Hilti X-HVB system
Solutions for shear connections

Contents

1. Introduction

Traditionally, in composite construction, shear connectors are welded to steel beams. Hilti X-HVB shear connectors, on the other hand, are directly fastened to steel beams with two X-ENP-21 HVB nails per shear connector and require no welding.
The information provided in this document applies to composite beam design in building construction.

The purpose of the X-HVB shear connector is to ensure mechanical connection between steel beams and concrete slabs. It is therefore designed to resist shear forces acting between these structural elements, promoting composite behavior.

This document is intended as a guide to the use of the Hilti X-HVB shear connector. It shows how the calculations are made and covers the following topics:
• Characteristics of the X-HVB shear connector system.
• Resistance of X-HVB in composite beams subjected to bending.
• Layout of shear connectors.
• Provisions for fire resistance.
• X-HVB in rehabilitation.

The information in this document is in accordance with European Regulations.

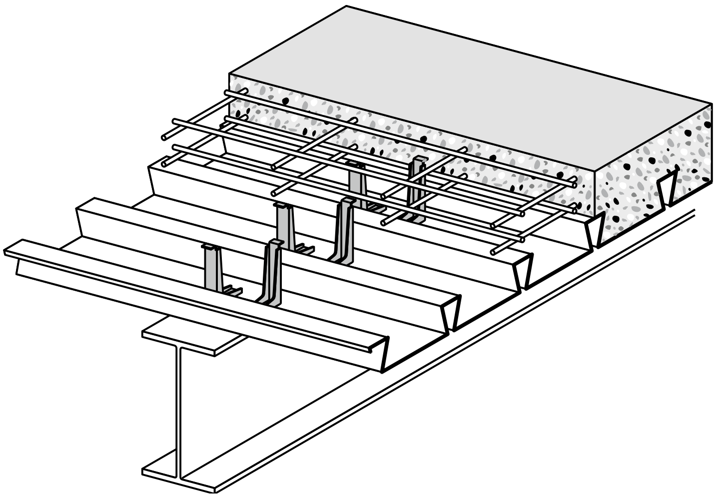


Figure 1: Typical application of X-HVB in new construction

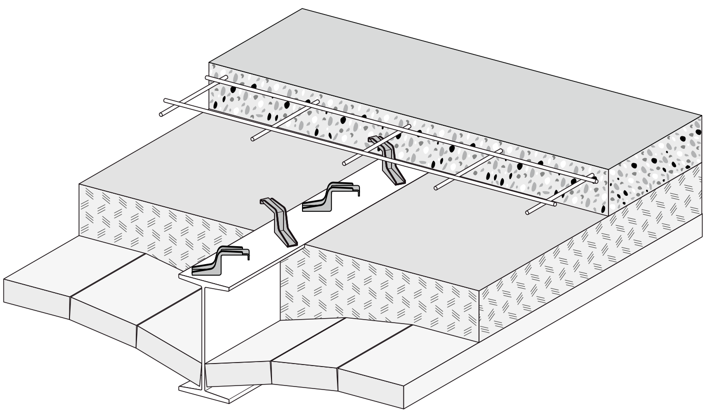


Figure 2: Typical application of X-HVB in rehabilitation

1.1 Hilti X-HVB shear connector at a glance

Figure 3: X-HVB shear connector

The X-HVB is a ductile shear connector in accordance with EC4 provisions. It may thus be used to design elastic or plastic shear connections.

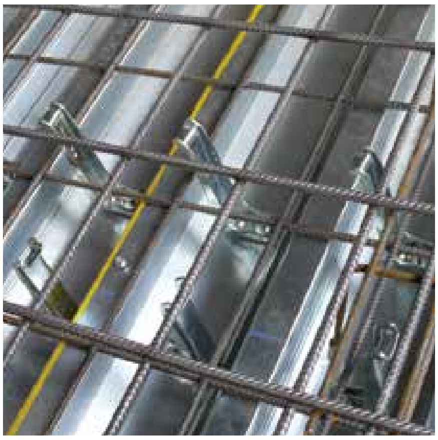


Figure 4: X-HVB shear connector with composite decking

Composite beams with or without steel decking
X-HVB is used to effectively transfer longitudinal shear forces between concrete slabs and steel beams.

Figure 5: X-HVB shear connector in re-habilitation

Rehabilitation
As each Hilti X-HVB shear connector is fastened to a steel beam with 2 nails, it is also suitable for installation on wrought iron and coated/painted beams.
This promotes composite behavior between existing steel elements and new concrete layers, increasing allowable loads in existing buildings.

Quick and easy to install – independent of site conditions
As no welding and therefore no electric power is required, the X-HVB can be installed in damp conditions, where welding may be unreliable.

1.2 Composite beam design

Cast-in-place concrete slabs supported by steel beams can be designed as composite or non-composite structures.
In other words, the steel beams supporting the concrete slab can be designed separately from the slab (**Figure 6-A**) or, alternatively, these structural components can be designed to act together as a single element that resists bending, i.e. making use of composite design. (**Figure 6 – B & C**).

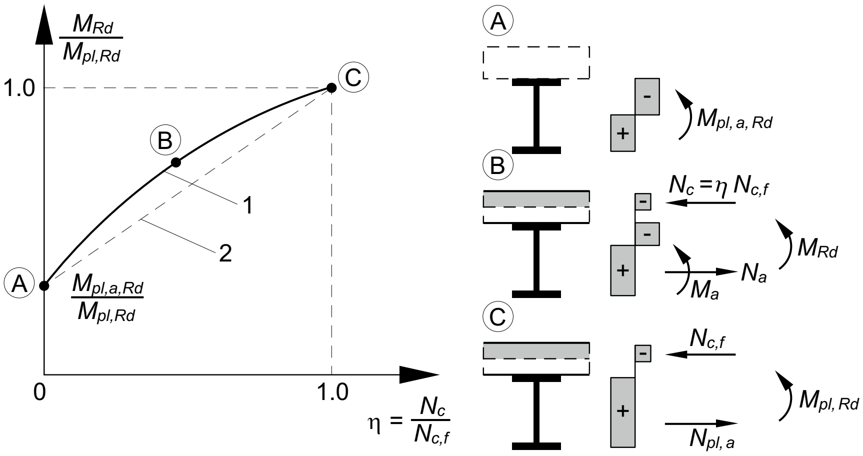


Figure 6: Degrees of shear connection, assuming plastic characteristics

In composite design (**Figure 6 – B & C**), shear connectors must be installed on the top flange of steel beams and are responsible for the transfer of longitudinal shear stress across the interface between steel and concrete.

