Shear strength of unwelded shear connectors for composite beams

Shear Strength of Unwelded Shear Connectors for Composite Beams

Résistance au cisaillement de connecteurs non soudés pour construction mixte acier-béton

Scherfestigkeit von ungeschweissten Schubverbindungen für Verbundträger

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SUMMARY
This paper describes push-out tests to determine the strength of several fixings used to provide the shear connection between composite slabs and composite beams. The research investigates the effect of varying the pattern of the fixings, the type and orientation of the profiled sheeting, the concrete strength and steel beam size.

RÉSUMÉ
Cet article décrit les essais de type «push-out» effectués en vue de déterminer la résistance de différents moyens de connexion entre les planchers mixtes avec tôle profilée et les poutres métalliques. L'étude traite de l'influence de l'écartement des fixations, du type et du sens porteur de la tôle profilée, de la résistance du béton et de la dimension de la poutre métallique.

ZUSAMMENFASSUNG
In diesem Referat werden «push-out»-Versuche beschrieben, in denen die Tragfähigkeit von mehreren Befestigungsvorrichtungen bestimmt wird, welche die Schubkräfte zwischen Platte und Träger des Verbundelementes übertragen. In der Forschungsarbeit werden die Auswirkungen untersucht, wenn das Muster der Befestigungsvorrichtungen, die Art und Orientierung der im Querschnitt dargestellten Verkleidung, die Festigkeit des Betons und die Dimensionen des Stahlbalkens verändert werden.

1. INTRODUCTION

Composite slabs of profiled steel sheet permanent shuttering and concrete provide for construction of spans up to three or four metres without additional support from beams. On large contracts, or in bridges, where spans in excess of 10 metres can be required, welded shear connectors provide economic composite beams. The aim of this research, into the use of unwelded shear connections, is to bring the economic advantages of composite beam construction to the intermediate span beams which are more common on smaller construction contracts. In addition, the results show the contribution of the unwelded fixings used to locate the profiled steel sheeting during construction to the shear resistance of composite beams with through-deck welded shear connectors.

Unwelded shear connectors have already been used in the construction of some buildings in the U.K., for example self-drilling, self-tapping screws for a hospital in Oxfordshire, and shot-fired fixings for a multi-storey car park and other small buildings in South Wales. In general, each application has had to be justified by beam load tests.

The advantages of using unwelded shear connectors are that it avoids the requirement for expensive three-phase welding equipment and trained operatives on smaller sites, or where only modest beam spans are used.

These methods of fastening are less weather-dependent, and should be attractive in developing countries where skilled staff are at a premium.

2. THE TEST PROGRAMME

2.1 Test variables

This paper describes the results obtained from push-out tests on four proprietary fixings which may be suitable for providing shear connection in composite beams. The push-out tests were based on the standard dimensions quoted in CP117 [1] for concrete cast directly onto the steel beam. The concrete area was increased, when necessary, to coincide with integer multiples of the pitch of the steel decking profiles. The aim was to ascertain the behaviour of the connections under a wide range of likely practical conditions. Consideration was therefore given to the following wide range of variables;

- the number and pattern of the different fixings,
- the type of profiled sheeting (dovetailed and trapezoidal sections),
- orientation of the profiled sheeting,
- type of concrete (normal weight and lightweight aggregate),
- size of the steel beam section.

A summary of the tests is given in table 1. Variations made to each of these parameters will be described in more detail.

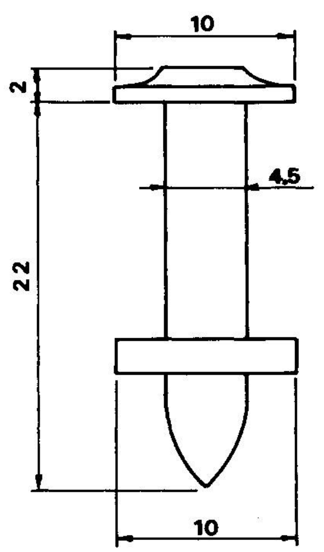
2.2 Fixings

The four types of fixing used as shear connectors in the tests are;

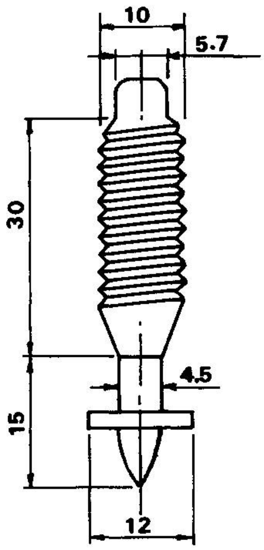
- shot-fired threaded studs,
- shot-fired nails,
- an angle bracket fixed by two shot-fired nails,
- self-drilling, self-tapping screws.

