.74		119.37		593.70		33.93	
	108.09		382.08		113.27		563.37		31.26	

TABLE III B

CONFIRMATORY TENSILE TEST RESULTS

Bar Type (16 mm)	Yield				Ultimate				Elongation, %	Average elongation, %
	Load, kN	Average load, kN	Stress, N/mm²	Average stress, N/mm²	Load, kN	Average load, kN	Stress, N/mm²	Average stress, N/mm²		
Full length	91.72	91.48	456.18	454.96	103.50	102.52	514.77	509.87	18.0	16.0
	91.23		453.74		101.53		504.97		14.0	
Butt welded	–	–	–	–	25.02	22.32	124.44	111.01	2.5	2.5
	–		–		19.62		97.58		2.5	

TABLE IV

CONCRETE TRIAL MIX RESULTS

Mix ratio	7 days			14 days			28 days		
	Weight, kg	Strength, N/mm²	Average strength, N/mm²	Weight, kg	Strength, N/mm²	Average strength, N/mm²	Weight, kg	Strength, N/mm²	Average strength, N/mm²
1 : 1.5 : 3	8.13	28.89	23.78	8.80	28.56	27.41	8.46	30.67	30.14
	8.02	23.33		8.63	26.56		8.72	28.58	
	8.26	19.11		8.47	27.11		8.61	31.16	
1 : 2 : 4	8.05	22.22	21.48	8.68	24.11	24.64	8.52	25.78	26.44
	8.32	23.33		8.45	26.22		8.64	27.11	
	8.10	18.89		8.48	23.89		8.30	26.44	

Trial mixes were prepared to achieve the targeted cube strength of 25 N/mm^2, Table IV. The concrete used for the investigation was mixed in ratio 1 : 2 : 4 (cement, sand and granite) with water cement ratio of 0.55 and batching was done by weight. The constituents were thoroughly mixed and poured into steel moulds and vibrated with poker vibrator. The concrete was allowed to set and labelled. The 2150 mm × 250 mm × 180 mm beams were demoulded after 24 hours and cured for 28 days wetting with water. Twenty-seven (27) 150 mm cubes were cast to monitor the strength of the concrete. The cube strength of concrete used for the investigation is given in Table V.

TABLE V

BEAM TEST RESULTS

Beam ID	Type of continuity	f_{cu}, N/mm^2	Failure load Q, kN	Moment capacity, kN·m	Average failure load, kN	Average moment capacity, kN·m	Deflection at mid-span, mm	Average deflection at mid-span, mm	Mode of failure	Crack pattern
AF1	FL	25.44	78.45	25.50			7.85			
AF2	FL	25.59	78.45	25.50	78.45	25.50	8.98	8.47	Flexure	Vertical cracks
AF3	FL	25.40	78.45	25.50			8.58			
BL1	LS	25.48	53.94	17.53			5.96			
BL2	LS	25.40	68.65	22.31	58.84	19.12	6.90	6.30	Flexure	Vertical/ lateral cracks
BL3	LS	25.54	53.94	17.53			5.90			
CB1	BW	25.50	39.23	12.75			3.92			
CB2	BW	25.30	29.42	9.56	32.69	10.62	2.51	2.93	Flexure	Vertical/ lateral cracks
CB3	BW	25.74	29.42	9.56			2.36			
Note: FL - Full length, LS – Lapped splice, BW - Butt weld AF1 – Series A, Full length, Specimen 1, 2 and 3										

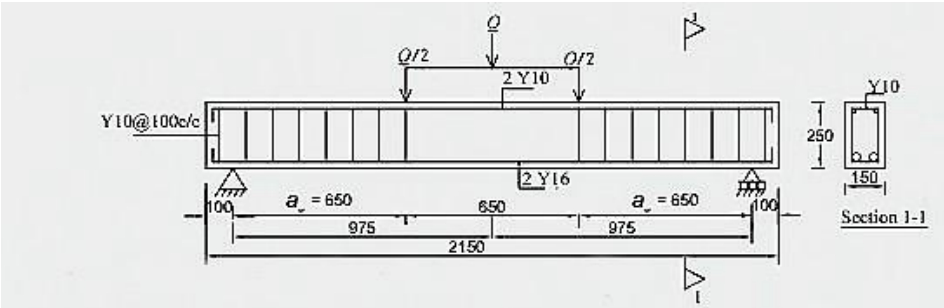

Fig. 2a. Showing RC beam loading with full length reinforcement bar.

