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REPORT

The Behaviour and Strength of Hilti HVB 80 and
HVB 105 Shear Connectors used for
Steel/Concrete Composite Construction

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July, 1984.

Technical Assessment

The behaviour and strength of HILTI HVB 80 and HVB 105 shear connectors used for steel/concrete composite construction.

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1. Introduction

In composite construction where concrete/steel profiled steel sheet composite floors are used in conjunction with the steel beams of a steel framed structure, the form of shear connection currently used is generally restricted to 'through the deck' welded shear studs.

Hilti AG (Schaan, Liechtenstein) have recently developed a new type of connector, a cold-formed channel section of "L" shape which is directly fastened to the steel beam through the profiled steel sheet by means of two shot-fired steel pins. (This fastening technique requires no electrical power supply or welding.)

A series of push-off tests has been carried out at the Hilti Laboratories in Schaan under the supervision of I.C.O.M. (Steel Structures, Federal Institute of Technology, Lausanne, Switzerland). To assist in the preparation of National Technical Assessments of the test programme, the test results and the proposed design values, meetings were held in Schaan where the facilities were inspected, tests witnessed and results assessed.

The consultants who carried out this work were as follows:

Professor J C Badoux Mr M Crisinel Mr V Laederach	}	Lausanne, Switzerland
Professor E R Bryan Mr D C O'Leary	}	Salford, Great Britain
Mr J Stark	-	Delft, Netherlands
Professor F Tschemmernegg	-	Innsbruck, Austria

The general conclusion of the work is that the Hilti shear connector for steel/concrete composite construction is a viable alternative to the conventional shear stud.

The strength and deformation capacity of the Hilti shear connector may be affected by the profiled steel sheet. The push-off tests reveal that this effect can be calculated in a manner similar to that for stud connectors.

Design calculations for composite beams using the Hilti connectors may be carried out employing either plastic methods for most cases in which the push-off failure mode was ductile or elastic methods for cases in which brittle failure was exhibited.

The results and conclusions based on these tests enable composite beams to be designed employing Hilti HVB shear connectors. Certain detailing requirements are stipulated which are similar to those required for stud connectors.

The assessment is based on the report on "Push-out tests of steel-concrete connections with Hilti HVB shear connectors"[1] and the Model Code for Composite Structures[2]. The British Standard Code of Practice for Composite Construction in Buildings (CP 117) is being redrafted and is expected to contain similar requirements to the Model Code.

2. Specification of Materials and Description of Tests

(a) Materials Specification

The materials employed in the test programme had the following specified properties:-

(i)	Concrete	- cube strength 22, 30 and 60 N/mm^2
(ii)	Profiled Steel Sheeting	- minimum yield stress range 220-320 N/mm^2
(iii)	Steel Mesh Reinforcement	- 2% proof stress minimum 540 N/mm^2
(iv)	Hilti Shear Connectors	- St 4 LG Steel (DIN 1624) minimum yield stress 200 N/mm^2
(v)	Steel Pins	- ENP 3.21 L15
(vi)	Beam Sections	- tensile strength range 398 to 478 N/mm^2

Confirmatory material tests were carried out on (i) and (vi). Quality assurance on (iv) and (v) is ensured by the manufacturers internal quality inspection.

(b) Testing Programme

The push-off tests carried out were designed to investigate the following:-

(i) the characteristic strength of two sizes of connector HVB 80 (80mm long) and HVB 105 (105mm long) (see Section 3(b))

(ii) the influence of profiled steel sheeting on the shear connector strength (Section 3(c))

(iii) the effect of the arrangement of connectors
- spacing 40mm and 100mm (Section 3(d))
- directional properties

(iv) the effect of repeated loading prior to the static list (Section 3(e))

(v) the effect of concrete strength on the strength of the shear connector
(Section 3(f))

A summary of the principal results is given in Table 1:
For modes of failure (see Section 3(a))

3. Interpretation of Results

(a) Load/Slip Relationships and Modes of Failure

The summary of results given in Table 1 indicates that the design strength for the shear connector depends on the load/slip behaviour of the push-off tests. The tests showed that there were basically three modes of failure. These are shown in Figure 4 and indicate the bases upon which the values in Table 1 were obtained.

The modes of failure were identified as:

Mode 1: Shear failure of connector at fastening
Mode 2: Local failure of concrete around fastenings
Mode 3: Total shear failure of concrete in horizontal plane

(b) Characteristic Strength of Hilti-Shear Connectors

In the tests series, the Hilti shear connectors exhibited ductile behaviour in a solid slab in a manner similar to that of shear stud connectors. The deformation capacity is high and the connector may therefore be considered flexible. At the ultimate limit state a relatively large degree of slip can occur between the concrete slab and the steel beam with no reduction in the strength of the connection.

