Splicing of reinforcement bars with epoxy joints

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The splicing of reinforcement bars in tension using epoxy-sleeve joints is described. The optimum length of the splicing sleeve required and the optimum bonding layer of epoxy resin in the joint were determined in direct tension tests. The performance of the epoxy-sleeve joint made to these optimum dimensions is then compared to that of a lap splice made according to the provisions of CP 110 in a beam flexure test. A sleeve length of 12 bar diameters and an optimum average thickness of 2 mm of the bonding layer of epoxy are shown to develop the full strength of the spliced bar. Tensile reinforcement bars spliced using epoxy-sleeve joints are shown to perform satisfactorily as flexural reinforcement in beams and compare favourably with the standard CP 110 lap splice. Epoxy-sleeve joints are shown to produce stiffer beams and reduced crack width at the joints.

Key words: adhesive-bonded joints; epoxy resins; tensile testing; bend testing; spliced joints; lapped joints; steel reinforcing bars.

Splicing of reinforcement bars becomes necessary partly due to the limited length of commercial bars, but more because of the awkwardness of interweaving long bars in construction. A good splice should be able to transmit the steel stresses from one steel bar to the other without adverse effects on the concrete surrounding it and the structure as a whole. Splicing of the bars as provided by the design codes may be in the form of lapping, threading of bars, welding or using sleeves. Obvious disadvantages exist with threading of bars or welding of high tensile reinforcement bars. Hence in a majority of cases, recourse is made to lapping of reinforcement bars. Besides causing additional congestion, particularly with larger bars, lapped bars require increased transverse reinforcement to contain the bursting forces developed at the lap joints. Recently, splicing of reinforcement bars with mechanical splices has attracted the attention of designers and such devices have been increasingly used in reinforcement bars in compression in reinforced concrete columns. Their use in tension is of limited application.

Early mechanical jointing developed for splicing reinforcement splices, in which the reinforcing bars were in tension, was by means of special jointing sleeves, which grip the jointed bar ends. Mechanical jointing sleeves were further developed by Eriksson[1], who reported the use of sleeve splices with cement-grout as the bonding material between the reinforcing bars and sleeve. Ivey[2,3] reported that the cement-grout sleeved splice has a superior mode of failure compared with lapped splices. The ultimate load on a sleeved splice was shown to be marked by a gradual loss of strength with increasing slip, while the lapped splice fails by splitting of the surrounding concrete leading to total loss of load-carrying capacity. Markestad and Johansen[4] reported a method of splicing deformed reinforcing steel bars using a steel pipe sleeve and resin mortar as the jointing medium. Various synthetic resins such as polyester, epoxy and sinmast were used with fine sand to form the filler in the mortar. The tests showed that spliced joints with resin mortar could be used successfully for splicing steel bars. However, Markestad and Johansen suggested that the temperature range in which epoxy mortar can be used for splicing steel bars subjected to tensile stresses may be limited, in view of increased creep with temperature.

The increased creep effects in the Norwegian study[4] could be explained as being due to the creep in the resin mortar between the sleeve and the deformed bars and is related to the minimum thickness of the bonding layer which is dependent on the size of sand used as filler in the resin mortar. In the present study, neat epoxy resin was used as the bonding medium so that the thickness of the bonding layer was kept to a minimum. However, different thicknesses of the bonding layer between the bars and sleeve were also investigated. The optimum length of the sleeve required to develop the ultimate strength of the spliced bar for this minimum thickness of bonding layer was determined. To assess the efficacy of such a joint, two beams of the same size but one with the main tensile reinforcement lapped in the middle of the span to the requirements of CP 110[5], and the other with the epoxy-sleeve jointed bar, were tested in flexure.

Determination of optimum sleeve size

This part of the investigation was directed towards obtaining the optimum length of the sleeve required for the minimum thickness of bonding layer. The shear stresses acting on the epoxy layer in an epoxy-sleeved joint are illustrated in Fig. 1. Assuming that the full shear strength of the epoxy (as given in specifications of the manufacturer) would be mobilized, the approximate length of the sleeve was estimated as 300 mm.

Variation of bonding layer thickness

Splices were made with sleeves of high strength ASAAB 750 steel of constant length 300 mm and external diameter 45 mm but with varying internal diameters of 29 mm, 30 mm and 32 mm to join Hybar deformed bars of 25 mm diameter. The epoxy resin used was Araldite AV138 with HV998 hardener, both manufactured by Ciba-Geigy of Switzerland. The resin and hardener were mixed in the proportion 100:40 parts by weight. The resultant mix was quite viscous but easily workable because of its soft consistency.