Each of these connections is shown in figure 1.

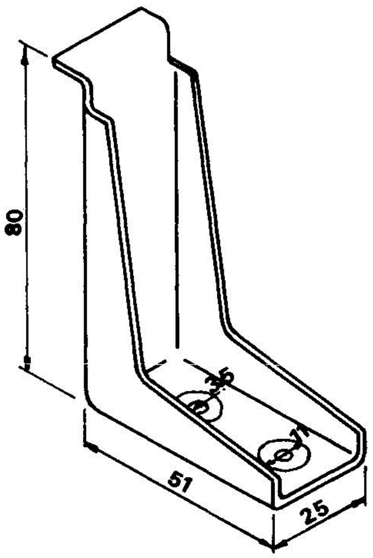
Seven different patterns of connection were used for each of the profile types. The cross-sectional dimensions of each profile influenced the choice of these patterns, which varied from two fixings per face to eight fixings per face in the push-out test (see figure 2).

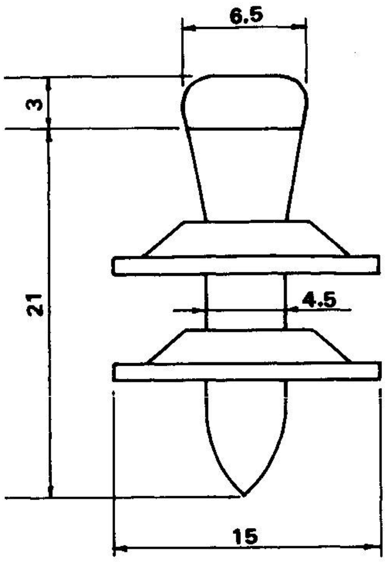


Shot-fired nail

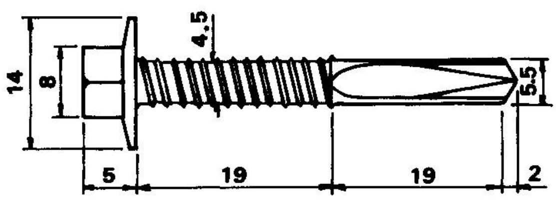


Shot-fired threaded stud



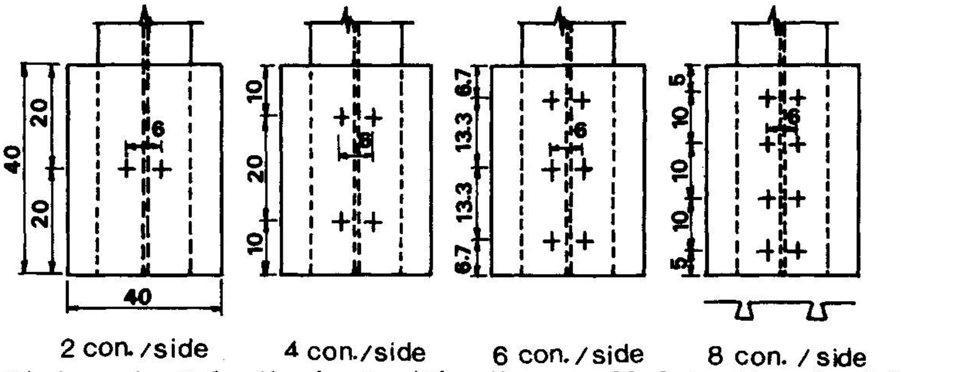


Angle bracket shear connector and detail of the shot-fired nails used to fix it

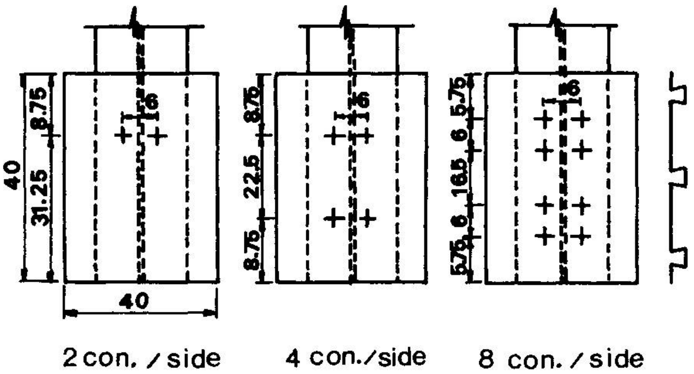


Self-drilling, self-tapping screw

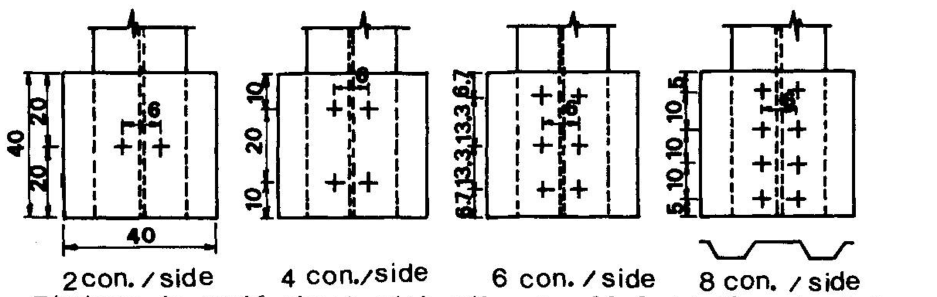
FIGURE 1. TYPES OF FIXING.



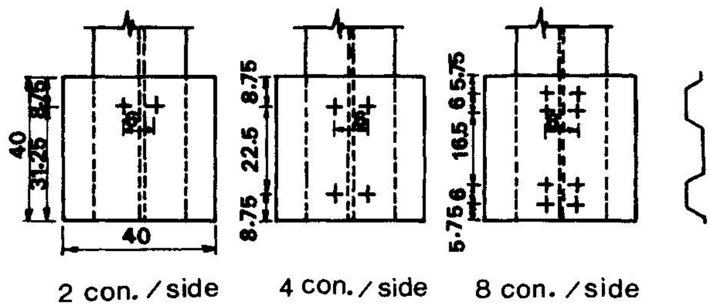
Fixings in Holorib sheet with ribs parallel to the steel beam



Fixings in Holorib sheet with ribs perpendicular to the steel beam



Fixings in CF46 sheet with ribs parallel to the steel beam



Fixings in CF46 sheet with ribs perpendicular to the steel beam

Dimensions in centimetres

FIGURE 2. FIXING PATTERNS FOR PUSH-OUT TESTS.

2.3 Profiled Steel Sheeting

Two types of profiled steel sheeting were used in the tests: Holorib, produced by Richard Lees Ltd., and CF46 produced by Precision Metal Forming Ltd. The thinnest available gauge of each type of sheeting was used, since shearing or tearing of the sheeting are the only likely effects contributing to any failure mechanism. The results should, if anything, give conservative strengths for the thicker sheeting which is available.

2.4 Orientation of the profiled sheeting

Composite slabs are most commonly designed as one-way spanning. The ribs of the sheeting are then orthogonal to the supporting beam which is likely to be designed to act compositely. Some degree of two-way action of the slab is inevitable when there is a trimming beam around the slab. Use of the profiled sheeting was therefore investigated in both orientations.

2.5 Types of concrete

Lightweight aggregate concrete is now common in the U.K. for composite slab/composite beam construction due to the enhanced fire protection provided and the reduced self-weight of members. Three types of concrete were used.