When slip occurs at the interface it is accompanied by simultaneous vertical displacement of the concrete. Shear connectors must therefore also be able to resist this displacement and thus prevent vertical uplift.

Full composite action is achieved when
- the full shear capacity of the steel or concrete can be utilized, i.e. the shear connection does not control the capacity of the composite beam
- and slip between the structural elements is negligible.

In cases where full composite action is not required, e.g. for limitation of deflection, the concept of partial shear connection is introduced,
- with limited slip at the interface
- and bending resistance is controlled by the degree of shear connection.

Since partial shear connection does not allow the full bending resistance of the cross-sections to be achieved, there are limitations regarding bending resistance with partial shear connection, which are further addressed in this document and fully in EC4 and EC8.

Composite beam design is especially suitable for cross-sections under positive bending moments, as concrete has good resistance to compression.
If steel decking is used, the decking's resistance to compression should be neglected.

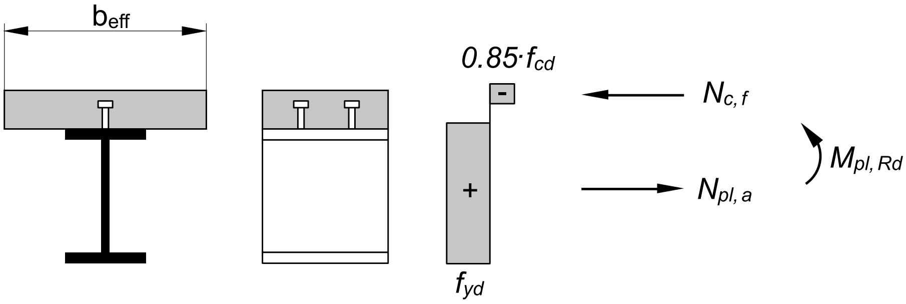


Figure 7: Example of plastic stress distribution for a composite beam with a solid slab and a full shear connection (positive bending moment)

Continuity of the beam can also create negative bending moments near supports. For negative bending moments, the slab's reinforcement is in tension and shear connectors must ensure that tensile force in the reinforcement is transmitted to the steel beam. When a profiled deck is used, it is assumed to be stressed to its design yield strength.

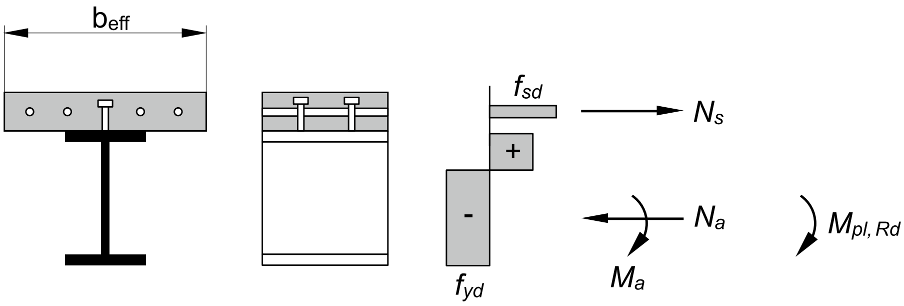


Figure 8: Example of plastic stress distribution for a composite beam with a solid slab and a full shear connection (negative bending moment).

Since the composite member cross-section is larger than the beam's cross-section alone, the respective moment of inertia is higher, resulting in higher resistance to bending. These considerations allow for slimmer design of structural components. The main benefits related to composite beam design are therefore related to the fact that use of a composite section allows for savings in material and space.

In modern construction, steel decking is used as permanent formwork for the concrete slab and as reinforcement for the composite deck.
The decking is utilized to limit the amount of slab propping during construction.

1.3 Types of shear connectors

1.3.1 Welded shear studs

Welded shear studs are the most common and traditional type of shear connectors. Typically, welded shear studs exhibit ductile behavior and have good resistance to horizontal shear and vertical uplift:
- Horizontal shear is resisted by the shank.
- Vertical uplift is prevented by the head.

When steel decking is used, either the studs are welded through the decking or the decking perforated and pre-welded studs fitted through the perforations.

Figure 9: Headed studs welded through profile deck

Inherent concerns related to welding are as follows:
- Welding requires skilled/experienced labor.
- Quality control checks may be ambiguous, i.e. visual inspection, sound produced when hammered, bending test.
- Equipment required on site, resulting in transportation costs and effort.
- Numerous electric cables required, which may lead to tripping hazards.
- Welding quality is largely dependent on beam surface conditions, i.e. humidity, rust, etc.
- Welds on wrought iron beams might be brittle and not effective.
- Direct welding onto galvanized beams may cause health issues.
- Finishing work is necessary after welding on coated/painted beams.
- Sites with fire regulations (fire watch) may restrict hot works, i.e. welding.

1.3.2 Hilti X-HVB shear connector

The Hilti X-HVB shear connector is an L-shaped shear connector which is fastened onto a beam with two nails driven by a powder-actuated tool.
The X-HVB is ductile and designed to resist
- longitudinal shear force
- and vertical uplift which is prevented by the X-HVB head and the nails.

Figure 10: Hilti X-HVB installed in profile deck

It is suitable for use at the connection between concrete slabs and steel beams with or without steel decking. As the X-HVB is fastened with Hilti direct fastening technology, it is versatile enough to be used in situations where welded studs are not applicable and/or not effective.

The X-HVB system does not require electric power, has an easy and approved inspection procedure and, unlike welding, it is not weather dependent and does not infringe site hot works, i.e. fire-watch, regulations. X-HVB placement is also not sensitive to the beams' surface treatment.

Typical features of the X-HVB are:
- simple, inexpensive installation equipment,
- fastening quality largely independent of weather conditions,
- fast installation allows flexible scheduling of work on the jobsite,
- zinc coatings or moisture do not affect the fastening quality.

When retrofitting/renovating older buildings, i.e. rehabilitation projects, the X-HVB is fastened to existing wrought iron beams that will support newly cast slabs. This method is used in flooring systems for rehabilitation purposes, mostly subjected to static loading.
The main advantages of using the rehabilitation technique are
- the increase in bending resistance,
- decrease in deformability/deflection

and hence the ability to adapt structures to modern load requirements and usage.

