Oct 20th, 12:00 AM

The Bi-axial Behaviour of Shear Connectors in Composite Slabs and Beams

Chris T. Duffy

David O'Leary

Michel Montourcy

Eleventh International Specialty Conference on Cold-Formed Steel Structures
St. Louis, Missouri, U.S.A., October 20-21, 1992

THE BI-AXIAL BEHAVIOUR OF SHEAR CONNECTORS IN COMPOSITE SLABS AND BEAMS

Chris T Duffy*, David O'Leary* and Michel Montourcy**

Introduction

The use of composite beams which utilise steel beams together with a composite steel sheet/concrete floor slab is well developed. Many forms of steel profile are used and the form of attachment to the steel beam is generally by welded shear studs or shot-fired shear connectors. The design procedures for these beams require a knowledge of the shear capacity of the connectors which may be influenced by the type of profile being used for the beam. This shear capacity is often deduced from information obtained from standard push-off tests which may or may not include in the test set-up the actual profile type to be used. There is variation between countries in the test procedures used for push-out tests; parametric studies on the sample size and loading procedures have not produced a definitive model. The proposed Eurocode 4 version has a test set up for the push-off tests which is broadly similar to past types but introduces an element of cyclic loading.

The development of composite floors has seen improvements in profile design leading to more efficient shear transfer. Work has also been carried out to increase the load capacity for these slabs by the use of end anchorages. These anchorages which prevent the slip of the profile steel sheet relative to the concrete are generally shear connectors attached to the supporting beams through the profiled steel sheet. In the majority of practical design cases the connectors used for the composite beam will, designed for or not, be capable of providing some force at right angles to the beam axis in the direction in which the slab is spanning. In an early reference[1] to this behaviour design account need only be taken if the connector was designed for such two-way action.

It, therefore, appeared necessary to consider how this two-way or biaxial behaviour affected the capacity of the shear connector when designed to act either in one or both directions. Certain codes referred to the capacity in both directions as a function of the traditional push-off value but this has been demonstrated as not being the case.

Existing Shear Connector Push-Off Tests

Standard test procedures are used to establish the shear capacity of connectors in solid slabs or in slabs with profiled steel sheeting. Work by Fisher[2] and others has permitted the influence of connector type and profile geometry to be considered in design. A typical set up is shown in Figure 1. The failure criteria which is primarily a function of concrete strength is either the cube strength up to 40 N/mm^2 or connector strength in shear above this value of 40 N/mm^2.

---

* Department of Civil Engineering and Construction, University of Salford, UK
** CUST, University of Blaise Pascal, Clermont-Ferrand, France.

End Anchorage Capacity

The capacity of an end anchorage to prevent slip between steel sheet and concrete was initially demonstrated by slab tests on composite slabs using indented and non-indented or plane profiles.[3] The failure form in these tests was characterised by a local buckling of the profile at the point of connection together with a possible tearing of the sheet if the sheet overhang was small. Tests by Profanter[4] produced a relationship which incorporated the sheet thickness and strength, the distance and the width of sheet influenced by the connector or anchorage.

The design formulae took the form:-

$$P_t = D_r.t\,(\alpha_z + \alpha_d)\,f_y$$

$$\alpha_z = \alpha_d = \frac{l_u}{D_r} - 0.3$$

where P_t = shear resistance provided by one welded connector
D_r = diameter of the weld at the bottom of the connector

t = profiled steel sheet thickness
f_y = yield strength of sheeting
l_u = distance between centre of connector and the end of the profiled steel sheeting.

Work at ICOM[5] Lausanne on full-scale slab tests and pull-off tests supported these proposals. The tests indicated that the predominant form of failure is due to buckling of the profile between the connector and the end of the profile, in certain cases with small end distances this could result in fracture of the profile.

Further to this failure forms similar to bolted connections were noted while the failure load varied non-linearly with the end distance.

