Pushout Tests on Lightweight Composite Slabs

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TESTS HAVE BEEN PERFORMED at the University of Colorado on composite specimens using a locally produced lightweight aggregate and a commercially available headed-stud shear connector.

The aggregate is an expanded shale, crushed prior to burning in a rotary kiln to produce a sealed surface. It is produced in three sizes—coarse, ¾ in. to No. 4; medium, No. 4 to No. 16; and fine, No. 16 to pan. Only one mix, a six-sack mix recommended by the manufacturer, was used in tests. It weighed 93 pcf and tested in excess of 5,000 psi at 28 days when properly batched. Strengths produced in these tests, however, ranged from 3,010 to 5,818 psi.

Studs used in tests were ½, ⅝, ¾, and ⅞-in. in diameter. Lengths were roughly four times the diameter, with some variation. Tensile yield strengths ranged from 61,000 to 69,000 psi with ultimate strengths from 65,100 to 75,200 psi. Elongation in 2 in. gage length ranged from 18.5 to 25.5 percent with reductions in area from 52.8 to 66.7 percent.

A series of pushout tests was performed patterned after the tests Dr. Ivan Viest had run at the University of Illinois using the same type of connectors and sand-and-gravel concrete. The details of the Colorado pushout specimen are shown in Fig. 1. Two studs were welded to each flange of a 16-in. length of 8 WF 48. A 6-in. slab of lightweight concrete with typical slab reinforcement was cast on one flange in a horizontal position. The next day, the specimen was turned over, and an identical slab was cast on the other flange. Flanges were greased before the slabs were cast to prevent bond and to reduce the effect of friction during testing.

Specimens were cured with wet burlap and tested when the first slab was 28 days old. Figure 2 shows a specimen in place in the 300,000 lb testing machine. The lower ends of the slabs bore against ¼-in. thick plywood. Load was applied to the beam through a

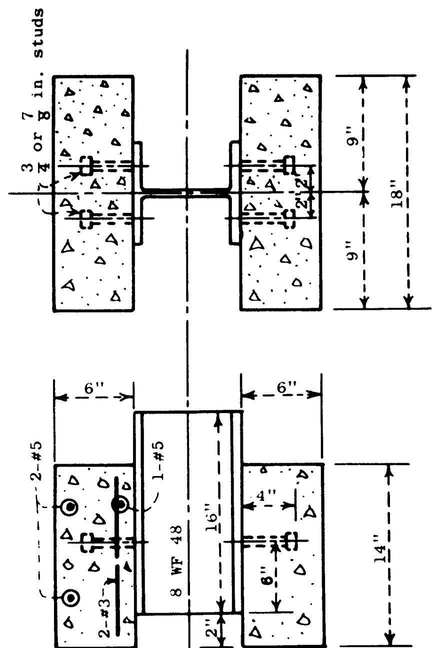

Fig. 1. Details of pushout specimens

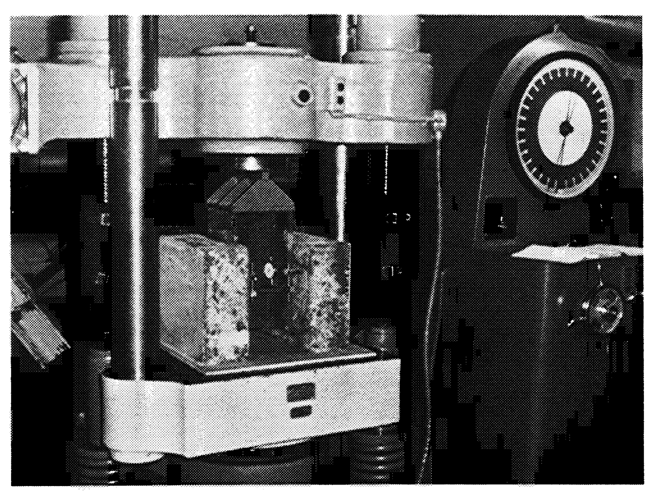

Fig. 2. Specimen in testing machine

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spherical bearing block in the testing machine and a specially constructed, stiffened bearing plate. Figure 3 shows the dial indicators attached to inserts in the slabs and bearing on angles welded behind the studs. These were used to measure the slip which took place between the beam and the slab at the level of the stud.

