RESEARCH ON THE PARTIAL-INTERACTION COMPOSITE BEAMS

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1. INTRODUCTION

In steel-concrete composite construction, headed-stud is the most widely used type of shear connectors. Its design is based on results from push tests. Push strength has been shown to be influenced by many parameters, such as: the properties of the concrete, stud details (diameter, height and strength) /4/, and transverse reinforcement /2/, /3/, /5/ etc. However, the behaviour of studs in a composite beam is different from that in a push test because longitudinal and transverse stresses in a slab are more complex. At the same time, the discussion on the influence of transverse reinforcement has been restricted to the reinforced or unreinforced push-out specimens. The full details of its location, strength and anchorage is not taken into account. In Sweden, the recommendation and specification for design of composite beams are not ready yet. If shear reinforcement in the flange is designed according to the Swedish Code for concrete structures, there is no requirement for its position. Up till now, there are few results reported on the behaviour of studs in the combination with the effect of detailng of transverse reinforcement in full-scale composite beams. Therefore, the purpose of this investigation is to study the behaviour of studs in composite beams and the influence of reinforcement detailing. This paper presents some of our results from tests on partial-interaction composite beams loaded with a concentrated line load.

2. EXPERIMENTAL PROGRAM

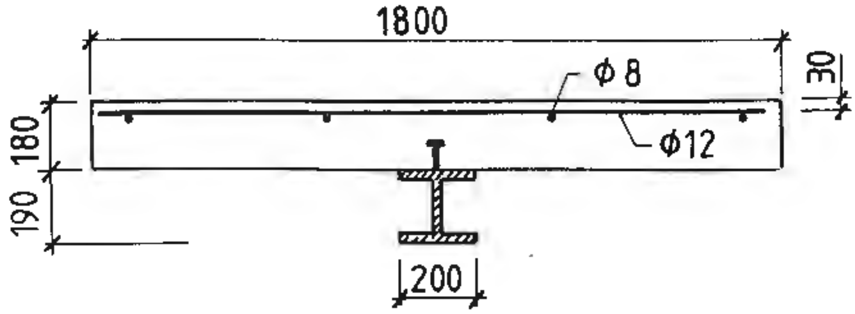
2.1 Specimens

Two full-scale partial-interaction composite beams were tested to failure with a span of 6.0 m. The main parameters of variation were: (1) The length of the shear span and (2) the position of transverse reinforcement in the concrete slabs.

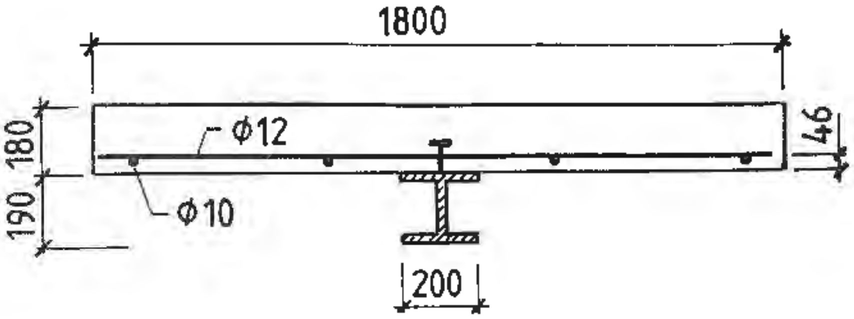
The composite beam consisted of a steel beam, HEA 200 (A_s = 5383 mm^2), and a solid concrete slab. The cross sections and distribution of transverse reinforcement in the beams are illustrated in FIGS. 1 and 3. The same amount of transverse reinforcement was used in both beams but at different positions. It was placed near the top of the slab in beam 1A and at the bottom of the slab in 1B.

The composite action between the steel beam and the concrete slab was provided by headed-stud shear connectors, named KÖCO TYP KKB. The diameter of the stud was 19 mm and the height 75 mm. The studs have a minimum tensile strength of 450 MPa. They were uniformly distributed along the entire beam with the spacing of 250 mm. On the principle of full-interaction design /1/, the total number of shear connectors needed for full-interaction composite beam should be 16 within the length of shear span. The actural number of studs, however, was 5 in the shorter (L_s = 1.11 m) and 8 in the longer (L_s = 1.67 m) shear span. The connector ratio n (which equals unity for full-connection design) then becomes 0.31 and 0.5.