2. Hilti X-HVB system

2.1 Introduction to the X-HVB

Figure 11: Hilti X-HVB shear connector and X-ENP-21 HVB nail

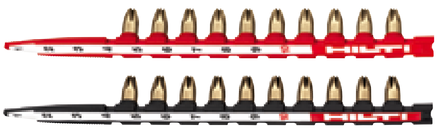


Figure 12: Red and black cartridges

Figure 13: Hilti DX 76 tool, equipped for X-HVB installation

The X-HVB system is an effective and efficient solution for secure shear connection. Direct fastening technology makes this shear connector easy to install since it can be set securely and reliably by workmen with simple training.

Hilti X-HVB shear connectors are fastened to steel components, typically the top flange of a steel beam, using a Hilti DX 76 or DX 76 PTR tool equipped with accessories specifically for this purpose.
The nail-driving energy is provided by Hilti DX cartridges (powder-actuated system).

As no welding is required, the X-HVB system can be installed under almost any site conditions. In addition, fastening quality assurance is provided by an easy and approved inspection process.

The system comprises the following items:
- X-HVB shear connector, available in different heights **(Figure 11)**
- X-ENP-21 HVB nails, two for each X-HVB shear connector **(Figure 11)**
- 6.8/18M cartridges, black or red **(Figure 12)**
- DX 76 (or DX 76 PTR) tool equipped for X-HVB installation **(Figure 13)**

2.2. Approvals

Several approvals have been awarded to the X-HVB system **(Table 1)** and the system is compliant with EN1994-1-1.

Socotec PX 0091/7	France
Socotec PX 0091/8	France
DIBt Z-26.4-46	Germany
TZUS 070-041312	Czech Republic
Rom.Ministry_AT 016-01/281-2013	Romania

Table 1: List of approvals

The German DIBt Z-26.4-46 approval addresses fire design as per EN1994-1-2 and the French Socotec PX 0091/8 approval specifically prescribes the use of X-HVB for rehabilitation purposes.

Approvals are subject to continuous changes related to code developments, product portfolio updates and new research results. Current approvals can be downloaded from the Hilti website or from the websites of most certification bodies.

2.3 Hilti shear connector and X-ENP-21 HVB nails

The L-shaped shear connectors are cold formed from steel and comprise the fastening leg, the anchorage leg and the head. The anchorage leg is cast into the concrete while the fastening leg is fastened to the steel beam with two X-ENP-21 HVB nails (**Figure 14**).

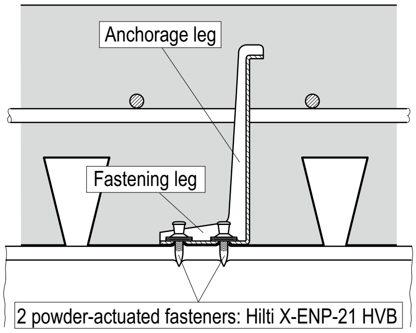


Figure 14: Shear connection in composite beams

The shear connectors are available in 6 different anchorage leg heights for different steel decking and slab configurations (detailed geometry in **Figure 15**):

Designation	Item number
X-HVB 40	2112256
X-HVB 50	56467
X-HVB 80	239357
X-HVB 95	348179
X-HVB 110	348180
X-HVB 125	348181
X-HVB 140	348321
Each connector fastened with two nails:	
X-ENP-21 HVB	283512

Table 2: X-HVB designations and respective item number

Note: The number following X-HVB indicates the approximate height of the shear connector in millimeters.

Note: The Hilti X-HVB 40 and X-HVB 50 are used specifically for thin slabs without steel decking in rehabilitation projects.

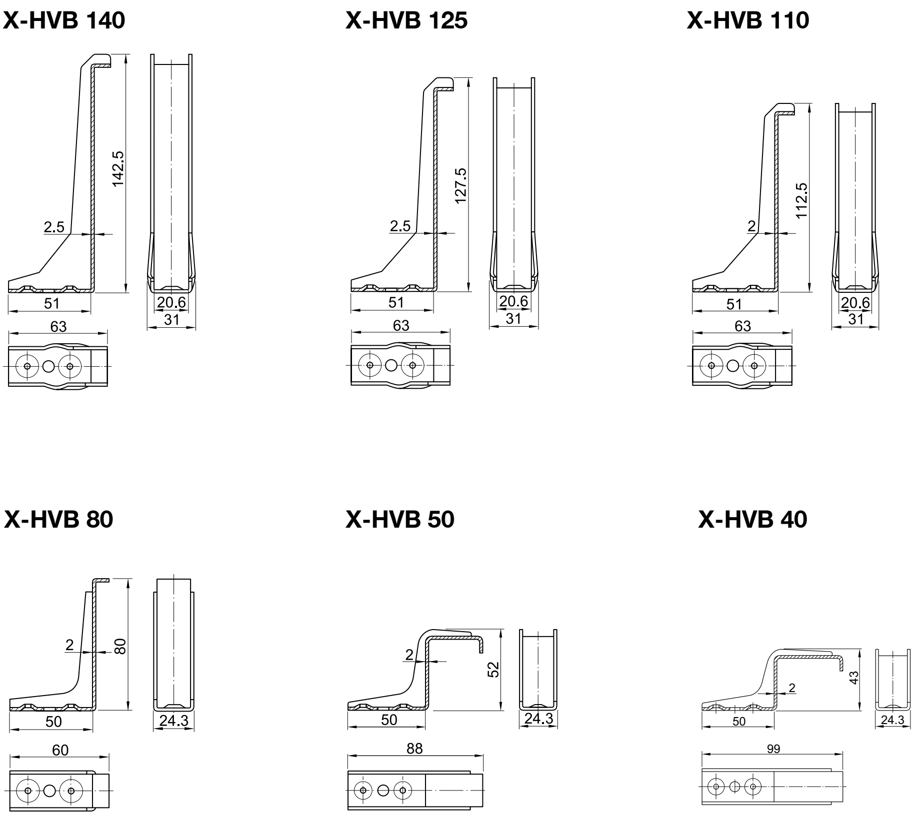


Figure 15: Detailed geometry of X-HVB

2.4 Material specifications

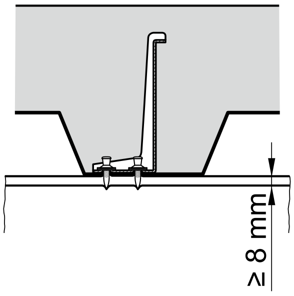


Figure 16: Minimum thickness of steel base material

X-HVB shear connector

Carbon steel	R_m=295-350N/mm²
Zinc coating	≥ 3 µm

X-ENP-21 HVB nails

Carbon steel shank	HRC58
Zinc coating	8-16 µm

2.5 Application requirements

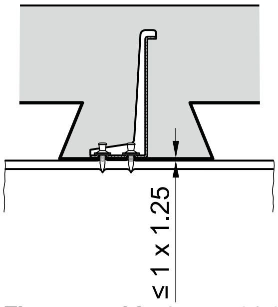


Figure 17: Maximum thickness of deck

Thickness of steel base material (beam flange) ≥ 8 mm.
Thickness of fastened material (steel decking) ≤ 1.25 mm.