For comparison the ICOM push-off test value for welded connectors (16 mm diameter) was 17.9 kN/connector compared to 20.0 kN/connector predicted by the Profanter equation (developed for 19 mm diameter studs). The design shear resistance for these studs in a composite beam is 47 kN.

Similar work on Hilti connectors indicated a value of 13.2 kN for HVB 95 connectors against a design shear resistance in beams of 28 kN.

Biaxial Test

In order to investigate the two-way behaviour of connectors a rig has been built to allow the simultaneous loading of a push-off/pull-out sample in the two perpendicular directions. The arrangement is shown in Figure 2. The jacks are controlled independently and enable the capacity of the specimen to be investigated for various combinations of load. In the case of the horizontal jack the load is applied via the steel beam as in the traditional push-off test and for the vertical force the load is applied via the profiled steel sheet in a manner similar to the ICOM test arrangement.

Test Details

The test specimen details are as shown in Figure 3. The profiled steel sheeting was cut from Hi bond/55/P600 with a nominal sheet thickness of 1.2 or 0.8 mm. Two universal beam sections were used together with six Hilti HVB105 connectors (three each side - one per trough). Mesh reinforcement (A142) was provided and normal-weight concrete (grade 30) was used; the sample was cast with the troughs vertical. Control cubes and cylinders were also cast.

Experimental Procedure & Behaviour

Tests were carried out on five samples. In order to maximise the information from the tests, the test procedure was varied so that points near to the boundary of the interaction curve could be obtained without necessarily causing the specimen to fail. The capacity of the sample in the two directions may be predicted from standard formulae in the push-off case and from experimental values in the pull-off case. The experimental results are shown in Table 1.

Conclusions

The interaction curve is shown in Figure 4. To date, the work indicates that from the results the effects of interaction are not highly significant due in part to the modes of failure being independent of each other and not interactive. In the case of the Hilti type connector the capacity as an end anchorage depends on the efficiency of the fixing enabling the foot of the connector to clamp the sheet. The two results suggesting a lower than expected value for the further horizontal capacity require investigation of the test set-up. The push-out test part of the sample is in fact one half of the test specimen used in the normal procedure which may have affected values together with the asymmetrical nature of the test producing an out of balance moment on the sample. For tests 2 and 3a the expected horizontal capacity was achieved suggesting that the vertical component of force had helped to align the sample. Modifications to the rig are being considered to improve this behaviour.

In conclusion the results are encouraging and underline the need to consider the actual failure form for design of shear connectors where dual behaviour is required. The evidence so far suggests no significant interaction and confirms that the anchorage failure form is tearing and buckling the sheet.

References

(1) European Convention for Constructional Steelwork. "European Recommendations for the Design of Composite Floors with Profiled Steel Sheet." ECCS - Committee 11. Constrado, 1975.

(2) Grant, J.A., Fisher, J.W., Slutter, R.G. Composite beams with formed steel deck. American Institute of Steel Construction, Engineering Journal, New York, Vol. 14, No. 1, 1977, pp 24-43.

(3) Laruaz, P. "Design and Behaviour of Composite Slabs with Profiled Steel Sheets", C.U.S.T. University of Blaise-Pascal, Clermont Ferrand/University of Salford. 1983.

(4) Profanter, H., Zum Nachweis der Blechzugkrafteinleitung durch Kopfbolzendubel-Endverankerung bei Profilblechverbunddecken (1. Teil). Stahlbau Rundschau, Wien, No. 59, 1982, pp 1-6.

(5) Daniels, B.J., Crisinel, M., O'Leary, D.C. "Testing of Continuous Span Composite Slabs with Hibond 55 Profiled Sheeting" Lausanne, Ecole Polytechnic Federale. 1990. Publication ICOM 229.

Test No	Loads at Failure (kN)		Profiled Sheet Thickness (mm)
	Horizontal	Vertical	
1	150	150	1.2
2	205	120	1.2
3	80	170	1.2
3a	200	80	1.2
4	170	0	0.8
5	172	0	1.2

Note: Results 3 and 3a have been obtained from the same specimen - the values given by test 3 are before failure.