All material strength parameters were obtained from material tests and are listed in TABLE 1. In this table, f_{cm} and f_{cbm} are the mean value of concrete compressive strength obtained from the cylinders (150 X 300 mm) and the cubes (150 X 150 X 150 mm), respectively. The f_{ct} is the mean value of concrete splitting strength from the cubes (150 X 150 X 150 mm).



(a) Beam 1A



(b) Beam 1B

FIG. 1 Cross Section

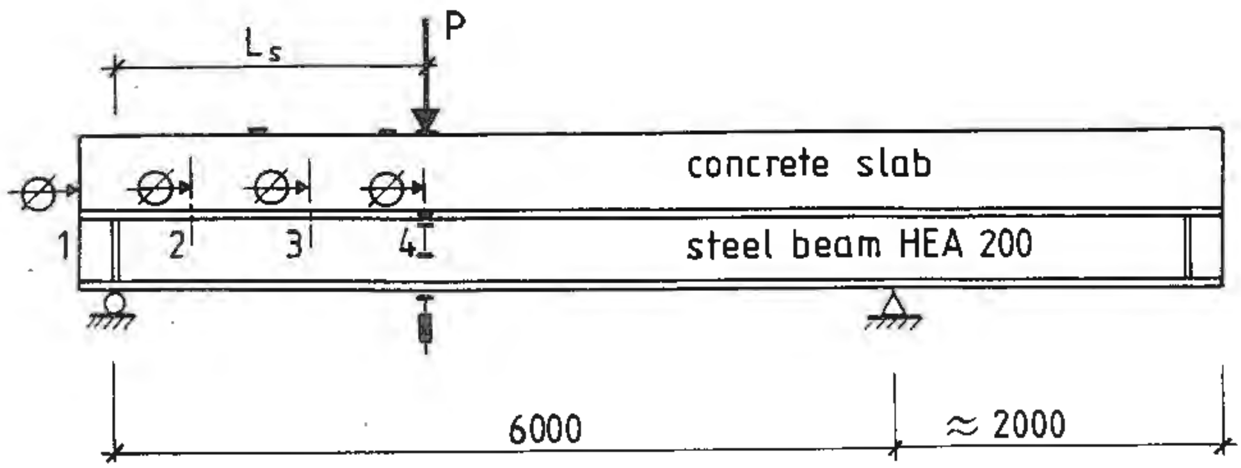
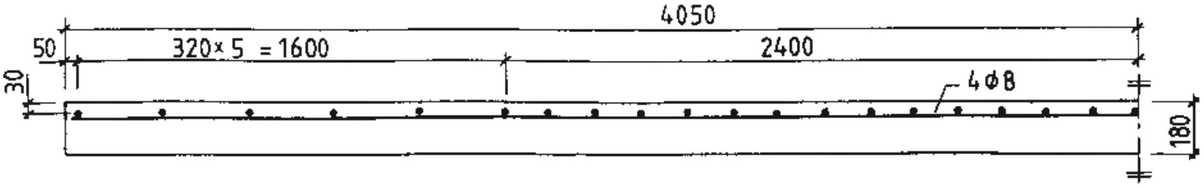
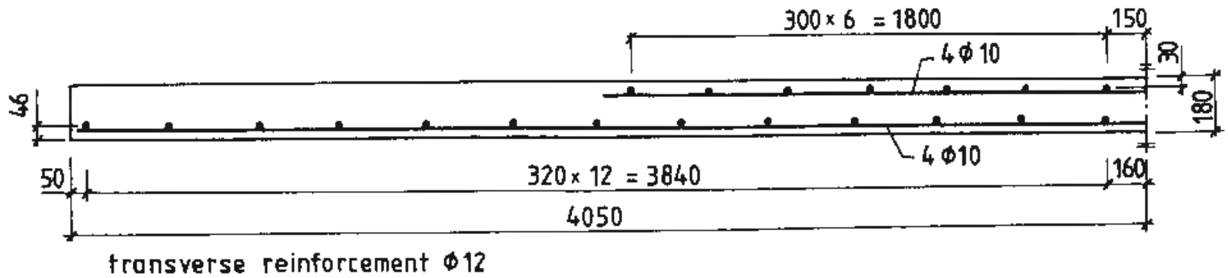