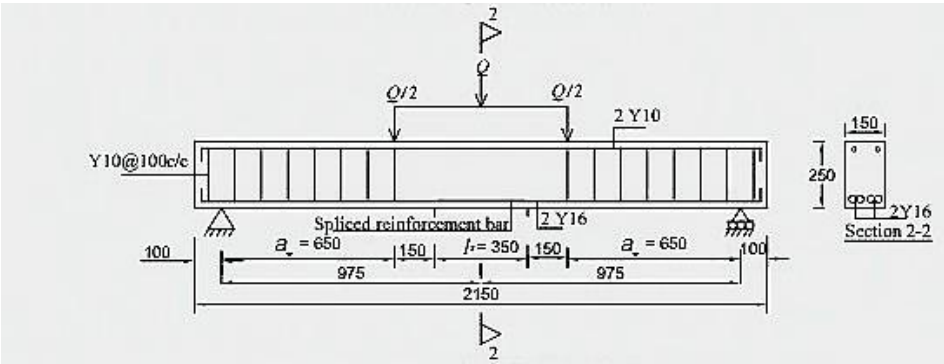

Fig. 2b. Showing RC beam loading with spliced length reinforcement bar.

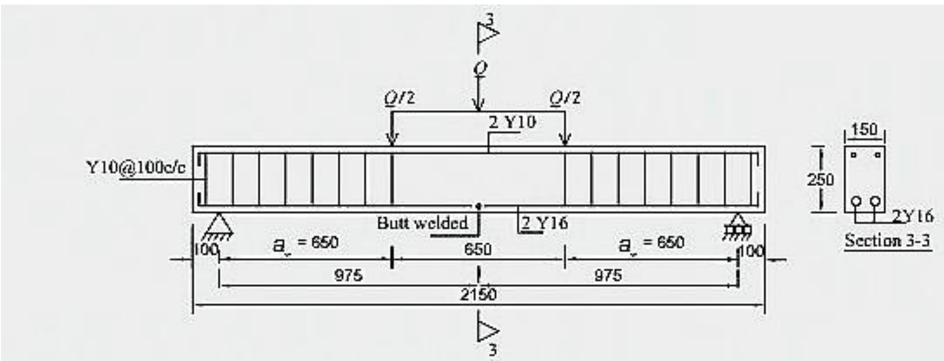

Fig. 2c. Showing RC beam loading with butt welded joint.

Note: All dimensions are in mm.

B. Beam Design

Lapped bars in contact and spaced apart have been reported to be satisfactory. In this investigation, the contact arrangement was adopted because this is the most probable on construction site. The loading points were 150mm from the lap ends thereby making the distance between the point loads to be l_s + 300 mm, where l_s = spliced length. The ultimate anchorage bond length recommended in [1] was used.

$$l_s = \frac{0.95 f_y \emptyset}{4\beta\sqrt{f_{cu}}}, \tag{1}$$

where: Coefficient depending on the ratio, h/b. β = 0.5,
Tensile Strength of reinforcement f_y = 460 N/mm^2,
f_{cu} = Compressive Strength.

Failure mode in flexure is strongly dependent on the shear span / effective depth ratio (a_v/d). Based on reported experimental studies [7] the failure pattern is given as:

$$6 > \frac{a_v}{d} > 2.5, \text{ Flexural failure.} \tag{2}$$

The $\frac{a_v}{d}$ was chosen to ensure flexural failure $\frac{a_v}{d}$ = 3, hence shear span, $a_v = 3d$.

III. Testing Procedure

The beams were tested in a four-point loading system under steel test frame with 69 N/mm^2 hydraulic jack. The beams were carefully centered under the steel frame and the hydraulic jack was centered on the secondary steel joist touching the frame. The dial gauge was positioned at the midspan soffit of the beam to take the deflection reading, and load was applied manually by pumping of the hydraulic jack until the failure of the beam, see Figure 3. The failure load, mode and crack patterns were noted. The cubes were weighed and tested in the 1560 kN capacity Budenberg compression testing machine. The failure loads were noted and used in calculating the compressive strength of the concrete and the maximum bending moments. The test results are shown in Table V.

Fig. 3. The test set up.

IV. Discussion of Test Results

Trial mixes were prepared with 1 : 1.5 : 3 and 1 : 2 : 4 mix ratios and the cube strengths were determined after crushing at 7, 14, and 28 days. The results are shown in Table IV, 1 : 1.5 : 3 gave 23.78 N/mm^2, 27.41 N/mm^2 and 30.14 N/mm^2, respectively, at 7, 14 and 28 days while 1 : 2 : 4 mixes gave a compressive strength of 21.48 N/mm^2, 24.64 N/mm^2 and 26.44 N/mm^2. Since the targeted compressive strength is 25 N/mm^2, the 1 : 2: 4 mixes with water cement ratio of 0.55 was adopted for the investigation.

Flexural strength is described as the tensile strength in bending; it is the modulus of rupture, a property of the structural member that indicates its ability to resist failure in bending. Flexural strength is expressed in terms of M/bd^2, as bd^2 is the same for all the beams tested, flexural strength is regarded as the bending moment at failure in this investigation. As follows from the above, the mode of continuity would affect the strength as it is well known that concrete is weak in tension, the reinforcement that is placed at the tensile zone (type, diameter, number and mode of its continuity) would determine the moment capacity hence the flexural strength of the beam.