In rehabilitation projects, application to thin beam flanges of minimum 6 mm is possible. Please refer to the DIBt and Socotec approvals and contact Hilti for detailed information.

Details of connector positioning, spacing and edge distances can be found in **Section 5: X-HVB positioning, spacing and edge distances.**

2.6 Tools

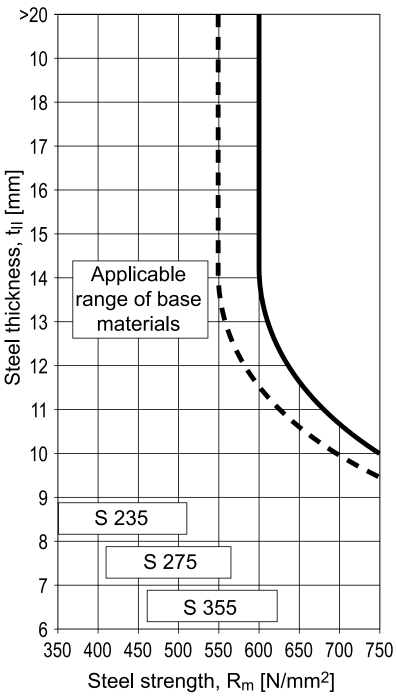


Figure 18: Application limit.
In thermo-mechanically rolled construction steel, the application limit is reduced by 50 N/mm² (dashed line)

Hilti supplies the DX 76 HVB tool already assembled for fastening X-HVBs (**Figure 13**). In addition, the DX 76 and DX 76 PTR tools can be used. In this case, the fastener magazine has to be replaced with the required piston and fastener guide for X-HVB installation. **Table 3** provides an overview.

Tool	Equipment	Designation	Item no.
DX 76 HVB	Equipped tool	DX 76 HVB	2090391
DX 76	Tool	DX 76 MX	285789
DX 76	Piston	X-76-P-HVB	285493
DX 76	Fastener guide	X-76-F-HVB	285486
DX 76 PTR	Tool	DX 76 PTR	384004
DX 76 PTR	Piston	X-76-P-HVB-PTR	388847
DX 76 PTR	Fastener guide	X-76-F-HVB-PTR	388846

Table 3: Designations of tool components for fastening the X-HVB

Figure 19: DX 76 tool

Figure 22: DX 76 PTR tool

Figure 20: X-HVB piston for DX 76

Figure 23: X-HVB piston for DX 76 PTR

Figure 21: X-HVB fastener guide for DX 76

Figure 24: X-HVB fastener guide for DX 76 PTR

2.7 Cartridges

The DX 76 and DX 76 PTR tools use 6.8/18M black or red cartridges which are supplied in strips of 10.
Selection of the cartridges is dependent on steel beam (base material) strength and thickness (**Figure 25**).

For thin base material from 6 to 8 mm thickness, red cartridges and energy setting 1 are recommended. If necessary, increase the tool energy setting till the correct fastener stand-off h_{NVS} is achieved. Blue cartridges may also be used - please refer to the Socotec PX 0091/8 approval.

Based on the cartridge recommendations, fine adjustments can be made by carrying out nail-driving tests on site. If nail stand-off lies between 8.2 and 9.8 mm after the nail is driven, the cartridge and the tool power settings are considered appropriate for the base material.

Table 4 provides information regarding cartridges relevant for X-HVB fastening.

Size	Color code	Power level	Item no.
6.8/18 M10 STD	Red	Medium high	416484
6.8/18 M10 STD	Black	Extra high	416486
6.8/18 M10 STD	Blue	Medium	416485
6.8/18 M10	Red	Medium high	50602
6.8/18 M10	Black	Extra high	50603
6.8/18 M10	Blue	Medium	50611

Table 4: Cartridges for X-HVB placement

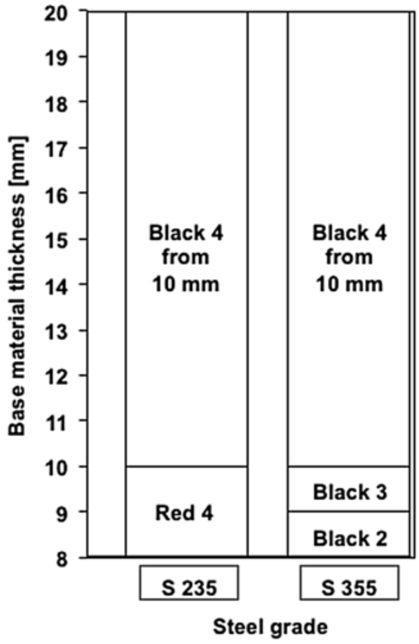


Figure 25: Cartridge pre-selection and power settings

2.8 Fastening quality assurance

The primary means of checking the quality of the nail fastening to the supporting beam is a visual check of nail stand-off (**Figure 26**).

The visual appearance of the top washer and the nail stand-off h_{NVS} indicate how the tool power setting should be adjusted (**Table 5**).

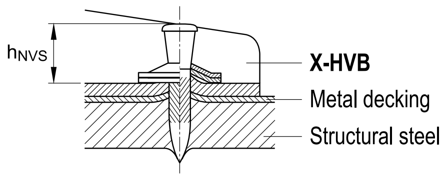


Figure 26: Nail stand-off for the X-ENP-21 HVB nail

Visual appearance	Corresponding nail stand-off, h_{NVS} [mm]	Adjustment required
Visible damage to top washer	$h_{NVS} < 8.2$	Reduce power setting or use lighter cartridge
Clearly visible piston mark on top washer 	$8.2 \le h_{NVS} \le 9.8$	No adjustment: Cartridge and power setting are correct
Visible gap between top and bottom washer 	$h_{NVS} > 9.8$	Increase power setting or use heavier cartridge

Table 5: Fastening inspection and nail stand-off

3. Benefits and value propositions

3.1 Benefits of steel/concrete composite structures

An optimal composite structure is one that exploits the benefits of both materials, in a truly unified structural system that overcomes the drawbacks of each material taken individually.