Two cases should be considered for design (1) the connector strength for the ultimate limit state based on a plastic calculation and (2) the connector strength based on an elastic calculation.

(1) Plastic Design Strength

For concrete grade 45 [according to the Model Code these strengths must be derived from concrete samples with a strength of 0.7 x 45 = 31.5 N/mm^2]

- connector Hilti HVB 80: R_d, 80 = 23kN
- connector Hilti HVB 105: R_d, 105 = 31kN

(2) Elastic Design Strength

There are no current British guidelines on the acceptable values of slip for elastic design. Using the Swiss guideline of a relative slip of 0.5mm leads to a reduction factor of 0.7 on the connector strength, hence

- connector Hilti HVB 80: R_d, 80, elastic = 16kN
- connector Hilti HVB 105: R_d, 105, elastic = 22kN

(c) Influence of Profiled Steel Sheeting on Shear Connector Strength

The reduction in strength of the Hilti shear connector caused by the presence of profiled steel sheeting is similar to that which occurs with shear studs. The range of values obtained is shown plotted in Figure 5. From these tests a factor of 0.5 is considered appropriate.

The value of the design strength is then taken as follows:

$$R_{d,rib} = r\, R_{d,sol}.$$

where $\cdot\ r = 0.50\, \frac{w}{e} \cdot \frac{h_D - e}{e} \leq 1.0$

and $R_{d,rib}$ = design strength of a Hilti HVB connector situated within a rib

$R_{d,sol}$ = design strength of a Hilti HVB shear connector situated in a solid slab

w = mean width of a concrete filled rib

e = depth of profiled sheeting

h_D = length of Hilti HVB shear connector

When the value of r is greater than 1.0, no reduction to the strength of the connector should be made with respect to its value in a concrete slab.

The factor $\left[\frac{h_D - e}{e}\right]$ which refers to the height of the connector above the profiled steel sheet is an important factor which affects both the strength, and perhaps even more importantly, the mode of failure. When $^w/_e$ < 1.8 and $h_D - e < 30$mm the tests exhibited brittle behaviour. These observations resulted in the detailing rules referred to later which generally require $h_D - e > 35$mm.

(d) Effect of the Arrangement of Connectors

Table 1 indicates that there is no significant difference between the design values R_d for the connectors spaced transversely to the beam at 40mm or 100mm centres. Also, the results of test series 3.1 and 3.2 (with the Hilti connectors facing in the same direction) are the same as the results of test series 1.2 (with the connectors facing in opposite directions). It may therefore be concluded that the direction of the connectors is not significant.

(e) Effect of Repeated Loading

For the test series carried out 10000 cycles of load between 0 and 0.5 Pu were applied prior to the static test to failure. No residual slip occurred at the end of the repeated loading, indicating that for this series the cyclic loading had no influence on the load/slip relationship.

(f) Effect of Concrete Strength

Two series of tests were carried out with two different concrete strengths ($22N/mm^2$ and $60N/mm^2$). The results indicated that the connector strengths for the $22N/mm^2$ concrete were less than (i.e. 0.94) the connector strengths for the $30N/mm^2$ concrete and exhibited ductile failure (except for series 1.3, 1.4 and 2.1 in which the profiled steel sheet type and height of connector caused a brittle failure). For a concrete strength of $60N/mm^2$ the connector strength was similar to that for the $30N/mm^2$ concrete but the failure form was brittle.

In the range of normal structureal concrete strength with a correct choice for profile sheet type and connector heights the failure mode is ductile. Connector strengths may be determined using the guidelines of the model code.

4. Detailing Rules

The detailing requirements for the Hilti shear connectors HVB 80 and HVB 105 are shown in Figure 6.

5. Agreed Design Values

We agree that the following design values may be adopted for the use of Hilti HVB shear connectors:-

The static design strength of a Hilti HVB shear connector to be used in the calculation of a steel to concrete connection is as follows:-

- If a plastic calculation of the ultimate strength of composite sections is made, the design ultimate strength, R_d, of a Hilti HVB shear connector in a solid concrete slab is as follows:-
  - for HVB 80: R_d = 23 kN
  - for HVB 105: R_d = 31 kN

- If an elastic calculation of the ultimate strength of composite sections is made, the design ultimate strength, R_d, of a Hilti HVB shear connector in a solid concrete slab is as follows:-
  - for HVB 80: R_d = 16 kN
  - for HVB 105: R_d = 22 kN

- In the presence of a slab comprising profiled steel sheeting which has ribs perpendicular to the steel beam, the values above should be reduced by the following factor r:

  $$r = 0.50 \frac{w}{e} \cdot \frac{h_D - e}{e} \leq 1$$

  This reduction factor is applied to each connector up to a maximum number of three connectors per rib arranged according to the rules given in Section 4.