The width and depth of the beam were made 180 mm and 250 mm, respectively. The length of the beam is a function of the lap length and the shear span.

$$L = l_s + 300 \text{ mm} + 2a_v + 200 \text{ mm} = 2150 \text{ mm}.$$

All the beams were cast with 2 numbers of 16 mm diameter high yield bars in the tension zone and 2–10 mm diameter bars as hangers in the compression zone of the beam with 10 mm diameter bars at 100 mm centres as shear reinforcement, at the shear span, to prevent shear failure. Three beams each were cast with full size bars, lap spliced bars and butt welded joint at midspan. The lap spliced bars were at the same location at the middle third span where the moment is constant.

The main bars for the butt-welded beam were cut at the same point (middle). After cutting, the bars were tacked head to head before full welding with 300 A / 32 V AC welding machine (Power Flex Welding machine) with gauge 10 electrodes. The joint was smoothened using metal grinding machine.

Tensile test was carried out on 10 mm and 16 mm diameter bars, the results of the test are given in Table III, the bars had an average yield stress of 809.3 N/mm^2, and 581.8 N/mm^2. Three beams were cast for each type of continuity and the average values of the failure load, moments and deflection were used in the comparison. The average values of the loads were 78.45 kN, 58.84 kN, and 32.69 kN, respectively, for beams with full length reinforcement, lapped splice and butt-welded beams. The average moment capacities of the beams were 25.54 kN·m, 19.16 kN·m and 10.64 kN·m, respectively, while the average maximum deflections were 8.47 mm, 6.30 mm and 2.93 mm (see Table V, Figures 4 and 5). The failure load and moment capacity were highest in the beams with full length bars because the stresses were fully transferred from the concrete to the steel reinforcement, while beams with lapped splice may not have been fully transferred because of the splicing length. Butt welded continuity has the least value for many possible reasons; the weld may not be full, the strength of the weld may not have been equal to the strength of the parent metal, welding requires a lot of skills and patience. It is no wonder the code recommends the use of couplers, which are unfortunately not used on many construction sites. The percentage loss in moment capacity (strength) was 58.34 % and 25 % for butt welded continuity and lap spliced reinforcement respectively. This is to say that where ever possible full-length bars should be used, and that when lapping is used it should be staggered to reduce the loss in capacity.

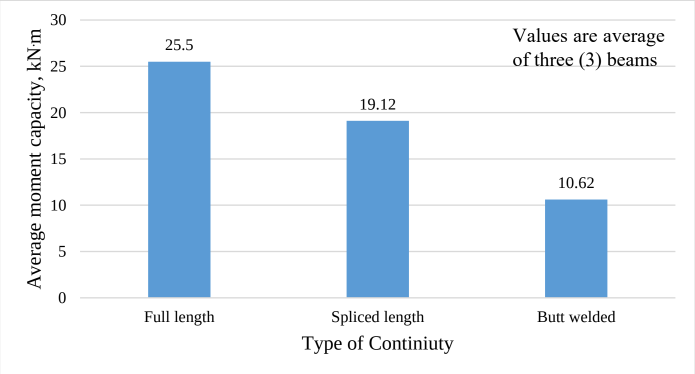

Fig. 4. Average moment capacity.

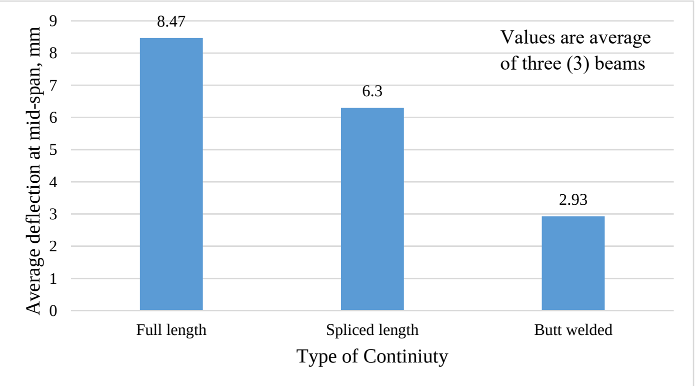

Fig. 5. Average maximum deflection at midspan (mm).