The surfaces of the bonding lengths of the deformed bars were wire-brushed to remove all loose rust, scale and cleaned with a solvent to remove all oil and grease. The internal surface of the sleeve, which had a rough machined face, was similarly cleaned of all oil and grease. The epoxy resin mix was then applied to the surfaces of the bar over the proposed bonding length and also poured into the sleeve. The epoxy-coated bar end was then pushed progressively into the sleeve at one end with a twisting motion. The bar was pulled out and pushed in a few times to expel any air trapped between the bar and the sleeve. This was repeated with the bar joining at the other end of the sleeve. Careful measures were taken to ensure that the sleeve was aligned symmetrically and centrally at the joint, with the two ends of the bars butting against each other, and concentric with the aligned axis of the bars so that the epoxy resin in the joint formed an annular ring concentric with the sleeve. The splice was left to cure for 3 days at room temperature (29°C) before testing.

The spliced joint was tested at room temperature in a 1000 kN Universal testing machine. Slip readings were taken both at the top and bottom ends of the spliced joint, tested in a vertical position as the tensile load was progressively applied, using the arrangement shown in Fig. 2. The joints were tested to failure and the modes of failure were noted.

The variation of the average of the top and bottom slip with the applied load for the three splicing sleeves of internal

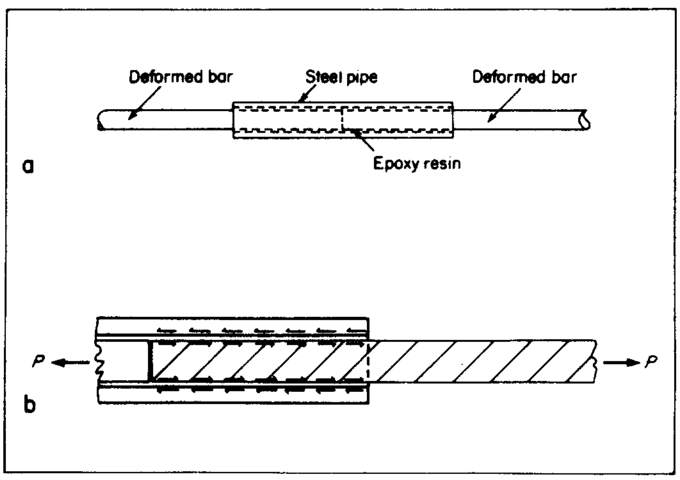

Fig. 1 Details of splice joint: (a) sleeved splice; (b) section of sleeve showing the shear stresses acting on the epoxy layer

