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Incremental Slip of Stud Shear Connectors under Repeated Loading

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Summary

A test to measure the incremental slip of stud shear connectors under repeated loading is described. Results of both symmetric and unidirectional cyclic load tests are presented, together with empirical equations for the rate of slip growth as a function of load.

1. Introduction

Incremental slip between the concrete slab and the steel beam in a composite beam constructed with stud shear connectors has been observed by a number of researchers while undertaking fatigue testing of shear studs, but relatively few have focussed on the importance of incremental slip in its own right, and attempted to quantify the slip behaviour as a function of load and number of cycles (see for example Hallam (1976), Hawkins & Mitchell (1984), Oehlers & Carroll (1987), Oehlers & Coughlan (1986)). Incremental slip occurs due to crushing of the compression concrete ahead of the shear stud, and yielding of the shear stud.

Under monotonic loading this slip is not detrimental to the behaviour of a composite beam, but rather it is beneficial because it provides the ductility in the shear connection which allows loads to be redistributed at the ultimate limit state. Under repeated loading, however, the slip accumulates with each cycle of load. If the slip increments reduce with load cycles, the slip will stabilise, and the beam can be considered to have "shaken down" to a stable equilibrium condition. If the slip increments are constant or increase with each cycle of load, then shakedown will not occur, and incremental collapse of the beam will result. A serviceability failure of the structure is the likely outcome of this latter situation.

An experimental investigation of the shakedown behaviour of composite beams conducted at Monash University (Thirugnanasundralingam 1991) showed that incremental collapse occurred at loads as low as 53% of the static collapse load. It is clear, therefore, that guidance is needed for designers on the shakedown loads for composite beams, and the rate at which incremental slip (and hence incremental beam deflection) will occur if the shakedown load is exceeded. To meet this need, a series of tests have been undertaken on composite beam specimens with the specific aim of quantifying the incremental slip behaviour, and obtaining an empirical relationship between the level of cyclic load and the rate of slip growth per load cycle.

2. Test set up

Many authors have discussed the requirements for a test set up that will give a true representation of the strength of shear studs in composite beams (see for example Viest (1956), Chapman (1964), Mainstone & Menzies (1967), Davies (1967a and b), Goble (1968), Ollgaard, Slutter & Driscoll (1971), Hawkins (1973), Johnson & Oehlers (1981), Maeda, Matsui & Hiragi (1983) and Gattesco & Giuriani (1996)). From this work, the "push-out" test has evolved as the standard test for the strength of stud shear connectors. The parameters of the test are described in various codes of practice (see for example Eurocode 4 (ENV 1994-1-1: 1992)). The test has gained acceptance despite the long recognised fact that prying forces are developed across the concrete-steel interface, resulting in tension in the shear studs. Therefore, the test can be considered as a standardised measure of shear stud performance, rather than an accurate reproduction of the behaviour that occurs in a composite beam. An analogy would be the cube or cylinder test for concrete, which has developed as a standard test despite the fact that the loading conditions for concrete in a beam situation are not accurately reproduced in the standard test.

In undertaking this investigation into the incremental slip of shear stud connectors under repeated load, an early decision had to be made as to whether to undertake the investigation using a test rig that would reproduce as accurately as possible the conditions in a composite beam, or to use the "push-out" test, adapted for cyclic loading, and accept the known differences between the test conditions and the situation that exists in a composite beam. The push-out test was adopted for this testing programme, because it was considered that, just as it has gained acceptance with industry as a standardised measure for the static strength of a shear stud, it has the potential to be accepted as the standard test for the incremental slip behaviour under repeated loading.