The main advantages of steel are:
- high strength / weight ratio, which leads to a significant reduction of the actions in the foundation,
- ductility of the material, which makes it especially useful in seismic areas,
- ability to easily use self-supporting profile decks and casting finishing concrete,
- possibility of realizing large spans,
- speed of construction,
- ease of structural changes and subsequent additions.

The advantages of concrete may include:
- the excellent compression behavior, enhanced by the increasing usage of high-strength concrete, makes it possible to design elements characterized by smaller cross sections,
- reduced instability and deformability due to the increased stiffness of the elements,
- good performance under fire conditions,
- moldability of the structural elements.

The combination of these inherent characteristics makes it possible to simply define the main structural advantages of steel/concrete composite structures:
- excellent static performance in terms of strength, stiffness and ductility,
- reduction of local and global instability issues,
- excellent performance in case of fire,
- good speed of construction.

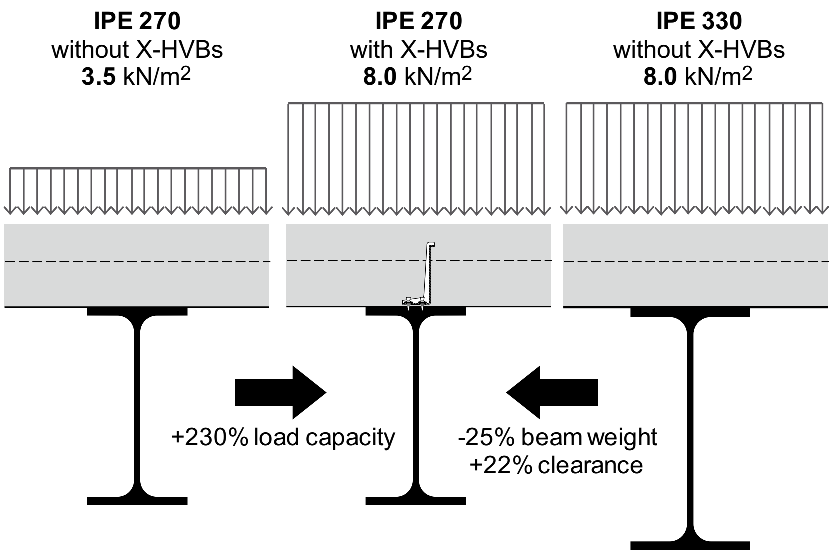


Figure 27: Example of the resulting benefits, taking the following parameters into account:
- beam: 6.0 m span, 2.0 m spacing, S275, unpropped during construction phase
- slab: 0.11m thickness, C25/30
- profile deck: Hi-Bond 55/800

A further advantage, typical of steel structures, is related to the possibility of making openings in the beam web, which allows a more rational and less invasive distribution of installations. This is extremely important for production and supply services facilities.

3.2 Value propositions in new construction projects

- Does not infringe site hot works, i.e. fire-watch, regulations.
- Easy and approved inspection method.
- Avoids pre-punching of steel decking which enables longer spans and less propping.
- Can be installed on coated and painted beams without need for subsequent finishing.
- Does not require use of welding equipment and generators, i.e. no equipment transportation to/from and on site.
- Installation quality is independent of site conditions, i.e. moisture after rain, light surface rust, etc.

The X-HVB system therefore supports fast construction assembly:
- when welded shear studs are pre-welded on primary beams in the yard/shop (ideal welding conditions) and shear connectors are required to be installed on secondary beams on site using the Hilti direct fastening method,
- in case of limited transportation and crane access,
- in remote areas.

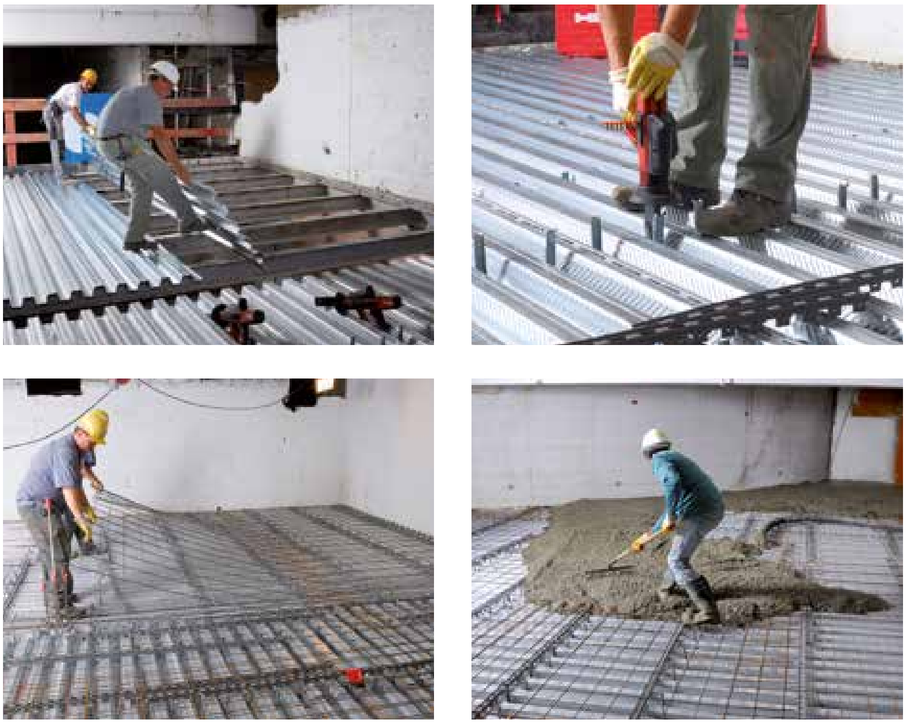


Figure 28: Installation phases for X-HVBs on profile decks (from left to right):
- laying of profile decks on steel beams
- installation of X-HVBs through profile decks
- laying of welded mesh reinforcement
- pouring of the concrete

3.3 Benefits in rehabilitation projects

The following can be considered as the main benefits of using composite structures in rehabilitation.