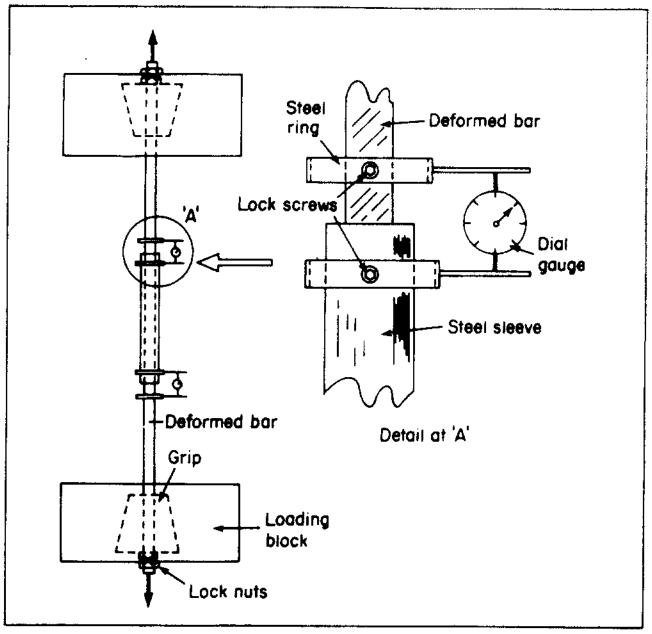

Fig. 2 Arrangement for testing splice joints

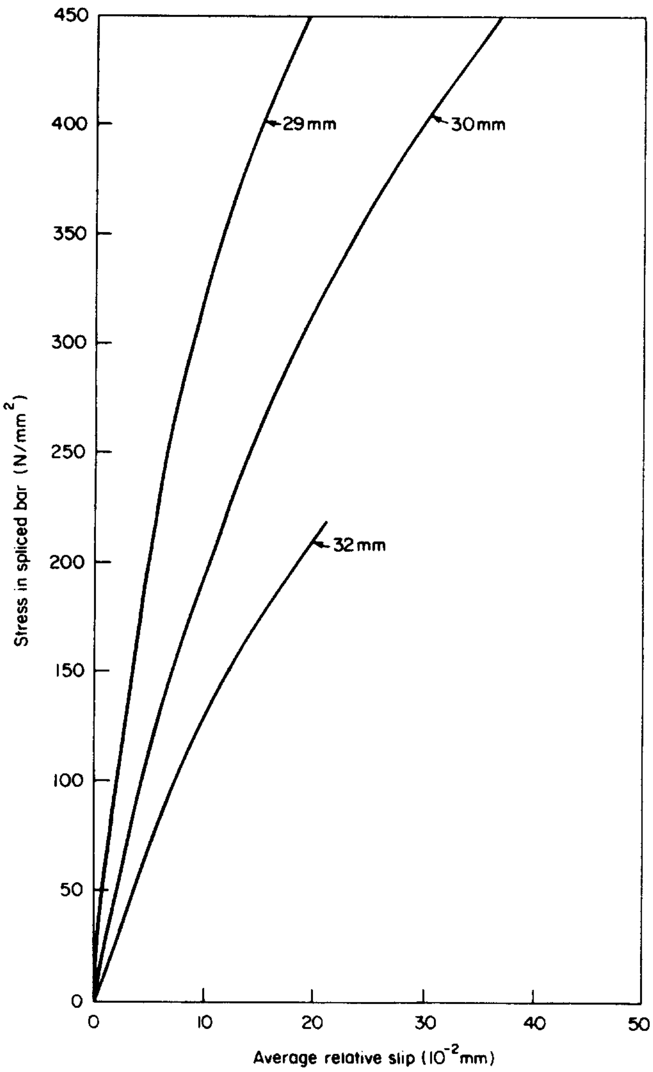

Fig. 3 Average relative slip of the joint for the three different internal diameters

diameters 29 mm, 30 mm and 32 mm is shown in Fig. 3. All the joints failed by pull-out of the bar from the sleeve and the stresses in the joint at failure are recorded in Table 1.

It is seen that the internal diameter of 29 mm gives the

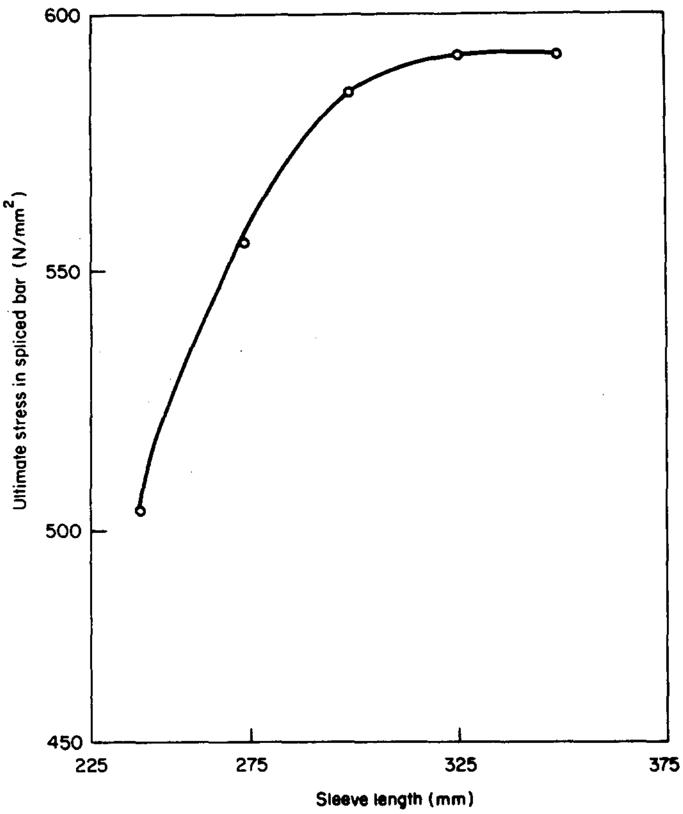

Fig. 4 Effect of sleeve length on the ultimate strength of sleeve splice joint

best performance and the maximum resistance to slip. Although the joint failed due to the pull-out of the deformed bar from the sleeve, the maximum stress of 589 N/mm^2 attained in the bar is very close to the ultimate strength of the bar of 593 N/mm^2* and higher than the yield strength of the bar of 503 N/mm^2. In fact, necking of the deformed bar was noticed close to the sleeve end and the reduction in diameter due to yielding probably caused the pull-out of the bar at the epoxy interface layer prior to the prospective fracture of the bar. The results show that the efficiency of the joint improves with reduction in the bonding layer. However, the optimum thickness of this layer is limited by the practicalities of pouring the epoxy resin mix in the joint and obtaining a completely filled joint. The sleeve with an internal diameter of 29 mm is considered to be the most suitable to splice 25 mm diameter bars.