For the first tests, two identical specimens with $\frac{3}{4}$-in. studs were cast. One of these was tested to failure by loading to successively higher loads and unloading as shown in Fig. 4. The slip at a given load and the residual slip after unloading could be determined from diagrams of this type. The other specimen was loaded to failure in increments without unloading. The load-slip behavior followed the dotted line of Fig. 5. Also shown is the line connecting the peaks of the load-unload curve of Fig. 4. This indicated that the cycling of the load did not affect the slip and that it was not necessary to run both types of tests. Both slip and residual slip could be obtained from the same load-unload test, so all subsequent tests were run in this fashion.

Residual slip results from a typical test are shown in Fig. 6. Considerable variation in residual slip was observed from one dial to another. Curves from all four dials broke at about the same load, however, and the average curve smoothed out the results. A quantity, termed the useful capacity, Q_{uc}, was determined from the average curve as the intersection of the straight-line lower part with a straight line projected backward, tangent to the upper part of the curve (Fig. 7). This

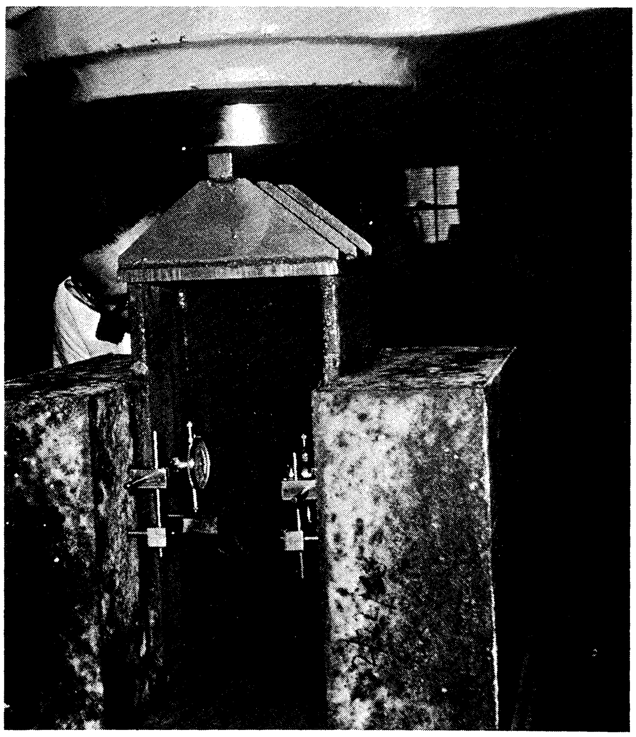


Fig. 3. Test setup showing dial indicators

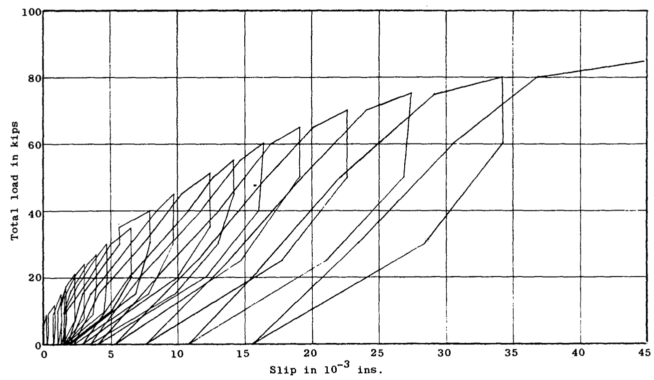


Figure 4

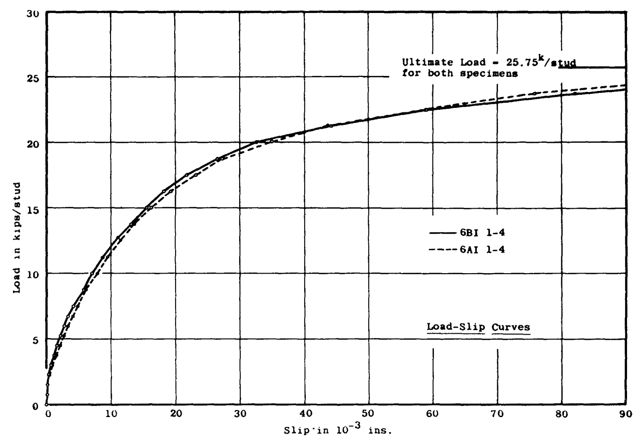


Figure 5

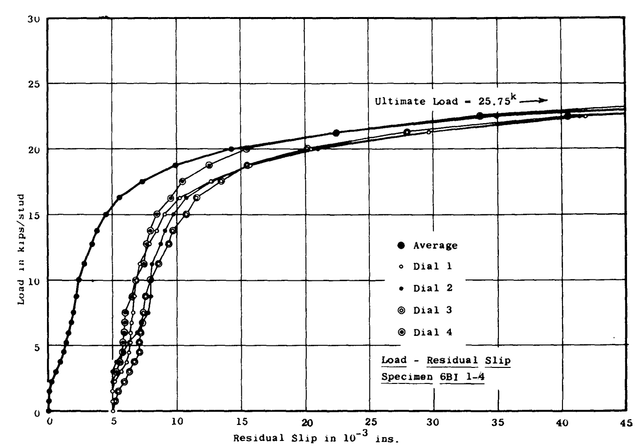


Figure 6

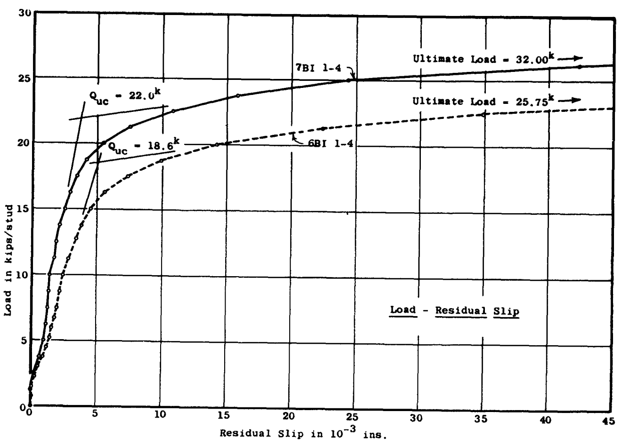


Figure 7

represents the load at which considerable inelastic action begins, or it is a kind of yield load for the stud-slab combination.

Failure was due to one or two studs shearing off in all specimens except the ⅞-in. one, which failed by slab cracking. After failure, the slabs were chipped away from the studs (Fig. 8). It was evident that considerable plastic action had occurred in the studs. The part of the slab in contact with the stud was glazed (Fig. 9) and discolored. Some of the concrete appeared crushed but could not be picked out with the fingers.

The studs still attached to the flanges were sawed off and tested in direct shear (Fig. 10). There was no noticeable difference in results in single shear and in double shear as far as ultimate shear stress was concerned.