Increasing the load-bearing capacity
Renovations often originate from requirements related to the change of intended use of the building, for example from house premises to offices with the consequence of higher loads transferred to the floor (both permanent and variable loads). It is therefore necessary to structurally strengthen the floor, thereby making the structure compatible with the new load-bearing capacity requirement.

Improvement of the flexural behavior
Older existing building slabs are generally designed for modest live loads, far below the values prescribed by current regulations in relation to the intended use of the structure. A higher stiffness is generally required, both to prevent damage of the partition walls and floors, and to improve occupancy comfort, limiting vibrations due to trampling and improving soundproofing.
The immediate effect of an improvement in the flexural stiffness of the slab is due to the beams no longer working separately but, owing to the interconnection to the new composite slab, creation of a monolithic structure that improves the global stiffness.

Improvement of the technical performance
Reinforcement of existing slabs using the composite slab technique results in other significant benefits to the properties of the floor.
- Sound insulation
  The creation of a new concrete slab, combined with a specific acoustic mat and, where possible, with a finishing screed, significantly improves the performance of apparent sound reduction index for airborne noise and the normalized impact noise level for structure-borne noise.
- Thermal insulation
  The use of lightweight solutions, in addition to improving the static behavior of the slab, ensures an increase of the thermal insulation of the horizontal partition. In fact, the structural lightweight concrete in conjunction with light finishing screeds, by virtue of the low thermal conductivity, contributes to the improvement of thermal transmittance of the entire horizontal partition.
- Fire protection
  The presence of a new concrete slab improves the fire behavior of the floor, in view of the presence of a layer filled with fireproof insulating material.

3.4 Value propositions in rehabilitation projects

The value propositions for new construction projects (as mentioned above) also make the X-HVB system particularly cost-effective in rehabilitation projects.

- In very thin slabs, the X-HVB 40 and X-HVB 50 may be used where there is no steel decking (**Figure 29**).
- Can be fastened to traditional, wrought iron beams where welding is not possible.

Figure 29: Existing slab to be strengthened with thin concrete layer

4. Shear connector design according to EC4

4.1 Load-displacement behavior of the X-HVB (ductility requirements)

According to EN1994-1-1 section 6.6.1.1 (5), a shear connector may be considered ductile if the characteristic slip capacity δ_{uk} is 6 mm or more.

The ductility of a shear connection is tested with push-out tests as defined in EN1994-1-1 section B2 guidelines.
The X-HVB is tested with similar a setup as similar to that shown in **Figure 30**.

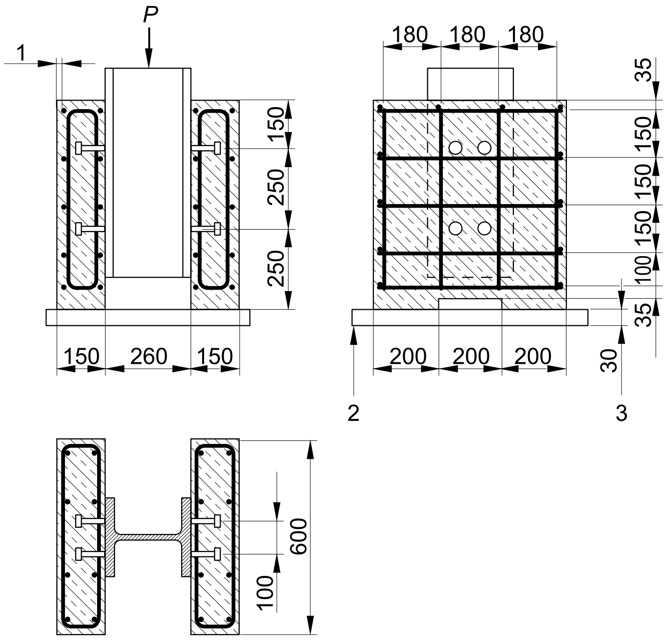


Figure 30: Push-out test setup according to EN 1994-1-1

Figure 31: Push-out test with X-HVB

Figure 32 shows an example of a load-displacement diagram obtained from these push-out tests.

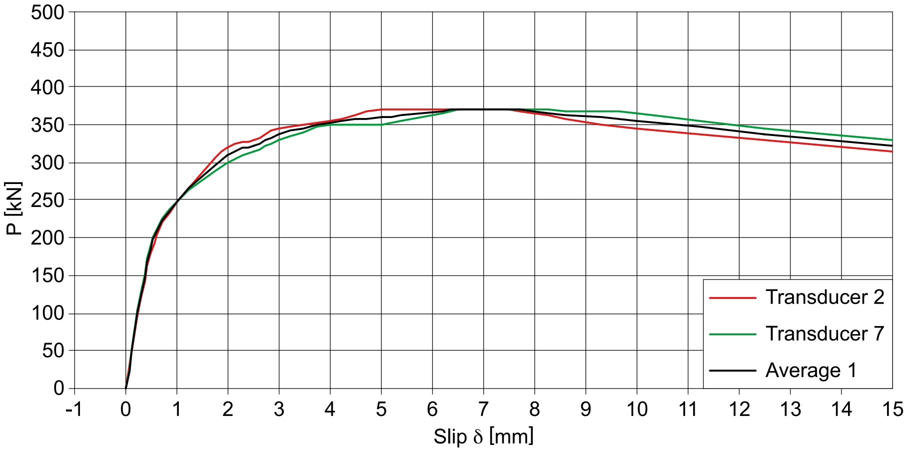


Figure 32: Load-displacement curve for push-out tests

Test results have shown that Hilti X-HVB shear connectors are ductile and meet the Eurocode 4 requirements for connections with plastic properties.

The connector's ductile load-bearing characteristics are ensured by design provisions, such as mentioned in:
- **Section 2.5. Application requirements**
- **Section 4.5. Shear resistance of X-HVB as per the Hilti Direct Fastening Technology Manual (DFTM) (Table 7)**
- **Section 5. X-HVB positioning, spacing and edge distances**

Where plastic stress distribution is taken into account in the beams, Eurocode 4 allows partial shear connection limited to 0.4 to be taken into account. The degree of shear connection is calculated as follows:

$$\eta = N_c / N_{c,f}$$

Where
- N_c is the design value of the compressive force in the concrete.
- $N_{c,f}$ is the design value of the compressive force in the concrete with full shear connection.