The tension properties of butt welded steel reinforcement were not tested during the investigation because it was obvious that the yield strength and elongation would be lesser than that of the full bar. However, a confirmatory test was later conducted on four (4) samples of 16 mm diameter high yield bars with two bars each with butt welded reinforcement and full-length bars. The results are shown in Table III b. The butt-welded reinforcement had no yield value as the load gauge did not read, while the yield stress for full length bars was 454.96 N/mm^2. The average ultimate stresses of butt welded, and full-length bars were 111.01 N/mm^2 and 509.87 N/mm^2, respectively. This is 78.2 % lower than the ultimate stress of full specimen. The average elongation was 2.5 % for butt welded bars compared to 16 % in full length bars. This is 84.4 % reduction in elongation. This is likely not to be unconnected with the deficiencies associated with butt welding which were mentioned above. The point of weld (middle of the tested length) appeared to be the weak zone, as the test samples actually break without necking at the weld point. The small elongation before the final failure may explain why the deflection was small in beams with butt welded reinforcement as compared to beams with full bars or with lapped splice.

Reduction in deflection of beam with butt welded reinforcement and lapped spliced bars were 5.54 % and 2.17 %, respectively, as compared to beams with full length reinforcement bars. While the reduction in deflection of beams with butt welded reinforcement when compared to beam with lapped splice bars was 3.37 %.

The deflection in beams with butt welded reinforcement was the least before failure probably because the butt-welded point was at the same location (centre) for the two main reinforcements. The loading arrangement may also have contributed to the low deflection. Again, the effect of the strength of the fusion material not being equal to the strength of the main bars, the welding may not have been full. Beams with lapped splice deflected more before failure because the length of the splice satisfied the minimum tension lap length, the stresses may have been fully transferred. Beams with full length bars were used as reference; the maximum midspan deflection was highest because there was no discontinuity of the main reinforcing bars.

The cracked pattern was summarised in Table V. Beams with full length of tension reinforcement had vertical cracks which commenced at the tension fibre and projected towards the compression fibre before failure. Lapped spliced beam had initial cracks about the lap ends (loading points) followed by longitudinal cracks along the spliced length. Cracks in beams with butt welded reinforcements were similar to that of the referenced beams but the number of cracks was not as many, all the beams recorded flexural failure.

V. Conclusion

Based on the test results and the analysis carried out the following conclusions can be drawn:

i. The failure load and moment capacity of beams with lap spliced tension reinforcement were higher than beams with butt welded tension steel rods. This is likely due to imperfections that are likely associated with butt welding and the strength of the weld.

ii. Beams with tension lapped splice bars had higher average deflection at midspan than beams with butt welded tension steel bars. This may not be unconnected with the butt welding of the reinforcement which may not have been full; the quality of the welding material may also have contributed.

iii. The average percentage loss in strength of beams with butt welded and lap spliced tension reinforcements was 58.34 % and 25.00 % respectively when compared to beams with full length tension reinforcement. The work has shown that joining/lapping of reinforcements brings about reduction in strength of the member which is not desirable, but where it is inevitable, the joining or lapping should be staggered.

iv. Lapped splice type of continuity is more efficient than butt welded type of reinforcement continuity. This is because of the higher percentage of strength loss recorded for butt welded continuity.

VI. Area of Further Work

In this work, different types of continuity were tested in tension. It is suggested that these modes of continuity be tested in compression to gain more knowledge on the effect of mode of continuity in compression.

References

[1] *Structural use of Concrete – Part 1: Code of Practice for Design and Construction*, British Standard BS 8110-1, 1997.

[2] M. Adom-Asamoah and R. O. Afrifa, "Investigation on the flexural behaviour of reinforced concrete beams using phyllite aggregates from mining waste," *Materials & Design*, vol. 32, no. 10, pp. 5132–5140, Dec. 2011. https://doi.org/10.1016/j.matdes.2011.05.043

[3] Dennis Morian et al., "multiple laboratory study of field-cured flexural beam strength," presented at the *2010 FAA Worldwide Airport Technology Transfer Conference,* Atlanta City, New Jersey, USA, 2010.

[4] M. Ahmed, J. Mallick, and M. Abul Hasan, "A study of factors affecting the flexural tensile strength of concrete," *Journal of King Saud University – Engineering Sciences*, vol. 28, no. 2, pp. 147–156, Jul. 2016. https://doi.org/10.1016/j.jksues.2014.04.001

[5] J. O. Ukpata and M. Ephraim, "Flexural and tensile strength properties of concrete using lateritic sand and quarry dust as fine aggregate," *ARPN Journal of Engineering and Applied Sciences*, vol. 7, no. 3, pp. 324–330, 2012.

[6] A. Tarabia, M. Diab, and M. Shoukry, "Improving the behavior of reinforced concrete beams with lap splice reinforcement," *Challenges, Opportunities and Solutions in Structural Engineering and Construction*, Oct. 2009. https://doi.org/10.1201/9780203859926.ch13

[7] F. K. Kong and R. H. Evans, *Reinforced and Prestressed Concrete*, 3rd ed. United Kingdom: Van Nostrand Reinhold Co. Ltd., 1987, Ch. 6, pp 198–201.

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