2.1 The test specimens

The two concrete slabs used for each push-out test were 450 mm (in the direction of the applied load) by 500 mm x 90 mm thick. Each slab was connected to the flange of a steel I beam with four 12.5 mm diameter by 50 mm headed shear studs. The studs were arranged in two rows with a lateral spacing of 65 mm (5.2 diameters). The longitudinal spacing was 50 mm. To prevent longitudinal splitting, the slabs were reinforced with two layers of 8 mm wires at 100 mm centres. Maeda, Matsui & Hiragi (1983) have identified the need for each pair of slabs to be cast horizontally with the shear studs vertical. Various researchers have used different methods to achieve this, including casting the slab for one side of the push-out specimen, inverting the specimen when the concrete has hardened sufficiently, and casting the other slab. This has the disadvantage that each specimen is by necessity cast from a separate concrete mix, and given the variation that occurs in concrete strength between mixes, the two slabs will very likely have slightly different properties. Another method that has been adopted is to cast the slabs onto separate steel plates which, when welded to a third plate, form the flanges and web of an I beam. In this research program, a modification of this procedure was undertaken whereby the studs were welded to a 20 mm plate. Each plate was subsequently connected to a flange of a rolled steel I beam by bolting the plate to the beam flange with 10 high strength 12 mm bolts. This procedure met the objectives of casting the specimens horizontally with the studs vertical, and from the same concrete mix, but avoided the need for expensive and time consuming welding as part of the specimen preparation. The plate was greased prior to casting to remove friction between the concrete and the steel.

2.2 The test rig

A purpose built reaction frame was constructed for these tests (Figure 1). Because the specimens were tested under cyclic load, the specimens were clamped between steel plates and the reaction frame acted in both tension and compression. The steel plates provided horizontal restraint to the slabs on their compression edge by friction between the concrete and the steel. The specimens were loaded by a 100 kN servo controlled Instron hydraulic actuator. Monotonic tests were conducted under displacement control (0.6 mm per minute) and the cyclic load tests were tested under load control, so that incremental slip measurements could be obtained. Slip between each slab and the steel plate to which it was connected was measured directly via a linearly variable differential transformer mounted on the steel plate and reacting against a bracket on the concrete slab. The compliance of the load frame, and any potential slip in the bolted connection between the steel plate and the steel I beam was therefore excluded from the slip measurements.

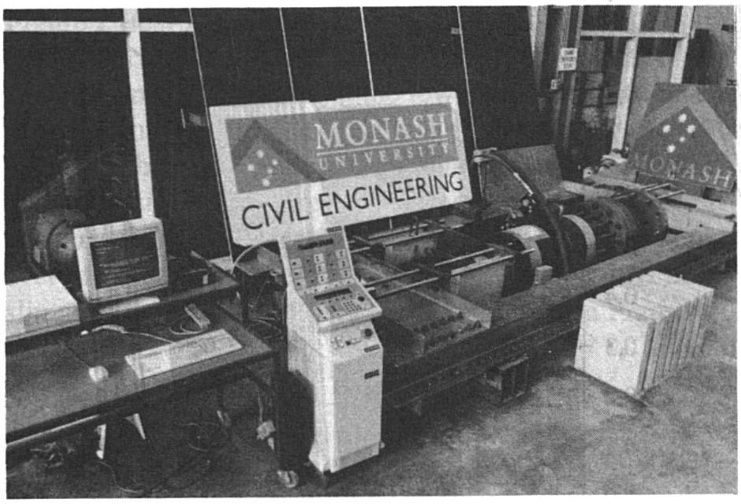

Figure 1: Test rig and specimens

3. Test results

3.1 Monotonic tests

Four specimens were tested under monotonic loading to establish the static strength of the stud shear connectors, Pu. The results of those tests are presented in Table 1 below.