Table 1: **Results from Bi-Axial Tests with Hi Bond 55 Profile and Hilti HVB 105 Connectors**

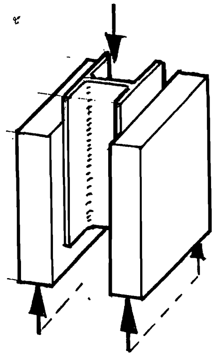

Figure 1. Standard push-out test

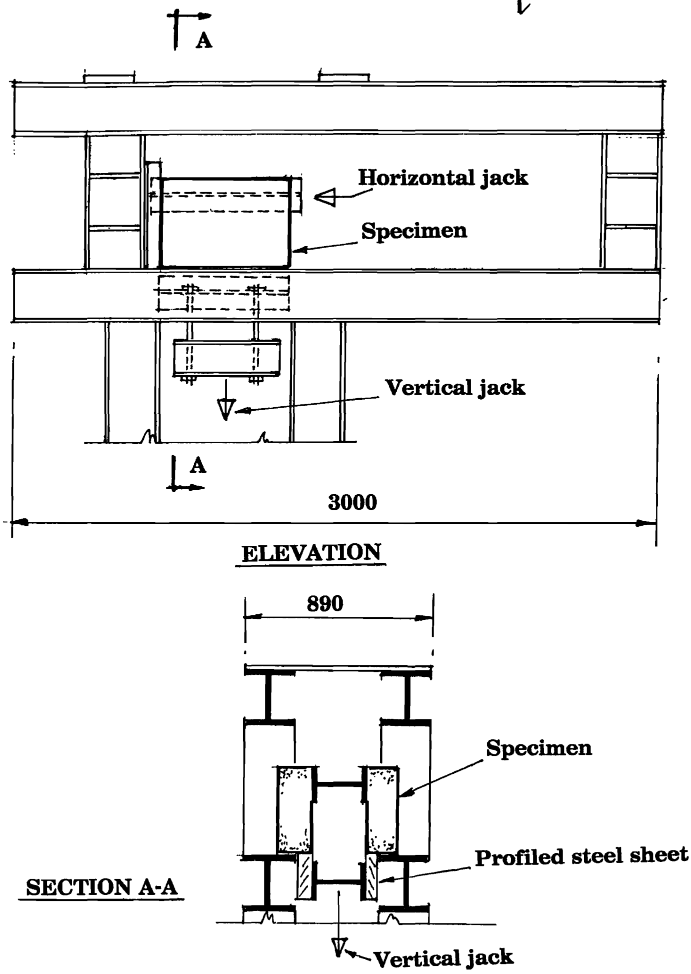