4.2 Concrete cover

EN1994-1-1, section 6.6.5.2, specifies that if concrete cover is required (exposure class as identified in EN1992-1-1, table 4.1), the nominal concrete cover
- can be 5 mm less than the values in EN1992-1-1, table 4.4.
- not less than 20 mm.

If no concrete cover is required, the code allows for the top of the connector to be flush with the top of the concrete slab.

Table 6 lists the recommended total slab thicknesses for the different X-HVBs. For more details, please refer to relevant Socotec and DIBt approvals.

Connector	Total slab thickness, h [mm]	
	No risk of corrosion	Risk of corrosion
X-HVB 40	50	60
X-HVB 50	60	70
X-HVB 80	80*/90	100
X-HVB 95	95	115
X-HVB 110	110	130
X-HVB 125	125	145
X-HVB 140	140	160

Table 6: Recommended total slab thickness, Socotec and DIBt
*DIBt recommendation only.

4.3 Distribution of shear connectors on beams

If plastic design is allowed, the shear connectors are spaced and distributed equally and uniformly along the beam, as the load is redistributed by the shear connectors. The shear connector used must fulfill the ductility requirements of the applicable section of Eurocode 4 - see section **4.1 Load-displacement behavior of the X-HVB (ductility requirements)**.
If elastic design is required, the shear connectors are distributed along the beam according to shear loads, i.e. higher shear loads near the supports or concentrated load are resisted by closer spacing of shear connectors. Such distribution ensures that each connector carries an equal share of the longitudinal shear force acting on the beam (**Figure 33**).

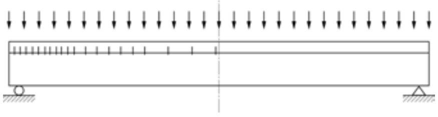


Figure 33: Graduated distribution of shear connectors

4.4 Longitudinal shear force between the concrete slab and the top flange of the steel beam

Shear connectors are designed to resist the longitudinal shear forces (as per stress distribution of the cross sections) in the horizontal plane between the concrete slab and top flange of the steel beam.
Typical plastic stress distributions are displayed in **Figure 34**.

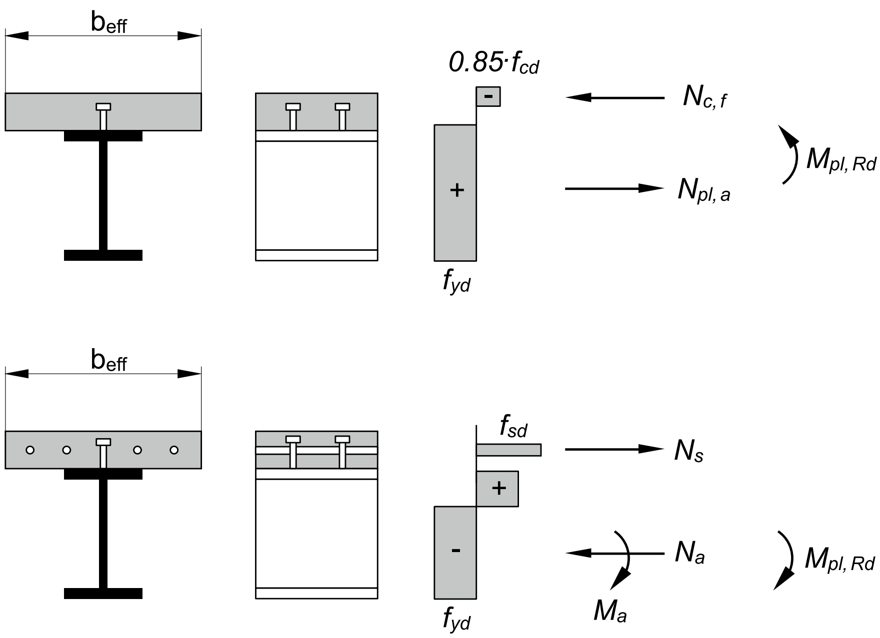


Figure 34: Typical plastic stress distributions for positive and negative bending moments

In case of plastic design, the full shear connection capacity, developed between the support and the center of the beam, must be equal or greater than the design compressive force Nc,f (in case of simple supported beam with uniform load applied).

Therefore, in full shear connection, the number of shear connectors to be used is determined by

$$\frac{\textbf{Design longitudinal shear force of beam}}{\textbf{Design shear resistance of single shear connector}}$$

4.5 Shear resistance of X-HVB as per DFTM

The loadbearing capacity of the X-HVB, i.e. shear resistance in a solid concrete slab, is the combined result of

- hole elongation in the fastening leg of the connector,
- local deformation of the base steel plus bending of the nails,
- bending of the X-HVB
- and local deformation of concrete in the contact zone with the connector.

4.5.1 Shear resistance of X-HVB in slab without steel decking

The shear resistance of the X-HVB is calculated with reference to recommendations in the Direct Fastening Technology Manual, and based on EN1994-1-1.

For slabs without steel decking and lightweight concrete / normal weight concrete (LWC/NWC), the shear resistance of the X-HVB shear connector is as follows (**Table7**).

Designation	LWC[1)] / NWC[2)]	Characteristic shear resistance, P_{Rk} [3)]	Design shear resistance, P_{Rd} [4)]	Allowable horizontal shear [5)]
X-HVB 40	LWC	25 kN	20 kN	N.A.
X-HVB 50	LWC	25 kN	20 kN	N.A.
X-HVB 40	NWC	28 kN	23 kN	N.A.
X-HVB 50	NWC	28 kN	23 kN	N.A.
X-HVB 80	NWC	28 kN	23 kN	14 kN
X-HVB 95	NWC	35 kN	28 kN	17.5 kN
X-HVB 110	NWC	35 kN	28 kN	17.5 kN
X-HVB 125	NWC	35 kN	28 kN	17.5 kN
X-HVB 140	NWC	35 kN	28 kN	17.5 kN

Table 7: Design shear resistance of the X-HVB

1) LWC: lightweight concrete with density of 1800kg/m3 and class L20-22
2) NWC: normal weight concrete with density of 2400kg/m3 and class C20-25
3) As defined in EN1994-1-1 (nominal strength in AISC-LRFD)
4) As defined in EN 1994-1-1
5) Allowable shear in AISC-ASD