Test number	Ultimate load per stud, Pu (kN)	Slip at ultimate load (mm)
2	47.4	
7	50.8	6.11
8	46.0	5.11
10	52.4	6.11
average	**49.2**	**5.78**

Table 1: Monotonic test results

3.2 Symmetric cyclic test results

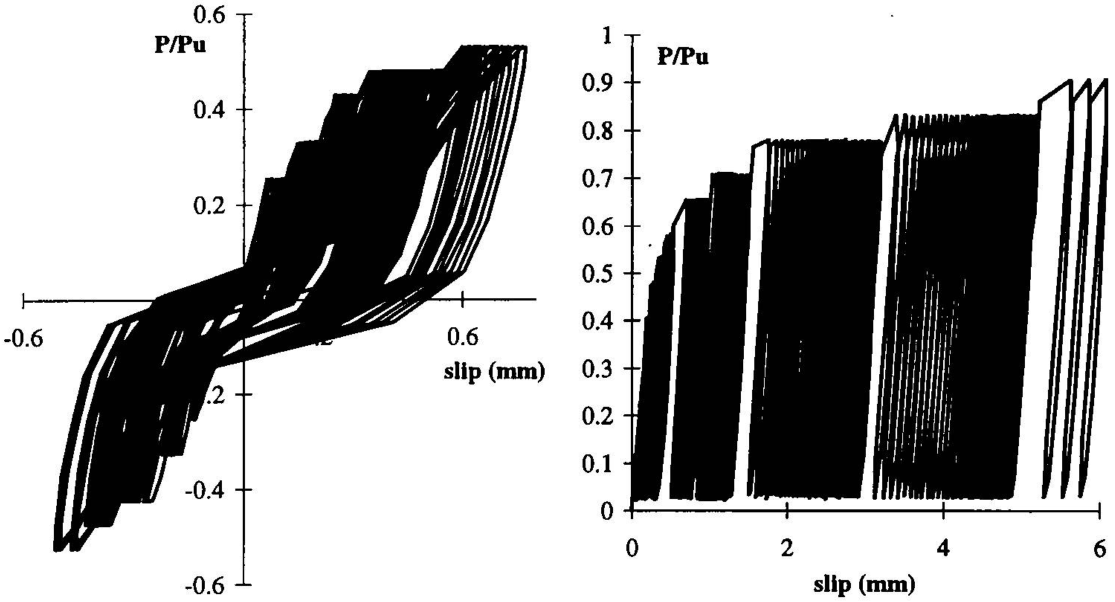

Fig. 2 Load versus slip plots for symmetric cyclic (test 15 - left) and unidirectional cyclic (test 13 - right) loading

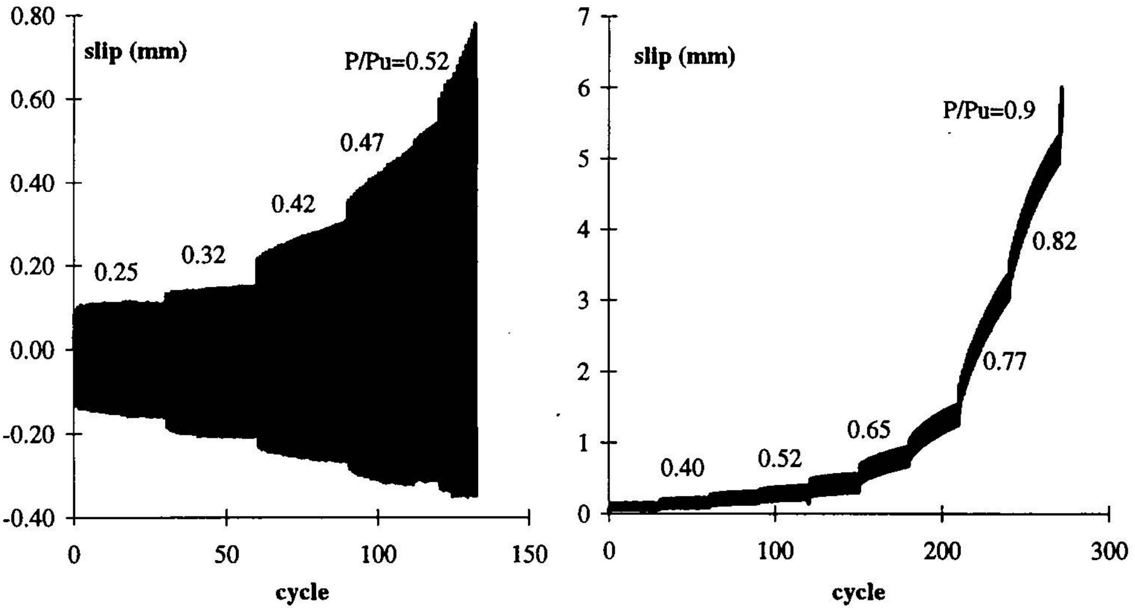

Fig. 3 Slip per cycle versus cycle plots for symmetric cyclic (test 15 - left) and unidirectional cyclic (test 13 - right) loading