- Normal weight concrete with a target characteristic strength of 40 N/mm^2. The solids content was in the ratio 1:2.36:4.03 (by weight), with a free water : cement ratio of 0.6. The mix had a 20 mm slump and density of 2350 kg/m^3.
- Structural lightweight concrete, also with a target strength of 40 N/mm^2. In this mix 'Lytag' with a maximum size of 10 mm was used as the only coarse aggregate. The solids ratio was 1:2.5:1.59, with a water : cement ratio of 0.75. The density of this mix was 1950 kg/m^3.
- Lightweight concrete with a target strength of 25 N/mm^2. Pumice aggregate graded from 15 mm to dust was the sole aggregate in this mix, for which the solids ratio was 1:2.09. A plasticising admixture was added to the water to compensate for the high absorbency of the pumice. The water : cement ratio was 0.65 and the resulting density was 1450 kg/m^3.

2.6 Size of steel beam

Work-hardening or crystalline phase changes due to heating were considered possible during the installation of the fixings. Any such effects would vary with the thickness of flange to be penetrated. Therefore three different sizes of steel I-beam were used to provide flange thicknesses ranging from 9.7 mm to 12.8 mm. The sections were;

- 305 x 103 UB25,
- 356 x 171 UB45,
- 406 x 178 UB60.

3. RESULTS

3.1 Failure modes and maximum shear strengths

There were four main modes of failure.

- Shearing of the connectors, when few connectors were used.
- Shearing of the concrete at the plane connecting the tops of the profiles.
- Separation of the concrete from the profiled sheeting.
- Tearing of the profiled sheet under the fixing heads.

When the failure was by shearing of the connectors, the average ultimate shear strengths obtained were 19.25 KN per shot-fired threaded stud , 11.8 KN per shot-fired nail, 20.25 KN per nail used to fix the angle bracket, and 14.38 KN per self-drilling, self-tapping screw.

3.2 The effect of test variables on failure mode and strength

In cases where failure was due to shearing of the fixing itself, less than a 5% reduction in shear strength per fixing was measured when the fixing density was increased. The self-drilling, self-tapping screws were almost twice as ductile as the shot-fired fixings, at equal loads. When failure was by shearing of the fixing or tearing of the sheet, the type of profiled sheeting had little effect. However, when the other failure modes predominated, the CF46 was strongest when orthogonal to the beam, and Holorib strongest when parallel to the beam.

The orientation of the sheeting had little effect when few fixings were used, with failure resulting from shearing of the fixings. When more fixings were used, shearing of the concrete occurred with the Holorib sheeting at shear stresses in excess of 0.92 N/mm^2 (0.59 N/mm^2 in pumice concrete) whereas separation was more likely with the CF46 sheeting at a shear stress above 0.49 N/mm^2 (0.42 N/mm^2 in pumice concrete). Higher shear stresses were required to produce concrete shear or separation failures when longer fixings were used. The longer fixings also produced slightly higher ultimate strengths when the sheeting ribs were parallel to the beam.

Strength results were almost identical when the normal weight and structural lightweight concrete were used. The very light pumice concrete showed signs of aggregate crushing in some tests. The flange thickness of the steel I-beams had no significant effect on the ultimate shear strengths.

4. CONCLUSIONS

Of the four types of fixing tested, only the shot-fired nails showed a tendency to tear through the sheeting. The low shear strength of these nails makes them of little use as independent shear connectors, though they make a useful contribution in conjunction with welded shear studs. The advantages of the self-drilling, self-tapping screws are greater ductility and security of fixing. Ease of fixing is the advantage of the shot-fired stud, but the greatest shear capacity is obtained with the angle bracket and its nail fixings.

Concrete shear failure and separation from the sheeting reduce the potential shear capacity of all these fixings when used independently, but steps could be taken to prevent these failure modes. Density of fixings and sheeting orientation would then have little effect on the shear strength.

Lightweight aggregate concrete should be avoided unless a structural lightweight mix is used, incorporating sand to prevent local crushing. Fire-rating and overall cost currently favour the use of lightweight coarse aggregate. Provided the fixings can penetrate the flange, any steel section can be used.

Full-scale beam tests are currently under way to justify the use of the push-out test results in composite beams incorporating the use of unwelded fixings as shear connectors.

REFERENCE

1. BRITISH STANDARDS INSTITUTION, CP117, Code of Practice for Composite Construction in Structural Steel and Concrete. BSI,London.