FIG. 2 Test Set-up and Instrumentation



(a) Beam 1A



(b) Beam 1B

FIG. 3 Arrangement of Transverse Reinforcement

TABLE 1. Measured material parameters

concrete				transverse reinforcement	
f_{cm} (MPa) 28 days	f_{ctm} (MPa) 28 days	f_{cbm} (MPa)		d = 12 mm	
		28 days	testing days	f_{ym} (MPa)	E_{sm} (GPa)
31.76	3.42	44.13	51.76	489	202

TABLE 2. Results of tests

No	L (m)	L_s (m)	P_{max} (KN)	slip at P_{max} (mm)	deformed shape of studs
1AF	6.0	1.11	329	11.3	
1AS	6.0	1.67	245	21.13	
1BF	6.0	1.11	406	8.32	
1BS	6.0	1.67	323	9.68	

2.2 Test Set-up and Instrumentation

The test set-up was identical for all tests and is shown in FIG. 2. In order to save materials and get more information, the composite beams were tested end by end, i.e. one end of the beam was tested to failure first and then the other end. Therefore the first tested end of the beam is indicated by F and the second by S in the notation, for example 1AF and 1AS.

The relative slip between the steel beam and the concrete slab was measured at different positions. The strain gauges were placed on the top and the bottom of the concrete slab, also on the upper and the lower flanges and centroid of the steel beam at the loading section (shown in FIG. 2). The strain distribution, deflection and slip were recorded at each load step. Details of the test are given in TABLE 2.

After the test the specimens were sawed longitudinally through the concrete slab and the studs. This made it possible to study the deformation of studs in detail.

3. RESULTS AND DISCUSSIONS

3.1 Load-deflection Curves

The measured load-deflection curves for two shear spans are shown in FIG. 4. At first the difference in slope of the curves 1A and 1B was very small. When the load had increased to a certain value the curves deviated from each other. This corresponded to the yielding of the steel beam. When the lower flange of the steel beam yielded the deflections in 1AF and 1AS increased significantly with a small increase in load. The specimens lost their capacity when the concrete at the end of the beam was pushed out by the stud. Different from that of 1A, deflection of beam 1B did not increase so quickly when the steel beam began to yield. Specimens could stand more load. The maximum capacity of 1B was obtained when the studs were sheared off. At this moment a big noise was heard from the studs breaking. Therefore there was a better composite action between the steel beam and the concrete slab in beam 1B where transverse reinforcement was placed in the bottom of the slab. The ultimate strength of composite beams was controlled by the strength of studs. The maximum loads obtained in 1B were 24 % higher for the shorter and 31 % for longer shear span comparied with those in 1A, shown in TABLE 2. Evidently transverse reinforcement plays an important role in the improvement of the behavior of the composite beams.