Six specimens were tested under cyclic load, where the loading pattern involved complete reversal of the load. The time for one load cycle was typically three minutes. The rate of loading was increased as the load range increased in order to keep the cycle time constant. The load was applied for thirty cycles at each load level. A typical load-slip plot is presented in Figure 2 (test 15). From the figure it is clear that the slip incremented with every cycle, even at the lowest applied load level, however it is not immediately clear from the figure whether or not shakedown was achieved at the lowest applied load level. In order to obtain a better appreciation of the rate of increase of slip with load cycles, the data was presented as slip versus cycle number. Again, the data for test 15 is presented in Figure 3. It is clear from this figure that at a given load range the slip increases approximately linearly with cycles, and so it was possible to fit a straight line to the data within any given load range. This was repeated for every test, at every load range, for load in each direction. The slope of the straight line gives the slip growth per load cycle. This is presented in Figure 4 on a logarithmic scale.

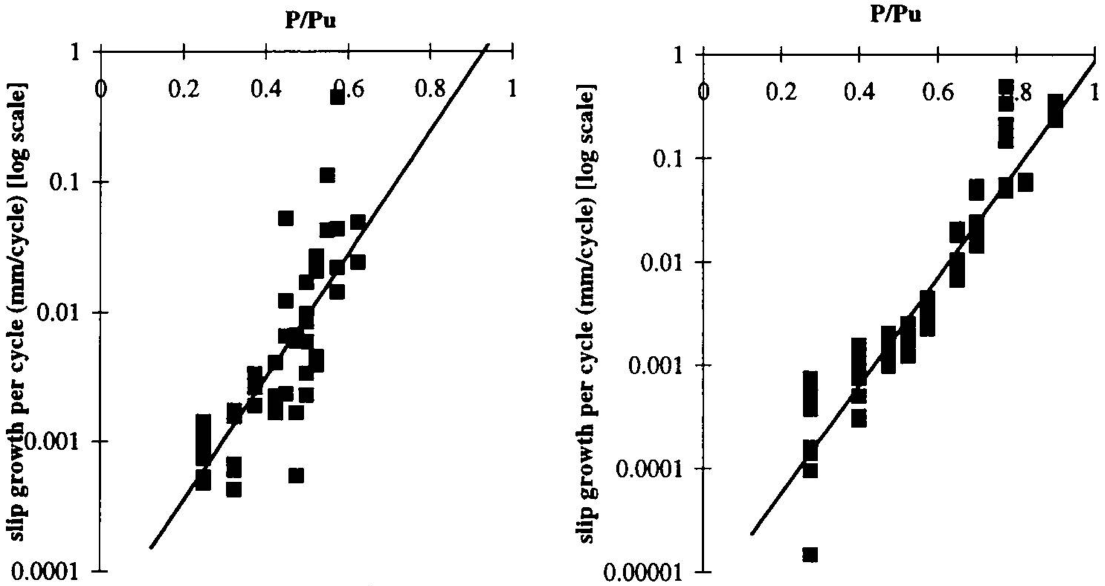

Fig. 4 Slip growth per cycle versus load plots for symmetric cyclic (test 15 - left) and unidirectional cyclic (test 13 - right) loading

3.3 Unidirectional cyclic test results

Three specimens were tested under cyclic load, where the load ranged from zero to maximum load. The time for one load cycle was typically one and a half minutes. A typical load-slip plot is presented in Figure 2 (test 13), the slip versus cycle number is plotted in Figure 3, and the slip growth per load cycle is presented in Figure 4 on a logarithmic scale.