- In the presence of a slab comprising profiled steel sheeting which has ribs parallel to the steel beam, the strength of the Hilti HVB shear connectors is given by the above values, without reduction if the ratio w/e is greater than 1.8, and with a reduction, r, if this ratio is less than 1.8.

- The connectors should face in the direction of the horizontal shear force, F, at the interface of the steel and concrete (Fig. 6b) or placed in alternative directions.

- The longitudinal spacing between two connectors should be not less than 100mm and not greater than the lesser of 600mm and 4 h_b (h_b is the thickness of the concrete slab).

- The transverse spacing between two connectors should be not less than 40mm.

- The spacing between a connector and the edge of the flange of the steel beam should not be less than 15mm.

- The connectors should penetrate the concrete above the ribs a minimum distance of
    - 30mm if w/e is greater than 1.8
    - the lesser of 2e/3 and 30mm if w/e is less than 1.8

- The minimum width of a rib filled with concrete should be at least 60mm, irrespective of the direction of the ribs relative to the steel beam.

- No more than three lines of connectors should be used per beam.

- The minimum concrete cover on a connector should be 20 mm in all directions. If a layer of concrete is not required for protection against corrosion, the top of the connector may be at the same level as the upper face of the concrete slab.

Fig. 6 gives a graphical representation of the rules outlined above.

Provided the above values and rules are complied with we consider the Hilti shear connector to be entirely satisfactory.