Variation of sleeve length

To determine the optimum length of sleeve of internal diameter 29 mm and external diameter 45 mm, the length of the sleeve was varied from 250 mm to 350 mm in steps of 25 mm. Two samples were tested for each length of sleeve. The spliced epoxy joints were made and tested following the procedure outlined above. Mean values of the stresses in the joint at failure are given in Table 2.

A plot of the ultimate stress against sleeve length in Fig. 4 shows that the optimum length of sleeve is between 300 and 325 mm. The bars in the 325 mm and 350 mm sleeved joints fractured outside the sleeve and therefore the ultimate strength of the bar is used to plot the graph. The maximum stress reached in the bar with the 300 mm sleeve was 585.9 N/mm^2, a value very close to the ultimate strength of the deformed bar of 593 N/mm^2. A plot of the variation of the average slip with load in the bar for the 300 mm and 350 mm sleeved joints is shown in Fig. 5. It

*Determined previously from a standard tensile test on the deformed reinforcement bar.

Table 1. Variation of stresses in joint at failure (constant sleeve length)

	Internal sleeve diameter (mm)		
	29	30	32
Stress of bar at pull-out (N/mm^2)	589	544	211

Table 2. Variation of stresses in joint at failure (constant internal sleeve diameter)

	Sleeve length (mm)				
	250	275	300	325	350
Mean stress in bar (N/mm^2)	504.5	554.3	585.9	593.0*	593.0*