3.4 Empirical relationship for the rate of slip growth

From the data presented in Figure 4, best fit lines were calculated to predict the slip growth per load cycle. This gave the following relationships:

symmetric cyclic load,

$\log_{10}$[slip growth per cycle (mm/cycle)] = -4.41 + [peak load (kN)] x 0.0119 *Eqn. 1*

unidirectional cyclic load,

$\log_{10}$[slip growth per cycle (mm/cycle)] = -5.29 + [peak load (kN)] x 0.0130 *Eqn. 2*

It is evident form figure 4 that symmetric cyclic loading leads to a faster growth of slip.

4. Conclusions

Incremental slip occurs in stud shear connectors under repeated loading, leading to incremental collapse of composite beams. Symmetric cyclic loading leads to a faster rate of slip growth than unidirectional cyclic loading. By using a push-out test adapted for cyclic loading, it is possible to obtain empirical equations for the rate of slip growth as a function of load. This information can be used by designers to estimate the rate at which incremental collapse will occur in composite beams under repeated loading.

5. References

Chapman, J.C. *Composite construction in steel & concrete - the behaviour of composite beams,* Structural Engineer Vol 42 No 4 April 1964 pp 115-125
Davies, C. *Small scale push-out tests on welded stud shear connectors,* Concrete Sept 1967 pp 311-315
Davies, C. *Steel-concrete composite beams with flexible connectors: a survey of research,* Concrete Dec 1967 pp 425-430
ENV 1994-1-1:1992 *Eurocode 4: Design of composite steel and concrete structures Part 1.1 General rules and rules for buildings*
Gattesco, N. & Giuriani, E. *Experimental study on stud shear connectors subjected to cyclic loading,* Journal of Constructional Steel Research vol 38 No 1 1996 pp 1-21
Goble, G.G. *Shear strength of thin flange composite specimens,* Engineering Journal AISC Vol 5 No 2 April 1968 pp 62-65
Hallam, M.W. *The behaviour of stud shear connectors under repeated loading,* University of Sydney School of Civil Engineering Research Report R 281 August 1976
Hawkins, N.M. & Mitchell, D. *Seismic response of composite shear connections,* Journal of Structural Engineering ASCE Vol 110 No 9 September 1984 pp 2120-2136
Hawkins, N.M. *The strength of stud shear connectors,* Civil Engineering Transactions IEAust 1973 pp 46-52
Johnson, R.P. & Oehlers, D.J *Analysis and design for longitudinal shear in composite T-beams,* Proceedings ICE Pt 2 71 Dec 1981 pp 989-1021
Maeda, Y. Matsui, S. & Hiragi, H. *Effects of concrete placing direction on static and fatigue strengths of stud shear connectors,* Technology Reports of the Osaka University Vol 33 No 1733 Oct 1983 pp 397-406
Mainstone, R.J. & Menzies, J.B. *Shear connectors in steel-concrete composite beams for bridges, Part 1: Static and fatigue tests on push out specimens,* Concrete Sept 1967 pp 291-302
Oehlers, D.J. & Carroll, M.A. *Simulation of composite beams subjected to traffic loads,* in "Composite construction in steel and concrete" C.D. Buckner & I.M. Viest ed 1987 pp 450-459
Oehlers, D.J. & Coughlan, C.G. *The shear stiffness of stud shear connections in composite beams,* Journal of Constructional Steel Research 6 (1986) pp 273-284
Ollgaard, J.G. Slutter, R.G. & Fisher, J.W. *Shear strength of stud connectors in lightweight and normal weight concrete,* Engineering Journal AISC April 1971 pp 55-64
Thirugnanasundralingam, K. *Continuous composite beams under moving loads,* PhD Thesis Monash University May 1991
Viest, I.M. *Investigation of stud shear connectors for composite concrete and steel T-beams,* ACI Journal Vol 27 No. 8 April 1956 pp 875-891