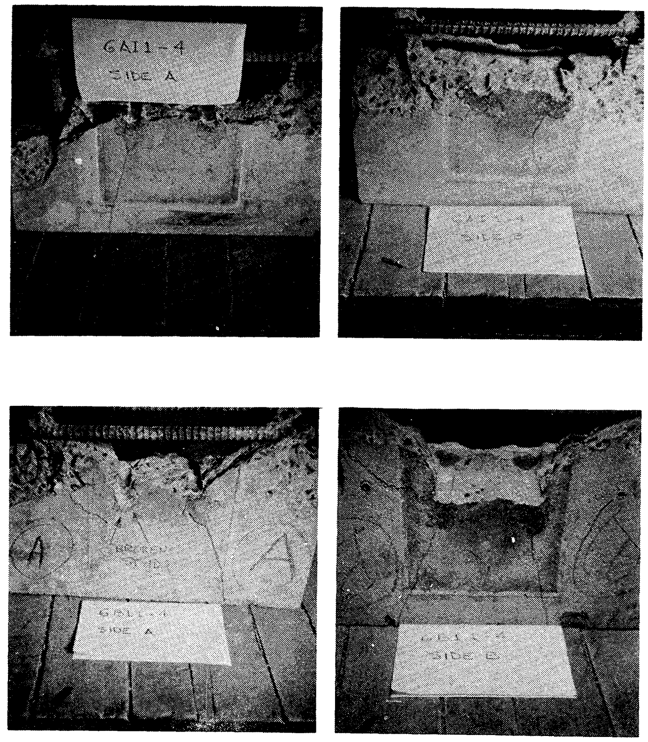


Fig. 9. Contact surfaces

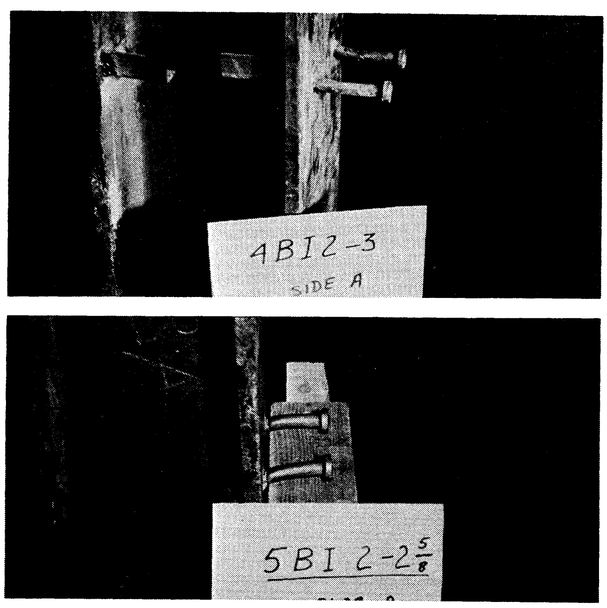


Fig. 8. Plastic deformation of studs

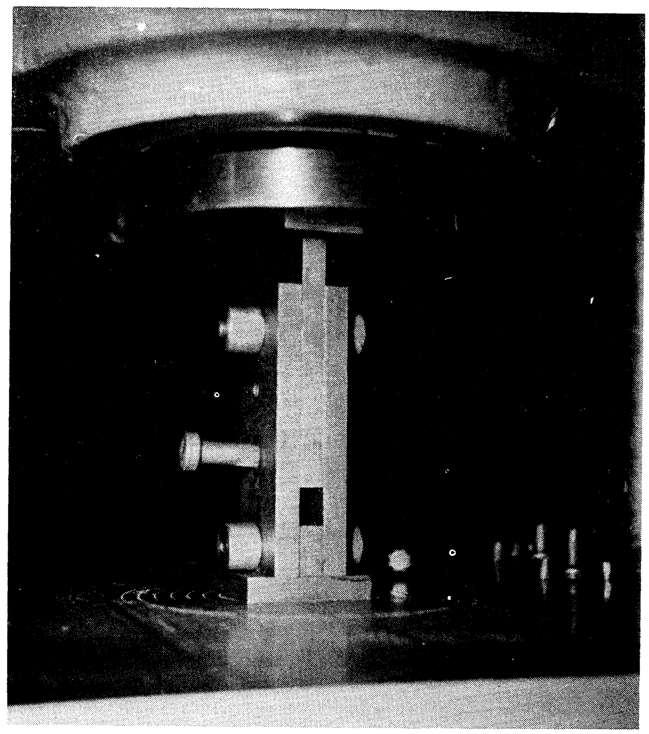


Fig. 10. Direct shear rig mounted in testing machine

RESULTS

Spec.	Corr. Q_{uc} kips	Q_{ult} kips	Q_{DS} kips	Q_{ult}/Q_{DS}
4BI 1-2	7.26	12.00	8.39	1.43
4BI 2-3	6.60	12.25	8.91	1.38
5BI 1-2$\frac{5}{8}$	8.56	17.00	12.70	1.34
5BI 2-2$\frac{5}{8}$	10.00	18.00	12.87	1.40
6BI 1-4	15.90	25.75	21.13	1.22
6BI 2-4	13.15	22.50	19.11	1.18
6BI 3-3	15.20	25.00	19.96	1.25
7BI 1-4	18.90	32.00	---	--
6BS 4-3	12.90	27.50	20.94	1.31
6BS 5-4	13.50	25.25	20.02	1.26

Figure 11

TEST RESULTS

Results of the pushout tests are tabulated in Fig. 11. The code used in identifying specimens is as follows: The first number is the stud diameter in ⅛th inches. (The prefix 4 indicates a ½-in. stud.) This is followed by a letter identifying the type of test. (B is a load-unload pushout test.) Next is a letter identifying type of concrete (I is lightweight; S is sand and gravel). The next number is the specimen number in the series (1 is the first of the 4B specimens.) Last is the length of stud (2 is a 2 in. long stud).