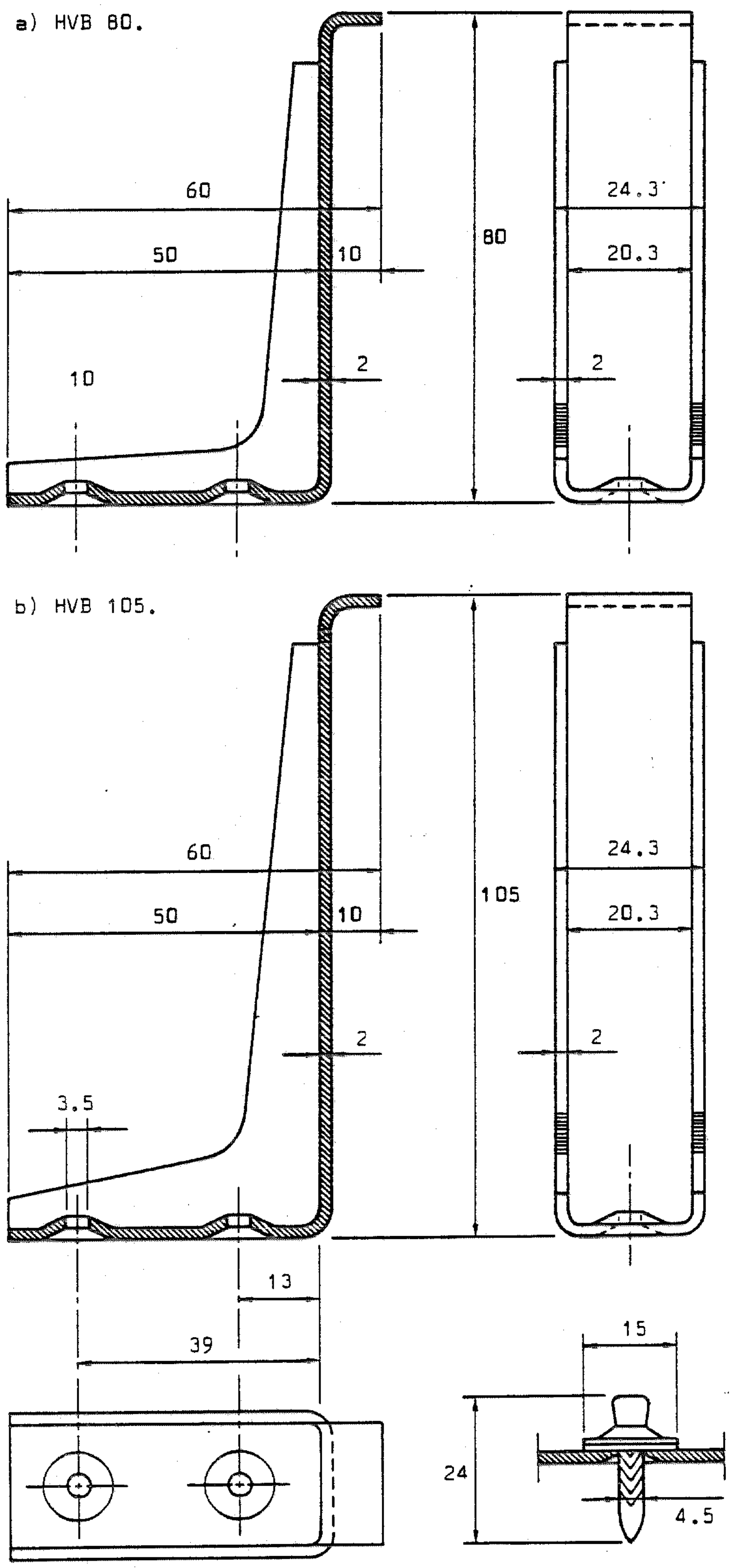
6. References

(1) Crisinel M. Push-out tests of steel-concrete connectors with Hilti connectors. Ecole Polytechnique Fédérale, ICOM - Construction Métallique, Lausanne, 1983.

(2) ECCS, Composite Structures, London, The Construction Press, 1981.

SERIES NO.	NUMBER OF SPECIMENS	CONNECTORS	SECTION	PROFILED SHEETING	TEST RESULTS			
					FAILURE MODE	P_{max} [kN]	P_u [kN]	R_d [kN]
1.1	3	HVB 80	IPE 180	HOLORIB 38	1	290	288	230
1.2	3	HVB 80	IPE 180	HOLORIB 51	2	228	200	160
1.3	3	HVB 80	IPE 180	MONTARIB 58	3	180	140	112
1.4	3	HVB 80	IPE 180	HI-BOND 55	2 – 3	112	100	80
1.5	3	HVB 80	IPE 180	—	1	240	232	186
2.1	3	HVB 105	HEB 240	COFRASTRA 70	3	295	154	92
2.2	3	HVB 105	HEB 240	COBACIER 80	2	230	226	162
2.3	3	HVB 105	HEB 240	MONTARIB 58	2	257	250	200
2.4	3	HVB 105	HEB 240	HI-BOND 55	2	228	208	166
2.5	3.	HVB 105	HEB 240	—	1	287	284	248
3.1	3	HVB 80	HEB 240	HOLORIB 51	2	233	200	160
3.2	3	HVB 80	HEB 240	HOLORIB 51	2	217	203	162
4	3	HVB 80	IPE 180	HOLORIB 51	2	228	210	168
5	3	HVB 80	IPE 180	—	1	206	198	158
6.1	3	HVB 80	IPE 180	HOLORIB 51	2	204	187	150
6.2	3	HVB 80	IPE 180	HOLORIB 51	3	233	185	148

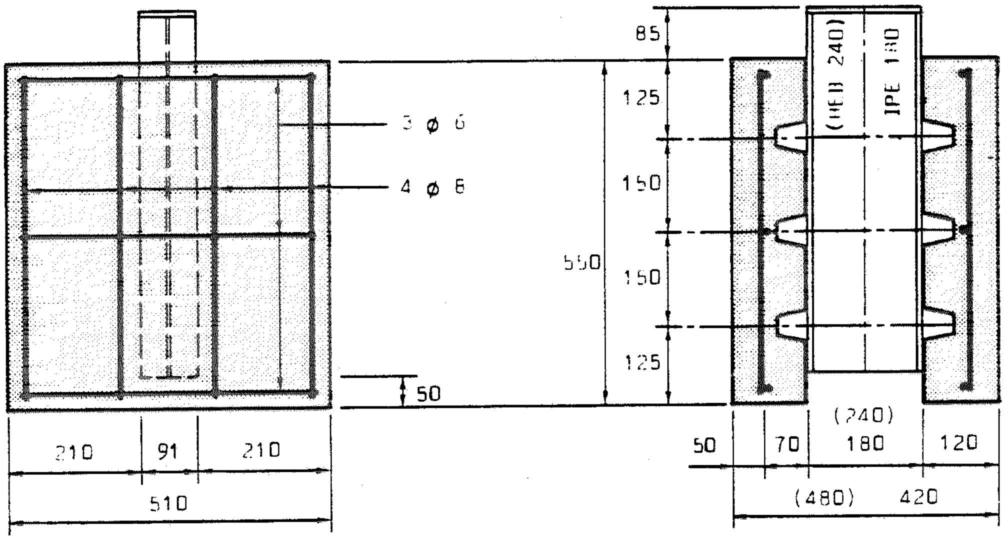
TABLE 1 : Test series and test results.