Test No.	No. of fixings	Type of sheet	Rib direction	Type of concrete	Type of beam	Test No.	No. of fixings	Type of sheet	Rib direction	Type of concrete	Type of beam
AN1	6	HR	PP	N	S1	CP3	4	HR	NN	P	S1
AN2	4	HR	PP	N	S1	CNS1	8	PMF	PP	N	S2
AN3	4	HR	NN	N	S1	CNS2	8	PMF	NN	N	S2
AN4	8	HR	NN	N	S1	CNS3	4	PMF	PP	N	S2
AN5	6	HR	PP	N	S3	CNS4	4	PMF	NN	N	S2
AN6	4	HR	PP	N	S3	CPS1	8	PMF	PP	P	S2
AN7	4	HR	NN	N	S3	CPS2	4	PMF	PP	P	S2
AN8	8	HR	NN	N	S3	CPS3	4	PMF	NN	P	S2
AN9	8	HR	PP	N	S1	CL1	8	HR	PP	L	S3
AN10	8	HR	PP	N	S3	CL2	8	HR	NN	L	S3
AN11	6	HR	NN	N	S1	CNS1M	4	HR	PP	N	S1
AN12	6	HR	NN	N	S3	DN1	4	HR	PP	N	S1
AP1	6	HR	PP	P	S1	DN2	8	HR	PP	N	S1
AP2	4	HR	PP	P	S1	DN3	4	HR	NN	N	S1
AP3	4	HR	NN	P	S1	DN4	8	HR	NN	N	S1
AP4	8	HR	NN	P	S1	DN5	4	HR	PP	N	S3
AP5	6	HR	PP	P	S3	DN6	8	HR	PP	N	S3
AP6	4	HR	PP	P	S3	DN7	4	HR	NN	N	S3
AP7	4	HR	NN	P	S3	DN8	8	HR	NN	N	S3
AP8	8	HR	NN	P	S3	DP1	4	HR	PP	P	S1
AL1	4	HR	PP	L	S3	DP2	8	HR	PP	P	S1
AL2	4	HR	NN	L	S3	DP3	4	HR	NN	P	S1
AL3	8	HR	PP	L	S3	DP4	8	HR	NN	P	S1
ANS1	6	PMF	PP	N	S2	DP5	4	HR	PP	P	S3
ANS2	4	PMF	PP	N	S2	DP6	8	HR	PP	P	S3
ANS3	4	PMF	NN	N	S2	DP7	4	HR	NN	P	S3
ANS4	8	PMF	NN	N	S2	DP8	8	HR	NN	P	S3
APS1	6	PMF	PP	P	S2	DL1	4	HR	PP	L	S3
APS2	4	PMF	PP	P	S2	DL2	4	HR	NN	L	S3
APS3	4	PMF	NN	P	S2	DL3	8	HR	NN	L	S3
APS4	8	PMF	NN	P	S2	DNS1	4	PMF	PP	N	S2
AN1F	4	HR	PP	N	S1	DNS2	8	PMF	PP	N	S2
APS1F	4	PMF	PP	N	S1	DNS3	4	PMF	NN	N	S2
BN1	6	HR	PP	N	S1	DNS4	8	PMF	NN	N	S2
BN2	8	HR	NN	N	S1	DPS1	4	PMF	PP	P	S2
CN1	8	HR	PP	N	S1	DPS2	8	PMF	PP	P	S2
CN2	8	HR	NN	N	S1	DPS3	4	PMF	NN	P	S2
CN3	4	HR	PP	N	S1	DPS4	8	PMF	NN	P	S2
CN4	4	HR	NN	N	S1	DN1F	4	HR	PP	N	S1
CP1	8	HR	PP	P	S1	DPS1F	4	PMF	PP	N	S1
CP2	4	HR	PP	P	S1						

<u>Key</u>

A...Shot-fired threaded studs
B...Shot-fired nails
C...Angle bracket shear connector fixed by two shot-fired nails
D...Self-drilling, self-tapping screws