The corrected useful capacity was used to compare results. This is the useful capacity obtained from the load-residual slip plot, corrected to a concrete strength of 4,000 psi by multiplying by the square root of the ratio of 4,000 psi to the actual concrete strength. This square root variation with concrete strength was found to exist in Dr. Viest's tests and appeared to give good results in the present tests. All values of Q_{uc} fitted the equation

$$Q_{uc} = 6.5\, d^2 f_c' \sqrt{\frac{4{,}000}{f_c'}}$$

rather well, with a maximum error of 15.8 percent. Dr. Viest recommended a coefficient of 5.25 for conventional concrete, a value 19 percent lower.

A study of load-slip plots showed that the useful capacity load corresponded to a residual slip of about 0.005 in. and a slip of 0.015 in. Dr. Viest found his useful capacities corresponded to residual slips of 0.003 in.

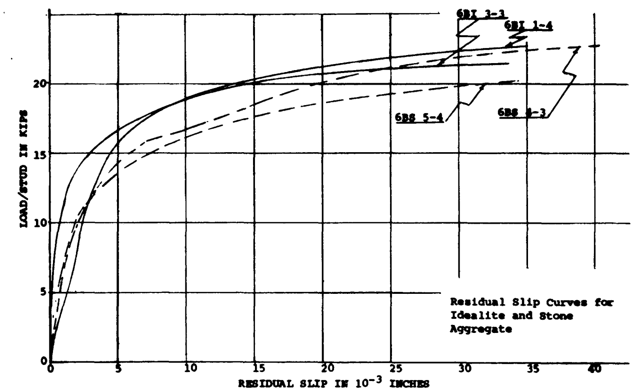
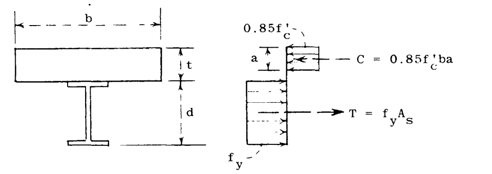