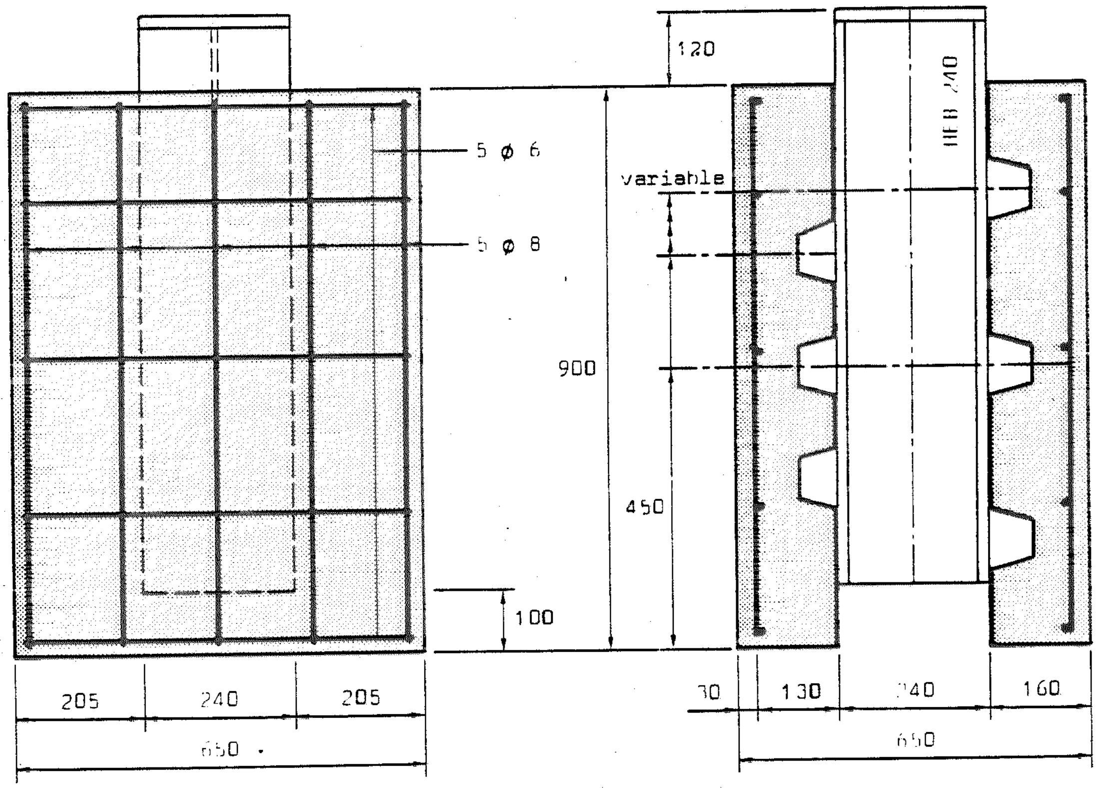
c) ENP 3-21 L15.

FIGURE 1

HILTI connectors.



a) Specimen with HVB 80.



b) Specimen with HVB 105.

FIGURE 2

Push-out specimens.