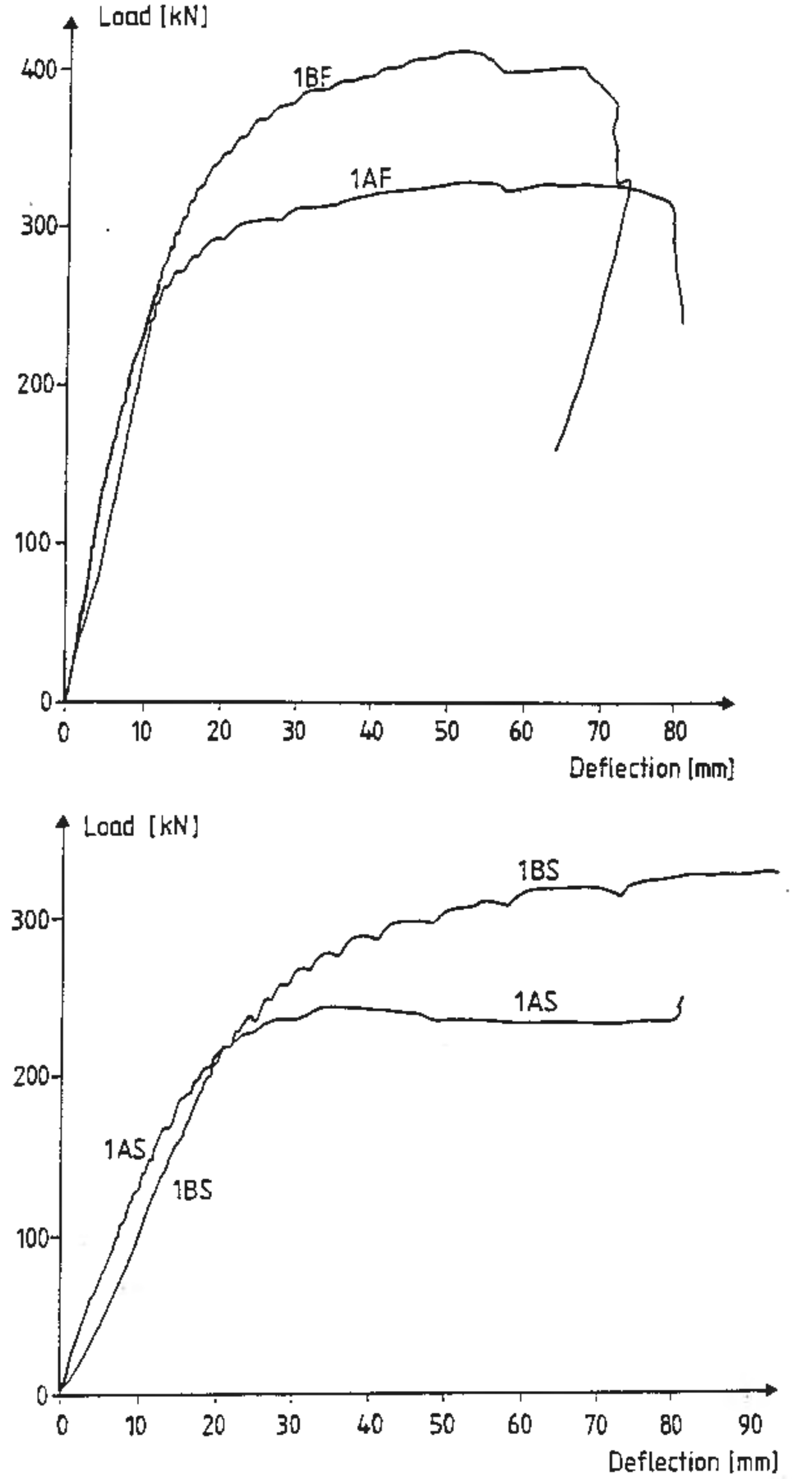


FIG. 4 Load-deflection Curves

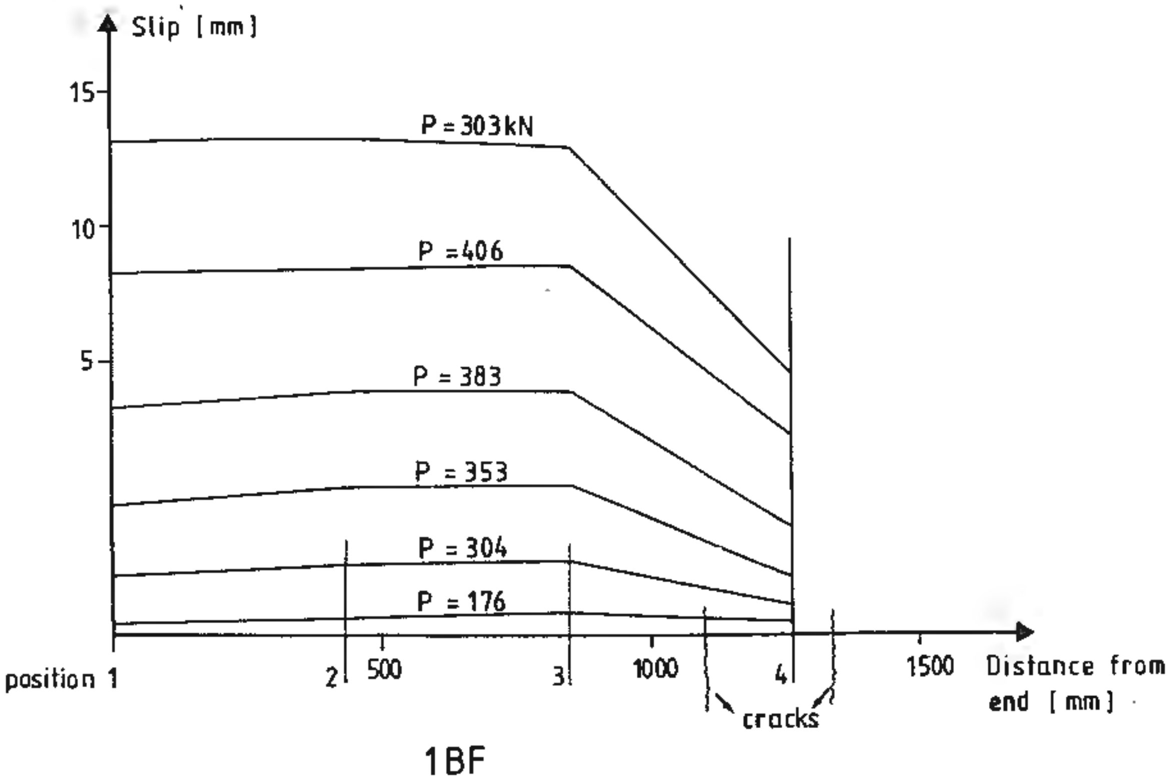


FIG. 5 Slip Distribution

3.2 Cracks and Slip Distribution

As mentioned before the relative slip between the steel beam and the concrete slab was measured at different positions. The slip distribution in the shear span for specimen 1BF is shown in FIG. 5. It is found that the slip values at the positions 1, 2 and 3 (see FIG. 2) are almost identical at the same load level. One bending crack was located between positions 3 and 4, and this made the slip value at position 4 comparatively lower. The same phenomenon was observed for other specimens. This indicats that the concrete slab moved stiffly from the position of the bending crack towards the end of the beam, and also shows that the bending crack affected the slip distribution along the shear span and the force taken by the studs. The first bending crack at the loading section was observed at a load between 80-100 KN in specimens 1BF and 1AF, and about 80 KN in 1AS. Considering the fact that bending crack occurs rather early in this type of composite beams with a relatively deep slab and shallow beam, the elastic analysis is only valid for rather low external loads.