*The bars failed in tension and hence the ultimate strength of the bar was taken

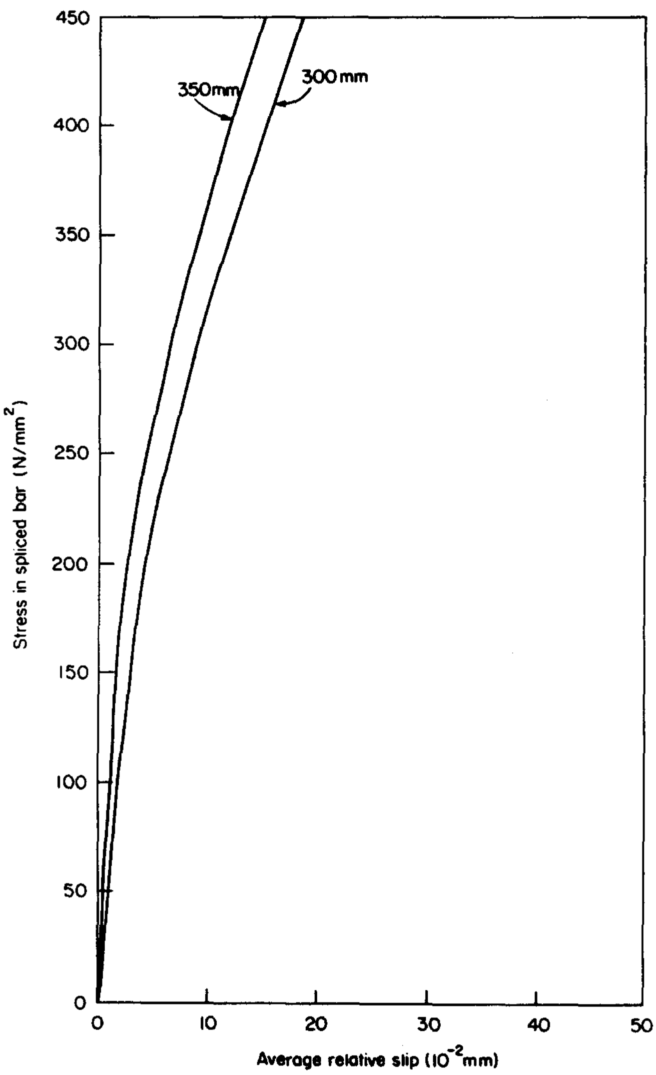

Fig. 5 Comparison of slip curves for sleeve lengths of 300 mm and 350 mm

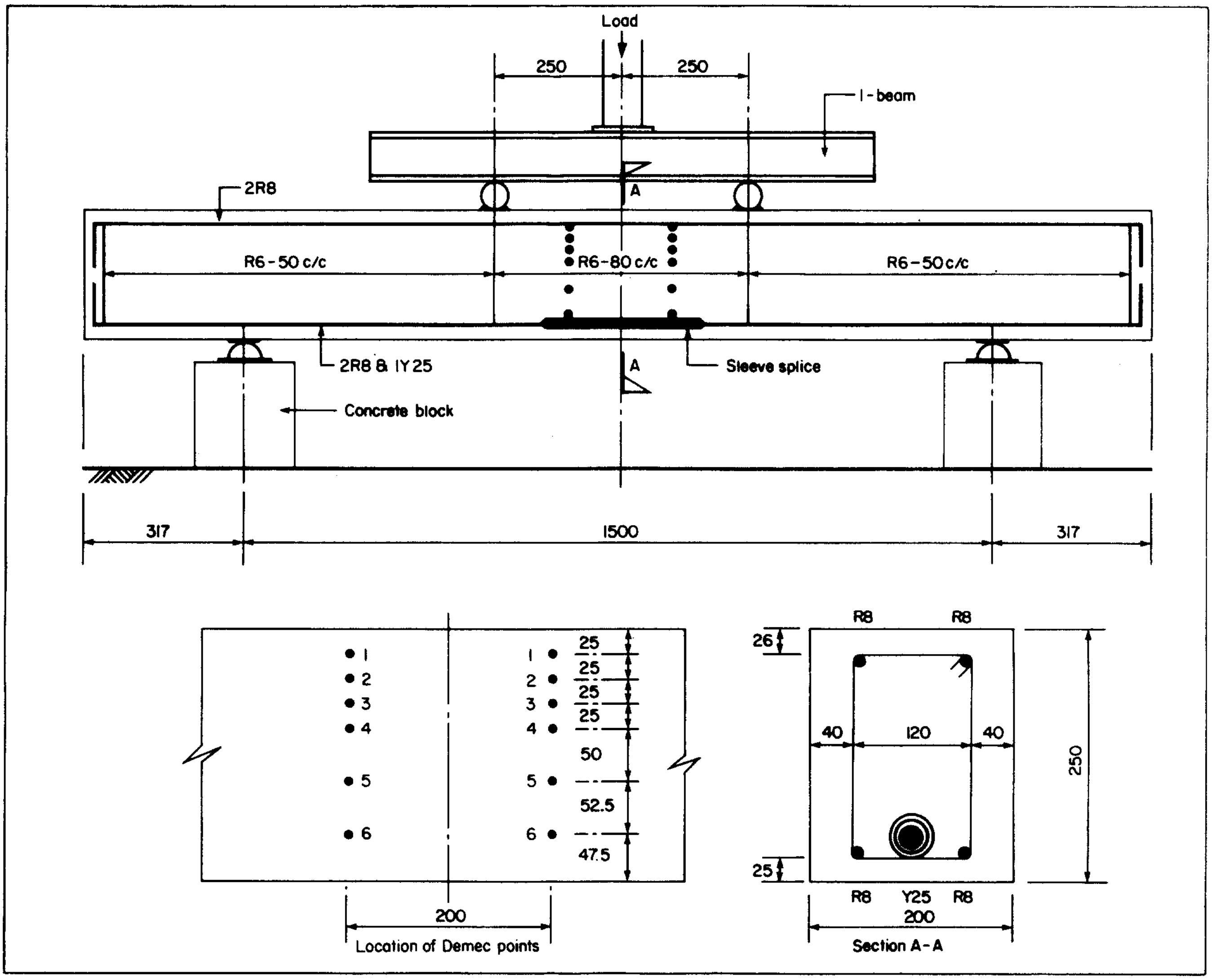

Fig. 6 Details of test beam and loading arrangement

is seen that the slip values with the 300 mm sleeve are slightly greater than those of the 350 mm sleeve but in view of the maximum stress 585.9 N/mm^2 reached in the bar being substantially greater than the yield stress of 503 N/mm^2, the sleeve length of 300 mm is taken as sufficient to develop the full strength of the bar. However, this falls short of the requirements of ACI 318-77[6] which require that a mechanical connection shall develop in tension or compression at least 125 percent of the specified yield strength of the bar.

Beam tests

The object of this part of the investigation was to compare the performance of the epoxy joint with the lapped splice provided according to CP 110. The behaviour of the beams reinforced with the two methods of splicing of the main reinforcement was studied in respect of the ultimate strength, failure mode, formation of cracks and their crack width and the relative stiffnesses of the beams.

Two beams were cast, one with each method of splicing and the main dimensions and reinforcement details are shown in Fig. 6. The main tensile reinforcement consists of two No 8 mm mild steel bars together with one No 25 mm diameter high yield UNISTEEL deformed steel bar placed at the bottom as shown. The deformed bar with the epoxy-sleeve joint at mid-span was used in one beam, whereas in the other beam the deformed bar was lapped vertically in mid-span according to the provisions of CP 110. One of the bars forming the lapped joint was suitably cranked to form the lap splice which extended over a length of 1076 mm.

The concrete mix was designed to achieve a target mean strength of 40 N/mm^2 at 28 days. A coarse aggregate of graded granite of maximum size 20 mm and graded mining sand were used. The beams were tested at 28 days in flexure and the test arrangement is as shown in Fig. 6. Demec stations were mounted on one face of each beam at mid-span to study the position of the neutral axis and its shift as the beam was subjected to load. Deflection of the beam at mid-span and strain readings on the face of the beam were recorded at different load stages of 1000 kg. The cracks were measured with a crack microscope and their progress with loading was observed.