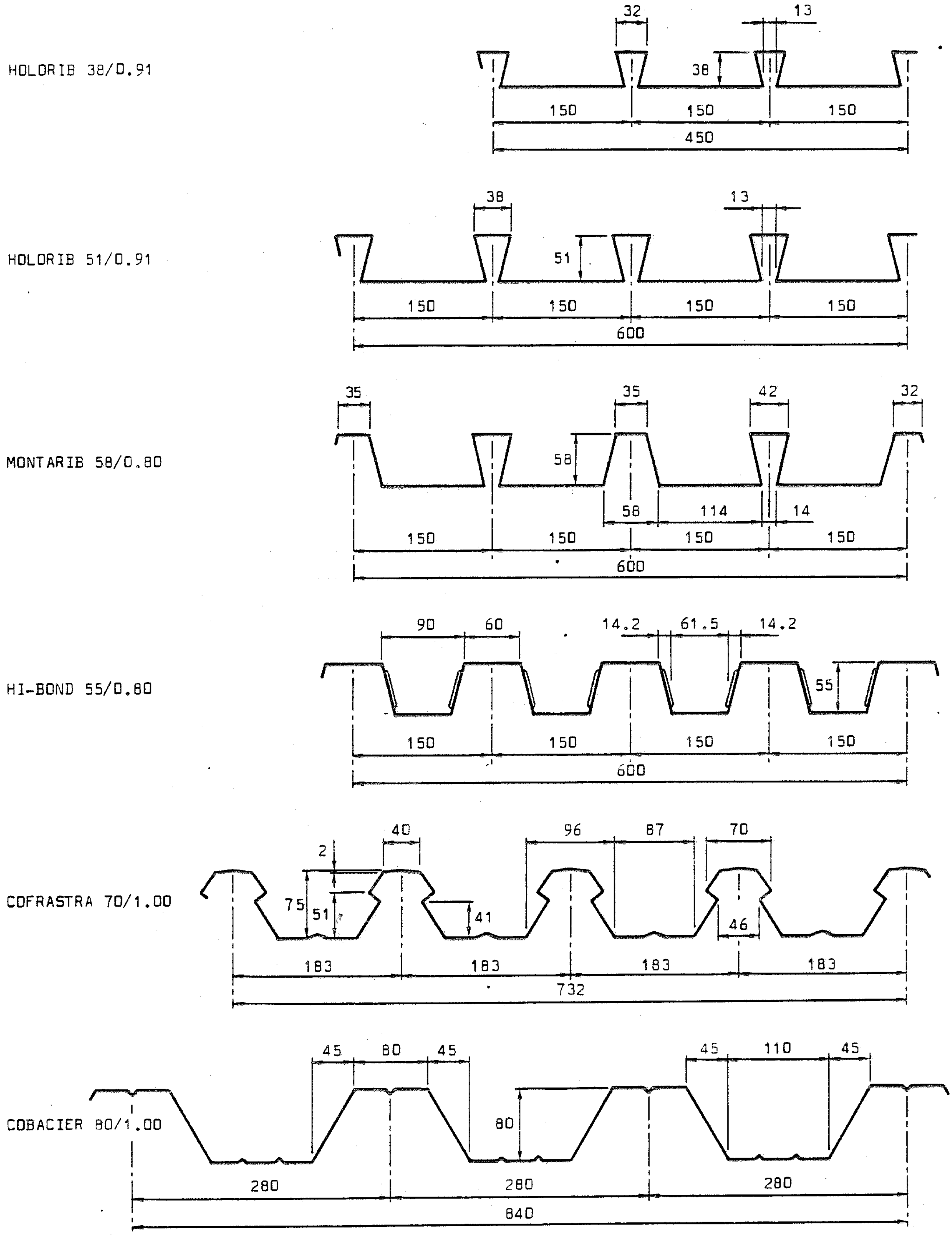
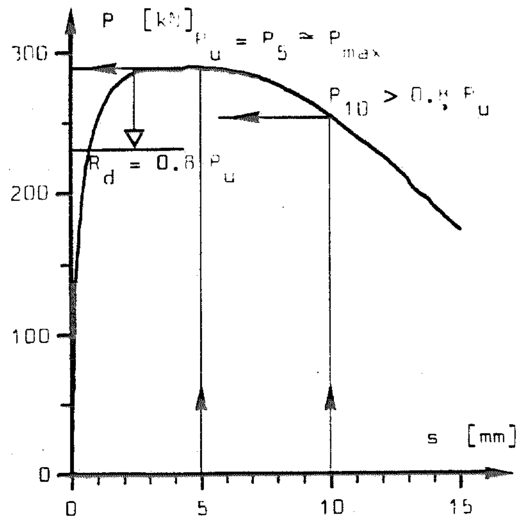
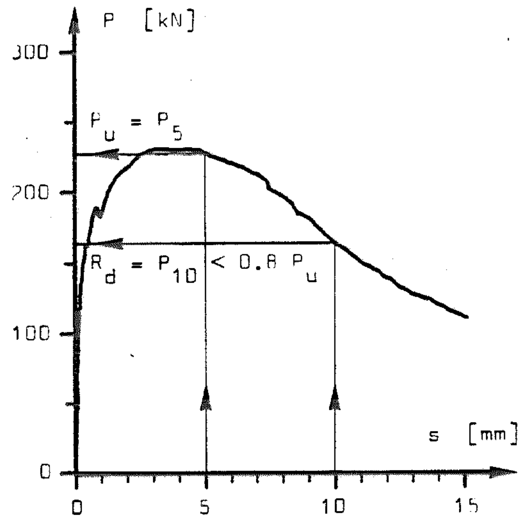