Two strain gages were placed on the top and across the longitudinal centreline of the concrete slab. They were located at the same position for the specimens with the same shear span. All longitudinal cracks on the top of the slab were initinated from the loading section and propagated towards both ends. The strain gages broke at almost the same load for the specimens with the same shear span. This indicates that the propagation of longitudinal cracks at the top of the concrete slab was mainly dependent on the bending moment. The measured width of longitudinal cracks on the top of the slab was 0.3-0.7 mm in specimens 1AF and 1AS, and 1.5-2.0 mm in specimens 1BF and 1BS. From photos it is found that longitudinal cracks were also formed at the bottom of the slab. The cracks in the top and the bottom of the slab were connected with each other. Transverse reinforcement near the top of the slab does not prevent the longitudinal cracks, but limits the extent of cracks.

3.3 Deformation of Studs and Transverse Reinforcement

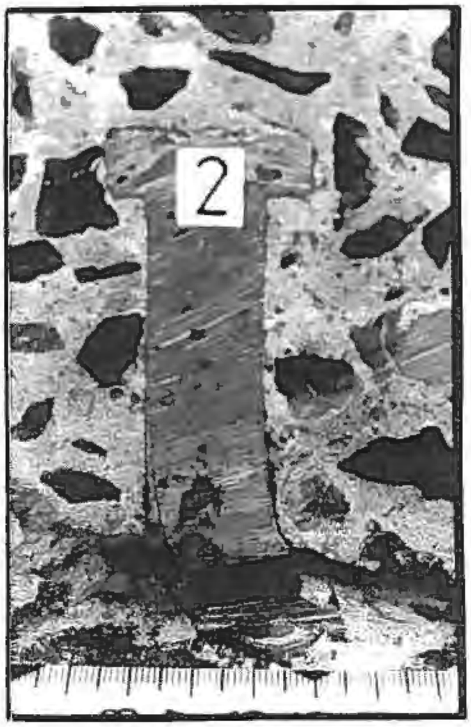
In order to examine the failure mode of the shear connectors, the specimens were sawed longitudinal through the slab and the studs after the tests.

The typical crack was developed in specimen 1BS (see FIG. 6). There was a long diagonal crack behand and a very compressived zone in front of a stud. Separation between the concrete and the stud head showed that the anchorage between them failed.