Figure 12



$M_u = f_y A_s (\frac{d}{2} + t - \frac{a}{2})$

For f_y = 36 ksi, beam an 8WF17, T = 36(5.00) = 180^k

Q_u for ½" stud = 12^k

No. of studs required = 180/12 = 15

Use 16 studs between load and end of beam

Figure 13

The ultimate loads did not appear to be affected by the concrete strength. In fact, in 75 percent of the cases, including the two where slab strengths differed appreciably, the studs in the stronger slab were the ones which sheared. The ultimate loads fit the equation $Q_u = 39.22\, d^{1.766}$ with a maximum error of 8.4 percent. The direct shear strengths of the studs were lower than the ultimate pushout strengths. The ratios of pushout to direct shear strengths vary from 1.18 to 1.43. It should be noted that the direct shear strengths represent shear stresses from 42 to 48 ksi, and the ultimate pushout strengths represent stresses from 51 to 60 ksi. It would seem, then, that not all the force applied to the pushout specimen is transmitted through the section of the stud which shears. It is likely that some force is transferred by friction and some through the weld root below the section which shears.

Two specimens using local sand and gravel concrete were tested for comparison purposes. The useful capacities were a little less than those for the lightweight concrete of comparable strength, but in line with the formula of Dr. Viest. The ultimate strengths were comparable, however. In the load-residual slip plots (Fig. 12), the sand and gravel curves do appear to break at lower loads than the lightweight specimens.

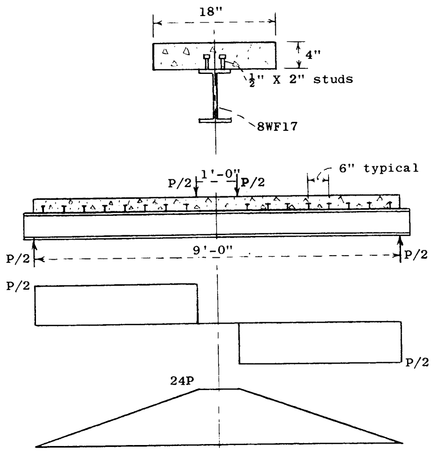
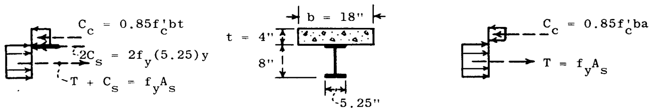


Figure 14



Beam A (Neutral axis in top flange)

$f_y = 44$ ksi; $f'_c = 3,154$ psi

$T + C_s = f_yA_s = 44(5.00) = 220^k$

$C_c = 0.85f'_cbt = 0.85(3.15)(18)(4)$

$= 193^k$

$2C_s = 2f_y(5.25)y = 2(44)(5.25)y$

Sum of forces = 0

$193 + 462y = 220$

$y = 0.06''$

$M_u = 220(4) + 193(2) - 462(0.06)^2/2$

$= 1,265$ k-ins.

$M = 24P_u = 1,265$

$P_u = 52.7^k$ vs. actual $P_u = 52.5^k$

Load/stud $= C_c/n = 193/16 = 12.06^k$

Beam B (Neutral axis in slab)

$f_y = 44$ ksi; $f' = 6,472$ psi

$T = f_yA_s = 220^k$

$C_c = 0.85f'_cba = T$

$0.85(6.47)(18)a = 220$

$a = 2.22''$

$M_u = T(\frac{d}{2} + t - \frac{a}{2})$

$= 220(8 - 1.11) = 1,527^{k\text{-}ins.}$

$M = 24\ P_u = 1,527$

$P_u = 63.6^k$ vs. actual $P_u = 62^k$

Load/stud $= C_c/n = 220/16 = 13.75^k$

Figure 15

Two beam tests were performed to check designs based on pushout test results (Fig. 13). For design purposes, an A36 8WF17 with an area of 5 sq in. was assumed completely yielded. Shear connectors would have to transfer the total tension of 180 kips to the concrete slab. Using the ultimate pushout strength of ½-in. studs, 15 would be required, but 16 were used.

The dimensions and loading were the same for both specimens and are shown in Fig. 14. A 4 in. thick by 18 in. wide lightweight concrete slab was connected to a 9 ft-6 in. length of steel beam with sixteen ½ × 2 in. studs on each half, arranged in two rows. Symmetrical loads were applied 6 in. off centerline to produce a maximum moment of 24*P* kip-in. Dial gages were attached at the ends and at the quarter point to measure slip, and SR-4 strain gages were mounted in the constant moment zone to measure strains. Each beam was loaded in increments to successively higher loads and unloaded to obtain slips and residual slips.