FIGURE 3

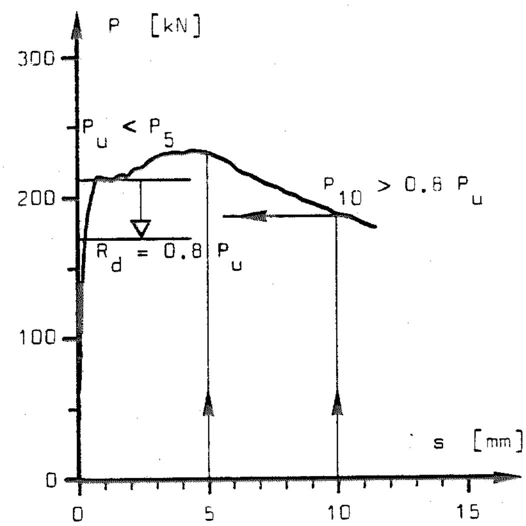
Profiled steel sheeting.



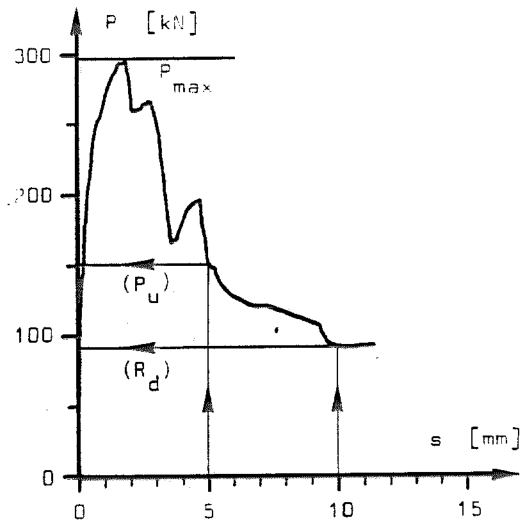
a) Ductile behaviour
(failure mode 1).



b) Ductile with declining portion
(failure mode 2).



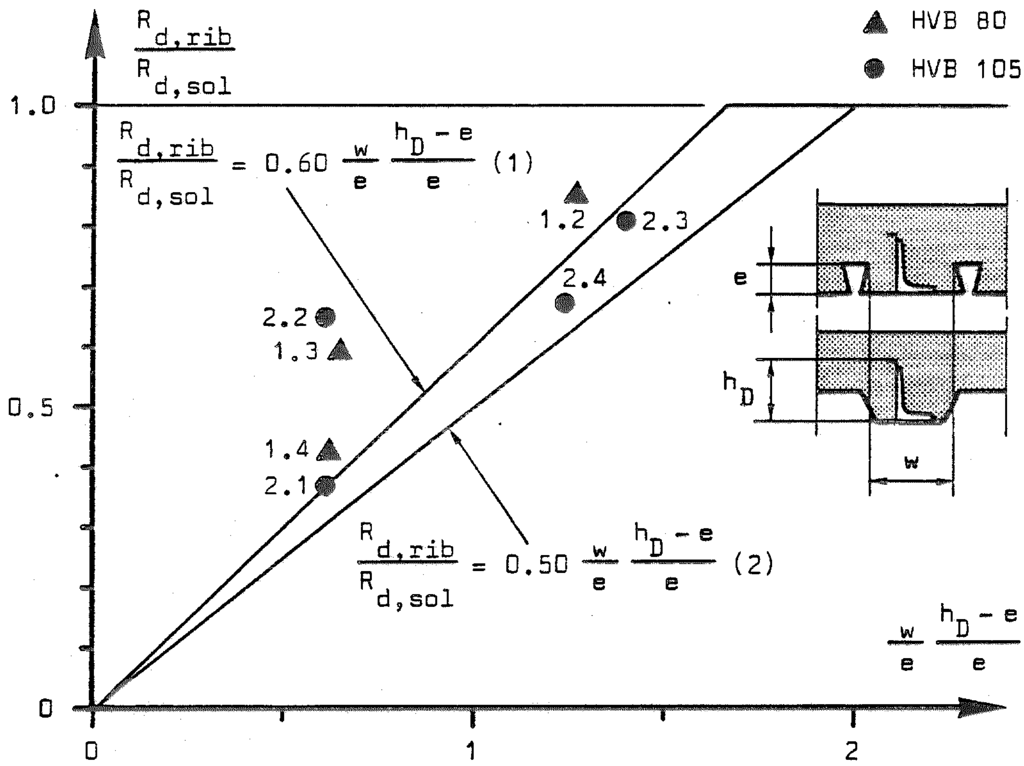
c) Particular ductile behaviour
(failure mode 2).



d) Brittle behaviour
(failure mode 3).