Results and discussion

A summary of the test results is shown in Table 3. The performance of the two types of joint are given both under service load and ultimate load conditions. However, the experimental ultimate loads obtained are much higher than the design ultimate strength of a beam without a joint in the tensile reinforcement. This effect is due to the larger size of the splice in the beam with the epoxy-sleeve splice and the greater steel area, resulting from the lap in the lapped splice in the region of maximum bending moment.

The design ultimate moment of the beam based on yielding of the tensile steel was 37.44 kNm giving an ultimate load of 15 270 kg. Based on this ultimate load and a load factor of 1.5, the service load was determined as 10 200 kg.

The load deflection characteristics of the beams are as shown in Fig. 7. It is observed that the deflections of both beams at the calculated service load of 10 200 kg are about the same, with the epoxy-sleeve spliced beam slightly stiffer than the lap spliced beam. The deflection/span ratios obtained were 1 : 672 for the epoxy-sleeve splice and 1 : 610 for the CP 110 lapped splice. The variation of the strain in the concrete at the level of the tensile reinforcement is shown in Fig. 8. The average strains recorded in the epoxy-sleeve splice beam at the tension reinforcement level are very much less than the strains recorded in the lap spliced beam. The neutral axis for the two beams are obtained from Figs 9 and 10 as 130 mm and 110 mm, respectively. The effective tensile forces in the two beams based on the measured values of neutral axis are obtained as 157.19 kN and 153.18 kN for the two beams. Hence, the difference in the strain levels is explained as due to the different effective cross-sectional areas of steel at mid-span. The epoxy-sleeve splice has an effective area of 1590 mm^2 compared to an area of 981 mm^2 for the lapped 25 mm diameter bars. The crack widths are also smaller with the epoxy-sleeve splice beam. The maximum limiting crack width of 0.3 mm at the level of the tensile reinforcement is reached in the lapped splice beam at a load of 14 000 kg compared to 20 000 kg for the epoxy-jointed spliced beam.

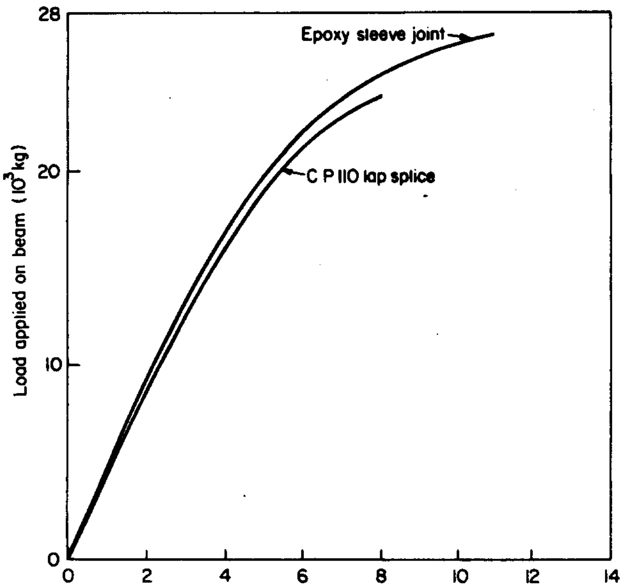

Fig. 7 Load/deflection characteristics of beam

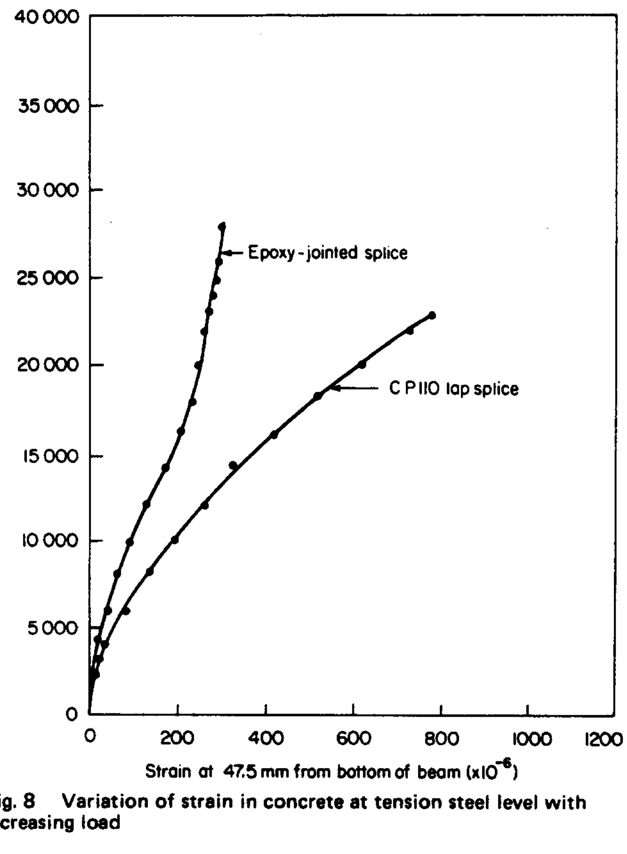

Fig. 8 Variation of strain in concrete at tension steel level with increasing load