One beam was tested seven days after casting when the concrete strength was 3,154 psi. The other was tested at 28 days, when the concrete strength was 6,472 psi. Both beams failed by yielding of the steel beam followed by crushing of the concrete.

The calculated ultimate loads for both beams are given in Fig. 15. These are amazingly close to the experimental values. The calculated load per stud for Beam B was 13.8 kips, about 15 percent higher than that from pushout tests, and the studs did not fail.

The failure section of one specimen is shown in Fig. 16. The yield lines which formed are marked with white chalk to be more visual. Note that tensile cracking of the slab penetrated for some height. The lower picture shows the other side of the same specimen.

Slip at the quarter point was similar to that obtained in pushout tests.

The beams designed using results of the pushout tests behaved quite satisfactorily.

OTHER TEST PROGRAMS

Tests are being performed with a Haydite-type aggregate at the University of Missouri under the direction of Dr. James W. Baldwin. Details of the pushout specimen are shown in Fig. 17. Both stud and channel shear connectors are included in the investigation. The data obtained from the pushout specimens (Fig. 18) is being successfully used to predict behavior of beams. An

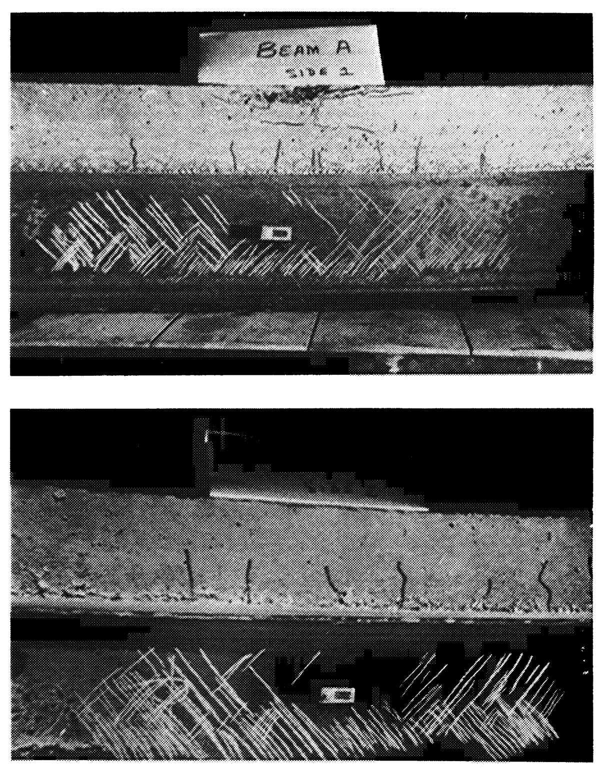


Fig. 16. Lueders lines at 62 kip load after having been outlined with chalk

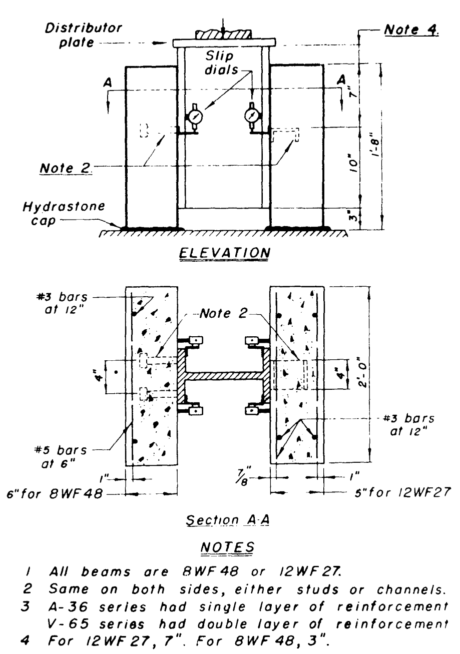


Fig. 17. Details of pushouts

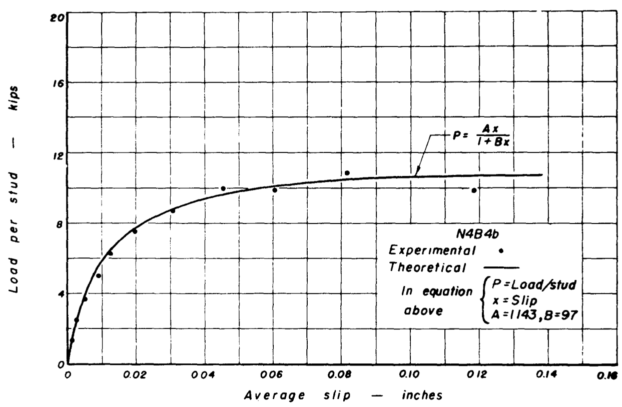


Fig. 18. Load-slip curve for pushout

equation has been fitted to the load-slip results, and it is hoped that a general equation can be developed that will eliminate the need for pushout tests. Unfortunately, the results of these pushout tests were not available at the time this paper was being prepared.

Pushout tests have also been performed at Lehigh University by Mr. Roger G. Slutter. He tested three identical specimens using four ½ × 3 in. headed studs on each flange of an 8WF28. Slabs were 4 in. thick × 24 in. wide. Concrete was made with lightweight expanded shale coarse aggregate, ¾ in. to No. 4, and local sand. It had a compressive strength of 6,290 psi at the time of test. The flanges of the beam were sandblasted and left ungreased prior to casting of slabs.