FIGURE 4

Load-slip relationships, modes of failure and rules for evaluation of test results.



R d,rib / R d,sol
HVB 80
HVB 105
1.0
0.5
0
R d,rib / R d,sol = 0.60 w/e (h D - e)/e (1)
R d,rib / R d,sol = 0.50 w/e (h D - e)/e (2)
1.2
2.3
2.4
2.2
1.3
1.4
2.1
e
h D
w
w/e (h D - e)/e
0
1
2

FIGURE 5

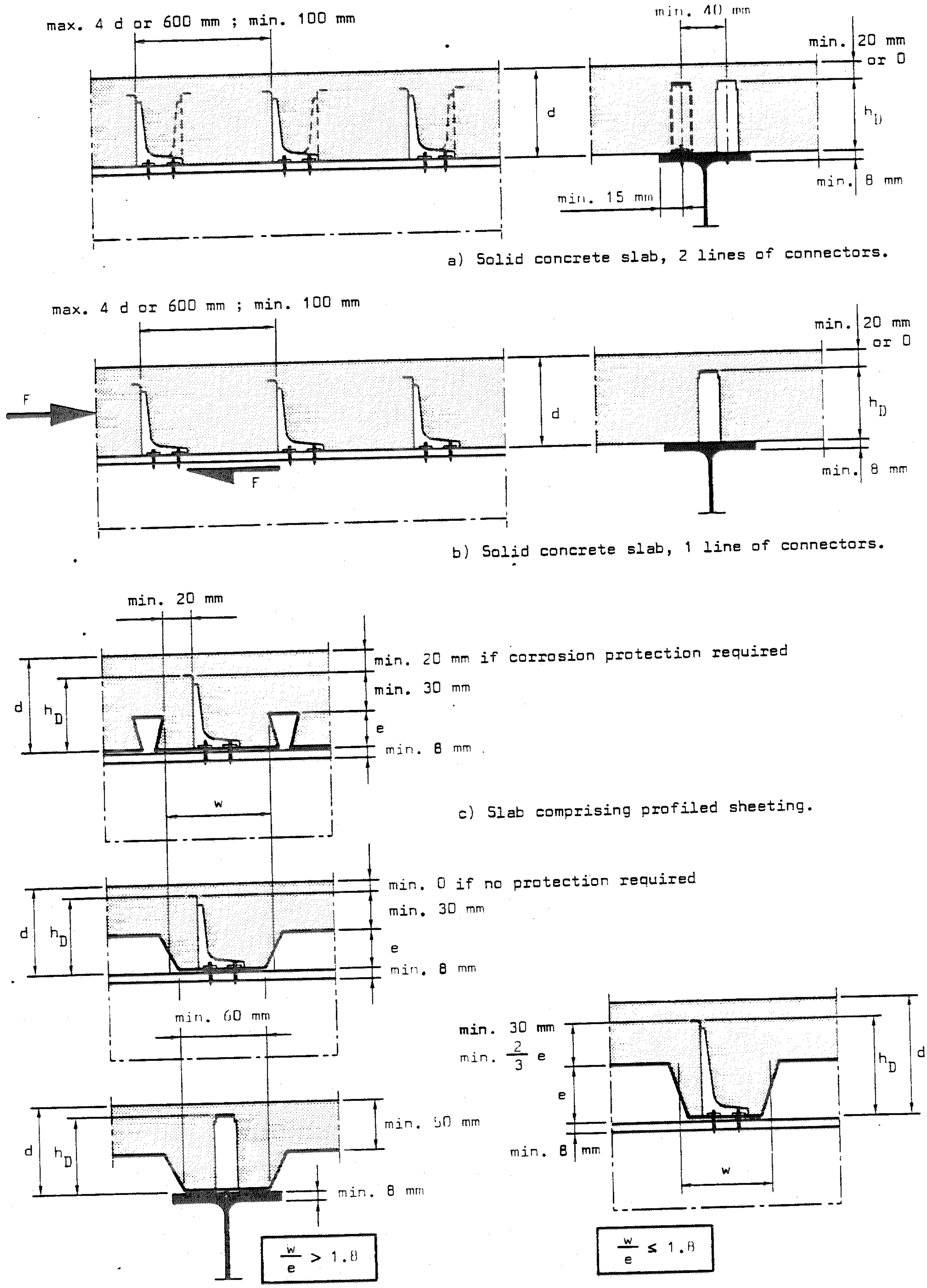


FIGURE 6

Detailing rules for HILTI connectors.