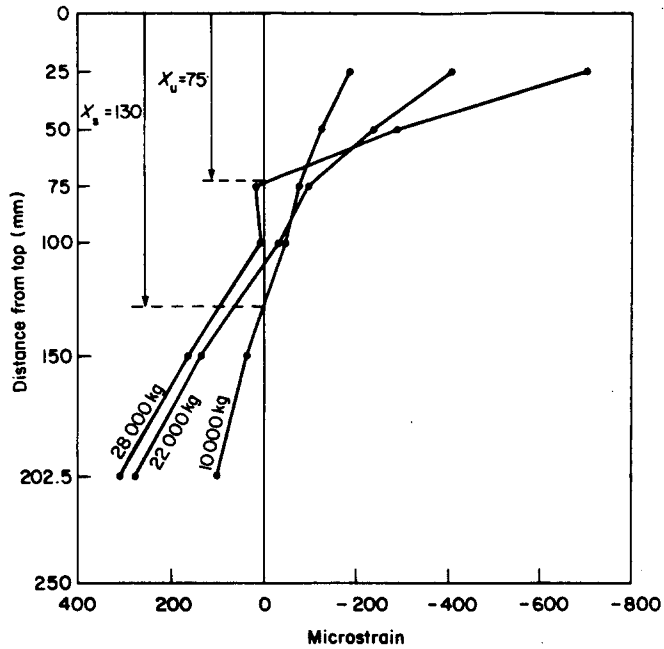

Fig. 9 Strain distribution of epoxy-sleeve joint

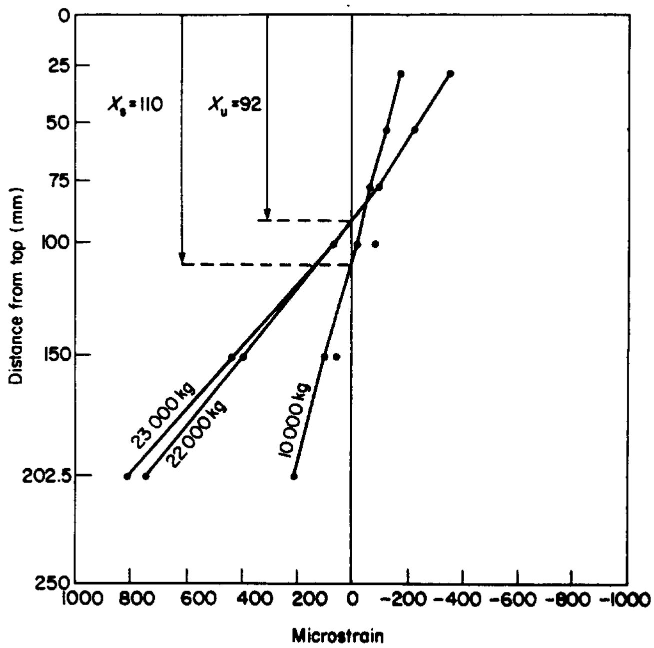

Fig. 10 Strain distribution of CP 110 lap splice

Table 3. Summary of beam test results

Type of load	Test	Type of splice	
		Epoxy-jointed splice	CP 110 lap splice
Service load	Service load (kg)	10.2×10^3	10.2×10^3
	Deflection (mm)	2.23	2.46
	Depth of neutral axis (mm)	130	110
	Ratio of neutral axis to effective depth	0.642	0.543
	Average strain at level of tension reinforcement	23×10^{-6}	48×10^{-6}
	Load at 0.3 mm crack width at level of reinforcement (kg)	20.0×10^3	14.0×10^3
Ultimate load	Cube strength of concrete (N/mm^2)	47.73	40.11
	Ultimate load (kg)	28.10×10^3	24.10×10^3
	Ultimate moment (kNm)	68.91	58.86
	Depth of neutral axis (measured)	75 mm at 28×10^3 kg	92 mm at 23×10^3 kg
	Calculated ultimate moment based on crushing failure of concrete (kNm)	64.08	62.82
	Average strain at level of tension reinforcement	296×10^{-6} at 28 000 kg	772×10^{-6} at 23 000 kg
	Deflection at centre of span (Load = 23 000 kg)	6.47 mm	7.19 mm
	Deflection at centre of span just before failure	10.86 mm at 27 000 kg	7.19 mm at 23 000 kg
	Maximum crack width just before failure	3.8 mm at 28 000 kg	6 mm at 24 000 kg
	Mode of failure	Crushing of concrete	Shear failure at ends of lap splice