Figure 2. TEST-RIG DETAILS

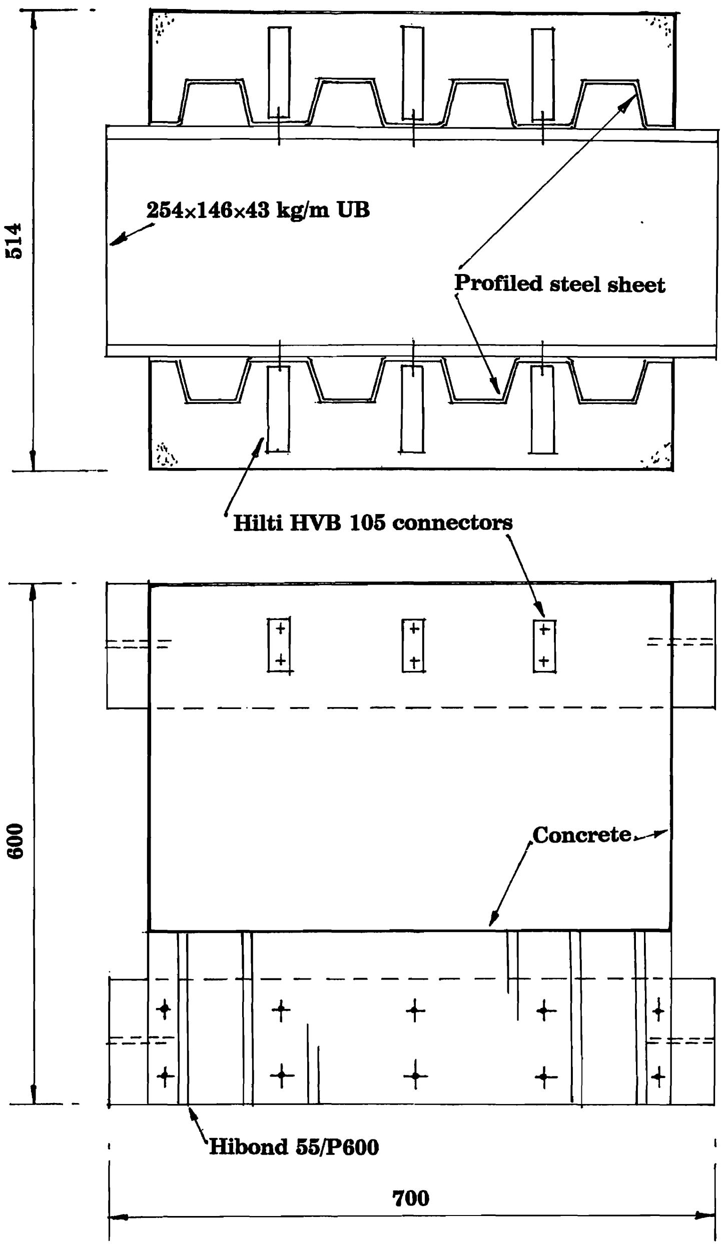

Figure 3. TEST-SPECIMEN DETAILS

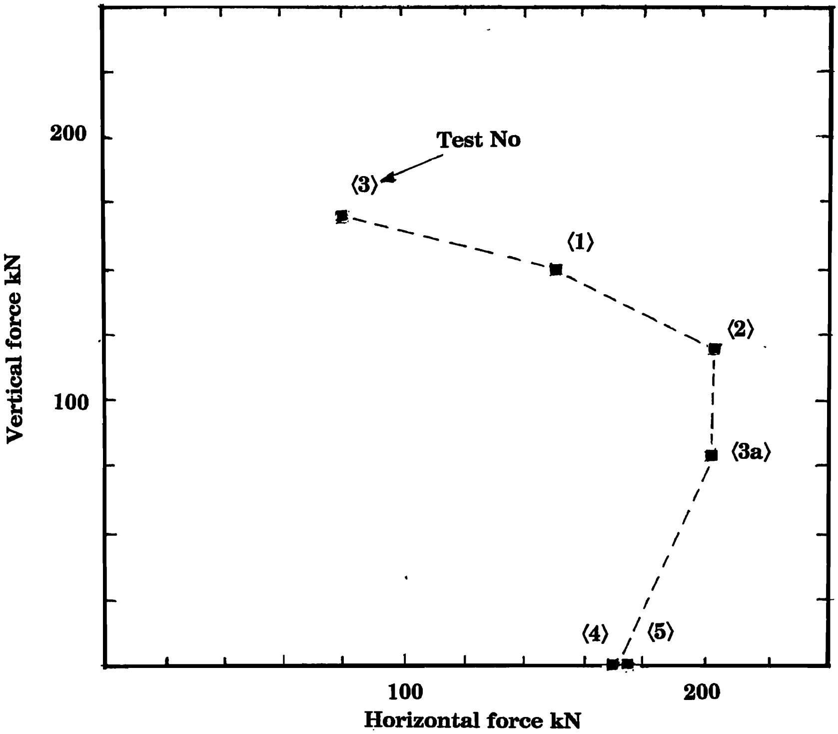

Figure 4. Experimental interaction diagram