HR Holorib sheet
PMF CF46 sheet

NN Ribs perpendicular to the beam
PP Ribs parallel to the beam
N Normal weight concrete
P Pumice lightweight concrete
L Lytag lightweight concrete
S1 UB25 steel beam
S2 UB45 steel beam
S3 UB60 steel beam

TABLE 1. SUMMARY OF THE TESTS

Test No.	f_{c28} (N/mm^2)	Failure Load (KN)	Load per connector (KN)	Failure mode	Test No.	f_{c28} (N/mm^2)	Failure load (KN)	Load per connector (KN)	Failure mode
AN1	40.5	205	17.1	C	CP3	24.9	80	10.0	C
AN2	42.0	155	19.38	S	CNS1	37.6	333	20.81	SEP
AN3	38.0	162	20.25	S	CNS2	42.8	305	19.06	SEP
AN4	42.0	190	11.88	C	CNS3	36.3	170	21.25	S
AN5	43.0	230	19.16	C	CNS4	42.8	160	20.0	P
AN6	38.0	155	19.38	S	CPS1	24.0	214	13.38	C
AN7	43.0	155	19.38	S	CPS2	24.0	160	20.63	S
AN8	43.0	215	13.44	C	CPS3	24.4	133	16.63	SEP
AN9	40.5	230	14.38	C	CL1	39.7	310	19.38	S
AN10	40.5	270	16.9	SEP	CL2	39.7	245	15.31	C
AN11	40.4	155	12.92	C	CNS1M	35.7	235	14.69	SEP
AN12	40.4	185	15.42	C	DN1	37.2	115	14.38	S
AP1	25.6	180	15.0	C	DN2	37.2	210	13.13	S
AP2	25.6	115	14.38	SEP	DN3	41.5	124	15.5	S
AP3	25.6	101	12.63	C	DN4	41.5	185	11.56	C
AP4	25.6	135	8.44	C	DN5	41.5	115	14.38	S
AP5	25.6	165	13.75	SEP	DN6	37.2	214	13.38	S
AP6	25.6	132	16.5	SEP	DN7	41.5	120	15.0	S
AP7	25.6	101	12.63	C	DN8	38.5	200	12.5	C
AP8	25.6	135	8.44	C	DP1	25.0	130	16.25	S
AL1	39.7	155	19.38	S	DP2	25.0	165	10.31	C
AL2	39.7	124	15.5	C	DP3	25.0	130	16.25	C
AL3	40.0	245	15.31	C	DP4	25.0	120	7.50	C
ANS1	40.6	215	17.92	SEP	DP5	26.3	110	13.75	SEP
ANS2	40.6	160	20.0	S	DP6	26.3	156	9.75	SEP
ANS3	35.5	144	18.0	S	DP7	25.0	118	14.75	C
ANS4	35.5	255	15.94	SEP	DP8	26.3	130	8.13	C
APS1	24.0	135	11.25	SEP	DL1	40.0	100	12.5	S
APS2	24.0	85	10.63	SEP	DL2	40.0	140	17.5	S
APS3	24.1	130	16.25	SEP	DL3	40.0	220	13.75	S
APS4	24.1	200	12.5	SEP	DNS1	37.6	110	13.75	S
AN1F	35.7	140	17.5	S	DNS2	36.3	160	10.0	SEP
APS1F	23.6	135	16.88	SEP	DNS3	36.6	100	12.5	S
BN1	41.4	125	10.42	P	DNS4	36.6	200	12.5	SEP
BN2	40.4	190	11.8	P	DPS1	25.1	92	11.5	S
CN1	41.4	345	21.56	SEP	DPS2	25.1	100	6.25	SEP
CN2	41.4	265	16.56	C	DPS3	24.6	105	13.13	SEP
CN3	38.5	160	20.0	S	DPS4	24.6	140	8.75	SEP
CN4	38.5	132	16.5	C	DN1F	35.7	135	16.88	S
CP1	24.9	275	17.19	C	DPS1F	23.6	100	12.5	SEP
CP2	24.9	150	18.75	S					

Key
C Shearing of the concrete
S Shearing of the connectors
SEP Separation between the steel and the concrete
P Pulling out of the concrete

TABLE 2. SUMMARY OF THE RESULTS