The ultimate moments recorded in the tests were much higher than the design ultimate moments and the beams failed due to crushing of the concrete. However, the lap spliced beam failed prematurely due to shear transfer of load at the ends of the lap. The calculated ultimate moment of 64.08 kNm for the epoxy-sleeve spliced beam (Appendix) based on crushing failure of concrete compares very favourably with the experimental value of 68.91 kNm. The experimental ultimate moment of the lap spliced beam at 58.86 kNm however, is lower than the value of 62.82 kNm calculated based on crushing failure of concrete. The premature shear failure at the ends of the lap is explained as due to the transfer of load from the lapped bar to the continuing bar. However, it is of importance to note that the lap splice, as well as the epoxy-sleeve joint, did not fail at the design ultimate load. Just before failure of the lap spliced beam, the deflection of 7.19 mm observed at mid-span at 23 000 kg is very close to 6.99 mm, the deflection of the beam with the epoxy sleeve joint at the same load of 23 000 kg. However, as load was increased, the deflection just before failure of the epoxy-jointed spliced beam at 27 000 kg reached a value of 10.86 mm.

The levels of strain at the level of the tensile reinforcement for the lapped splice beam were greater than the corresponding strain levels for the epoxy-sleeve joint. The strain level at a load of 23 000 kg of the lap spliced beam (failure load 24 000 kg) was 772 microstrains compared with 296 microstrains for the epoxy-sleeve joint at 24 000 kg (failure load 28 100 kg). The variation of strain levels with load is shown in Fig. 8.

The crack widths obtained in the epoxy-sleeve beam were smaller than those obtained in the lap spliced beam. The maximum crack width, obtained in the epoxy-sleeve beam at a load of 28 000 kg was 3.8 mm compared to a crack width of 6 mm at 24 000 kg for the lap spliced beam.

Conclusions

Epoxy-sleeve jointing is an effective method of splicing reinforcement bars. There is very little relative slip between the sleeve and the spliced bar until the load is very close to failure load.

A sleeve of 12 bar diameters develops the full strength of the spliced bar. However, the thickness of the bonding layer should be as small as possible, consonant with the practicality of being able to pour the epoxy mix in the joint and obtain a completely filled joint. A sleeve of internal diameter 29 mm is considered to give the most suitable bonding layer thickness for a 25 mm diameter bar. The size for various diameters of bars has to be established.

Tensile reinforcement bars spliced using epoxy-sleeve joints perform satisfactorily as flexural reinforcement in beams and compare favourably with reinforcement lapped according to CP 110.

Epoxy-sleeve joints produce stiffer beams and reduce the crack widths of beams at the joints. They also transfer the tensile force from one bar to the other through the sleeve effectively, without the attendant shear failure that may occur with lapped joints at points of cut-off.

Acknowledgements

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Appendix

Calculation of ultimate load at failure

Epoxy-sleeve joint beam

Compressive strength of concrete = 47.73 N/mm^2
Breadth of beam = 200 mm
Effective depth of beam (to centre of steel) = 202.5 mm
Observed depth of neutral axis = 75 mm

Maximum compressive strength of concrete in flexure = 0.6 x cube strength.
A factor of 0.85 is used to correct for a rectangular stress block instead of a parabolic stress block.
Hence moment of resistance due to concrete

$$= (47.75 \times 0.6 \times 0.85) \times \frac{200 \times 75 \times \left(202.5 - \frac{75}{2}\right)}{10^6} \text{kNm}$$

$$= 60.27 \text{ kNm}$$

Moment of resistance due to compression steel of two Nos 8 mm mild steel bars

$$= \frac{250 \times 100.5 \times (202.5 - 26)}{10^6} = 3.81 \text{ kNm}$$

$\therefore$ Total moment of resistance = 60.27 + 3.81 = 64.08 kNm

CP 110 lap spliced beam

Compressive strength of concrete = 40.11 N/mm^2

Observed depth of neutral axis = 92 mm

Moment of resistance due to concrete

$$= (40.11 \times 0.6 \times 0.85) \times \frac{200 \times 92 \times (202.5 - 46)}{10^6} \text{ kNm}$$

$$= 58.91 \text{ kNm}$$

Moment of resistance due to compression steel = 3.81 kNm

$\therefore$ Total moment of resistance = 58.91 + 3.81 = 62.82 kNm