Dial gages registered slip as load was applied to failure. Failure was due to shearing of studs. Useful capacity was taken as load for 0.004 in. slip. Values obtained were 7.91, 8.51, and 7.31 kips with an average of 7.91 kips. This compares with 6.59 kips by Viest's formula and 8.15 kips by the Colorado formula. Ultimate strengths averaged 11.88 kips per stud compared to the 12.13 kips of the Colorado tests. Photographs of failures appear quite similar to Colorado results.

Dr. A. A. Toprac has also done some pushout studies at the University of Texas. No doubt his results will be made available in the near future.

The Colorado tests indicate that the particular lightweight concrete tested is at least as good as sand-and-gravel concrete in composite construction. The Missouri and Lehigh investigators seem to have reached the same conclusion for the concretes they used. These are tests on only three of the many lightweight concretes on the market, however, and obviously more tests are called for. This statement should be qualified, however. The more test results are observed, the more the author is inclined to believe that there is *less* variation in properties of lightweight aggregates produced by the rotary kiln process than most engineers believe. At the same time, there is *more* variation in the properties of sand-and-gravel concretes than most engineers believe. The author has every confidence that lightweight concretes with proven records of performance will prove out in composite tests, but believes that the tests *should* be made. The pushout test, which is relatively inexpensive, is an adequate test.

SPECIFICATION PROGRAMS

One other question arises which has nothing to do with whether the concrete is sand-and-gravel or is lightweight, but is of much more importance. The AISC Specification contains no material property requirements for shear connectors. Conceivably, someone could weld A141 rivets on to a beam and count them as effective as the 60 ksi yield point studs used in the tests reported here. It is respectfully submitted that AISC should include a material requirement for shear connectors, just as it does for all other structural fasteners.

ACKNOWLEDGMENTS

The cooperation of the Burkhardt Steel Company, which donated some of our pushout and both beam specimens, is gratefully acknowledged. Also, the help of Mr. Tilak Dhir, who did some of the testing, was very much appreciated.

Figures 17 and 18 in this paper are taken from "Load-Deformation Behavior of Composite Bridge Stringers" by Gene M. Sweeney, a thesis submitted in February, 1965, to the Faculty of the Graduate School of the University of Missouri in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.