The deformation of the second stud from the end is shown in FIG. 7(a)-(d) for each of the four tests. The deformed shape of the stud is similar to that illustrated by the other researchers /4/, but with large deformation. Such large deformation in the shank near the base of the stud shows that rather great horizontal shear force was taken by the shank of the stud. FIG. 8 illustrates the deformed shapes of the first three studs which were fractured in the test in specimen 1BF. The studs with apparent permanent deformation broke not only at the interface between the shank and the welded collar, but also at the deformed shank.

The deformed shape of the studs was different in 1AS, as shown in FIG. 7(c). The studs were almost straight but rotated an angle about 17 degrees from the vertical position. Probably the longitudinal crack at the base of the studs started early and propagated quickly due to the absence of transverse reinforcement. Therefore the concrete surrounding the stud lost its strength. It was apparent that the concrete in front of the stud in 1AS was crushed and that the concrete was much more damaged than in other specimens. The observed behaviour shows that transverse reinforcement around the studs not only took horizontal shear force but also improved the whole situation of the concrete in the vicinity of the connectors and prevented local failure which could have resulted in beam failure. The effect of transverse reinforcement on the strength and failure mechanism needs more experimental and theoretical work.

(a) 1AF



(b) 1BF

(c) 1AS

(d) 1BS

FIG. 7 Deformation of Studs

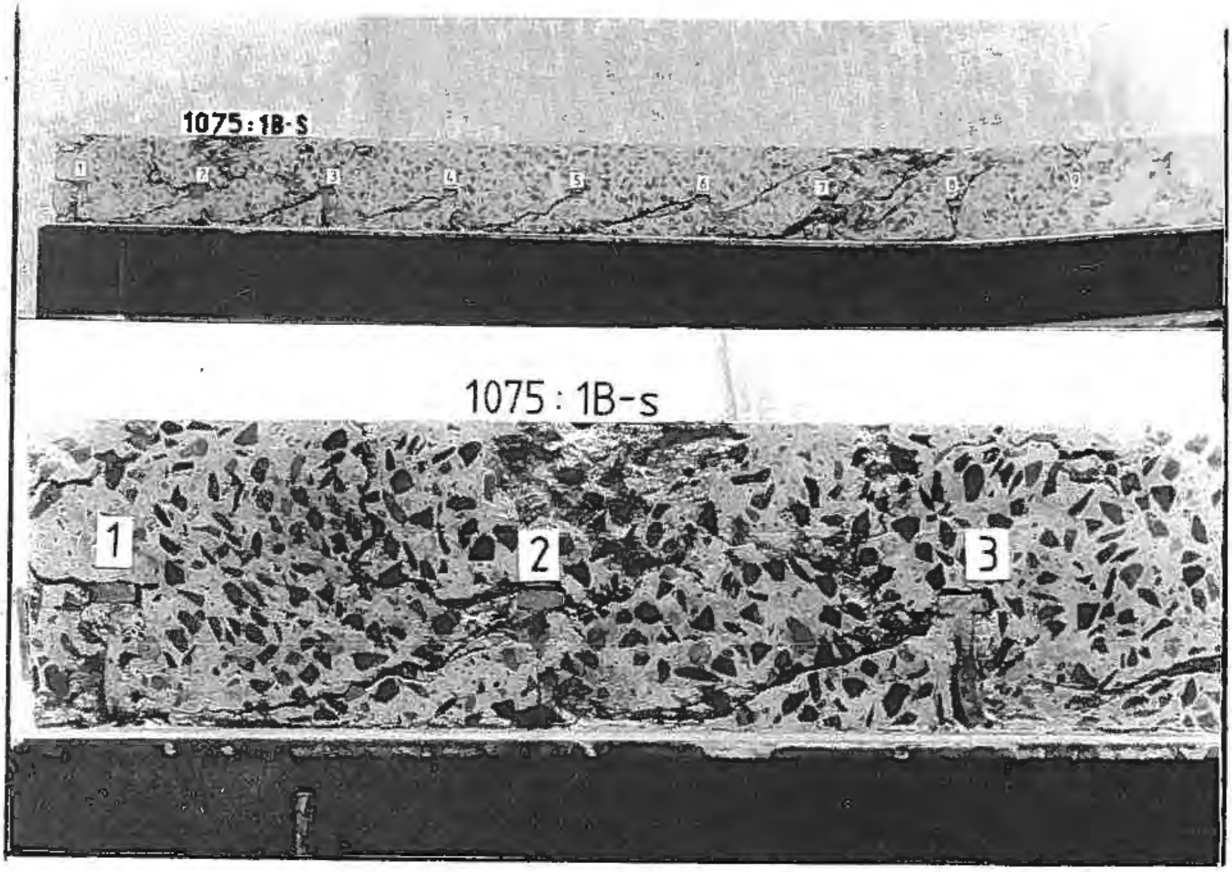


FIG. 6 Crack Distribution in 1BS

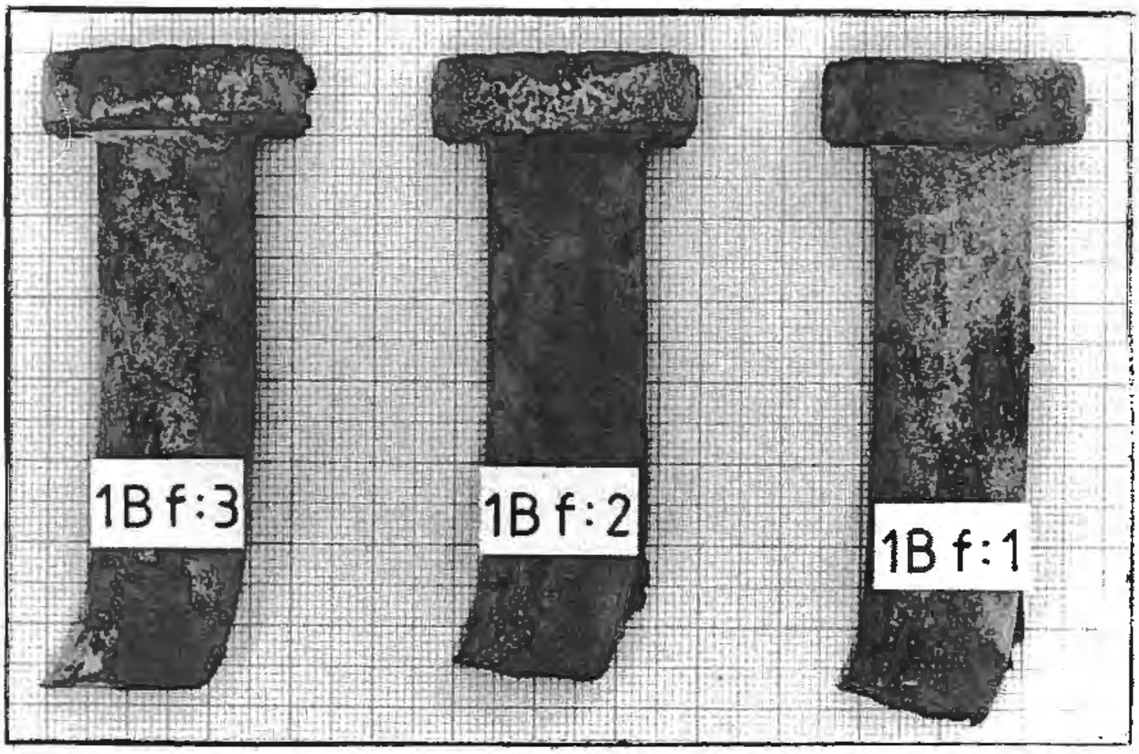


FIG. 8 Fractured studs in 1BF

4. CONCLUSIONS

1. The slip distribution along the length of the shear span was influenced by bending cracks.

2. The studs suffered very complicated stresses in the composite beam. The fracture of the shank which gives the greatest strength of a stud in push tests was observed from the specimens with transverse reinforcement at the bottom of a slab for the two shear spans.

3. The position of transverse reinforcement effects the ultimate capacity of composite beams. The maximum load on beam 1B is 24 % higher for shorter and 31 % for longer shear span than that on beam 1A. Therefore, it is better to place transverse reinforcement at the bottom of the slab with regard to the strength, especially for longer shear spans.

5. ACKNOWLEDGEMENTS

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7. NOTATIONS

f_{cbm} mean value of cube compressive strength

f_{cm} mean value of cylinder compressive strength

f_{ctm}	mean value of cube splitting strength
f_{ym}	mean value of yield strength of transverse reinforcement
E_{sm}	mean value of modulus of elasticity for the steel beam
d, ϕ	diameter
L	length of span
L_s	length of shear span
P_{max}	maximum load on specimens