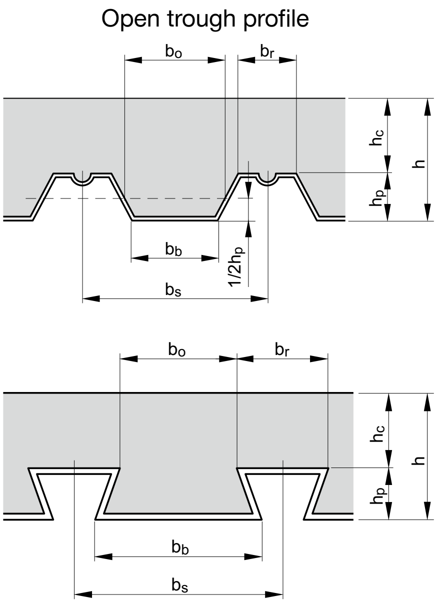


Figure 35: Steel decking profile geometries

4.5.2 Shear resistance of the X-HVB in slab with steel decking

When profile steel decking is present, the shear resistance of the X-HVB is calculated by multiplying the shear resistance without steel decking with reduction factors that are dependent on decking orientation and profile geometry.

Steel decking with ribs parallel to supporting beam – Design shear resistance of each X-HVB is design shear resistance in **Table 7** multiplied by reduction factor k_p or k_l, ($\leq$ 1) where

$$k_p = 1 \quad \text{, for } b_0/h_p \geq 1{,}8$$

$$k_p = 0{,}6\,(b_0/h_p)\big((h_{sc} - h_p)/h_p\big) \quad \text{, for } b_0/h_p < 1{,}8$$

Please refer to **Figure 35** for profile geometries.

Steel decking with ribs transverse to supporting beam – When the ribs are transverse to the supporting beam, the shear resistance of each X-HVB is influenced by reduction factor, k_t.

$$k_t = (0{,}7/\sqrt{n_r})\,(b_0/h_p)\big((h_{sc} - h_p)/h_p\big) \leq 1$$

Where,
b_o is the width of the steel decking profile
h_p is the height of the steel decking profile
h_{sc} is the height of the X-HVB
n_r is the number of X-HVBs per rib, ≤ 2 even when more X-HVBs are installed in a rib.

Fastener selection with regard to the profile deck
The maximum allowable steel decking height is as per **Table 8** is shown below.

Designation	Maximum decking height, h_p (mm)	
	b_0 / h_p ≥ 1,8	b_0 / h_p < 1,8
X-HVB 80	45	45
X-HVB 95	69	57
X-HVB 110	75	66
X-HVB 125	80	75
X-HVB 140	80	80

Table 8: Maximum decking heights, according to DFTM

Note: The X-HVB 40 and X-HVB 50 are not to be used with profiled steel decking.

4.6 Substituting welded shear studs with the X-HVB in design

Shear resistance of headed studs in slabs without steel decking

Section 6.6.3.1 of EN1994-1-1 states that the design resistance of a headed stud, automatically welded to a steel beam, should be the lesser value of:

$$P_{Rd} = \frac{0{,}8 f_u \pi d^2/4}{\gamma_V}$$ EN1994-1-1, (6.18)

$$P_{Rd} = \frac{0{,}29 \alpha d^2 \sqrt{f_{ck} E_{cm}}}{\gamma_V}$$ EN1994-1-1, (6.19)

Where,

$\alpha = 0{,}2(h_{sc}/d + 1)$,for $3 \leq h_{sc}/d \leq 4$ EN1994-1-1, (6.20)

$\alpha = 1$,for $h_{sc}/d > 4$ EN1994-1-1, (6.21)

γ_V is the partial safety factor (recommended value = 1.25)
d is the diameter of the stud shank.
f_u is the specified ultimate tensile strength of the stud material but not greater than 500 N/mm^2.
h_{sc} is the overall nominal height of the stud.

Shear resistance of welded studs in slab with profiled steel decking

When profiled steel decking is used, the shear resistance of the welded stud is calculated by multiplying **the shear resistance without steel decking by reduction factors that are dependent on decking orientation and profiles.** These reduction factors may significantly reduce shear resistance.
Steel decking with ribs parallel to supporting beam - the reduction factor k_l is:

$$k_l = 0{,}6\,(b_0/h_p)\left((h_{sc}/h_p) - 1\right) \leq 1{,}0$$ EN1994-1-1, (6.22)

Where,

$$h_{sc} \leq h_p + 75\,mm$$

Steel decking with ribs transverse to supporting beam - The values of reduction factor k_t are governed by **Table 9** (Table 6.2 of EC4) and the following equation:

$$k_t = 0{,}7/\sqrt{n_r}\,(b_0/h_p)\left((h_{sc}/h_p) - 1\right) \leq 1{,}0 \qquad \text{EN1994-1-1, (6.23)}$$

Where,
n_r is the number of welded studs per rib, not exceeding 2.

Number of stud connectors per rib	Thickness t of sheet (mm)	Studs not exceeding 20 mm in diameter and welded through profiled steel sheeting	Profiled sheeting with holes and studs 19 mm or 22 mm in diameter
$n_r = 1$	≤ 1.0	0.85	0.75
	≥ 1.0	1.0	0.75
$n_r = 2$	≤ 1.0	0.7	0.6
	≥ 1.0	0.8	0.6

Table 9: Upper limits for the reduction factor k_t (Table 6.2 of EC4)

Comparison of the applicable design values between X-HVBs and headed studs shows that the headed studs clearly lose ground to X-HVBs when profile decks are used, as allowance must be made for a reduction in loading capacity when perforated sheets are used or when studs are welded through the sheets.

With nailed shear connectors, however, the method results in no loss of loading capacity. **Table 10** shows an example for comparison.

	P_{Rd} [kN]		
		Composite slab	
Means of shear connection	Solid slab	Perforated steel deck	Steel deck with studs welded through or with driven nails
Headed studs d=19 mm[1)]	70.6	42.4	49.4
Shear connectors X-HVB 125	28.0	28.0	28.0

[1)] Where α = 1, n_r = 2, t ≤ 1

Table 10: Comparison of the maximum design values for headed studs and X-HVB nailed shear connectors for C30/37

When comparing the designed shear resistances of both welded shear studs and the X-HVB, the number of X-HVB required to substitute welded shear studs can be determined by simple division of the respective longitudinal shear resistances.

5. X-HVB positioning, spacing and edge distances

5.1 General rules

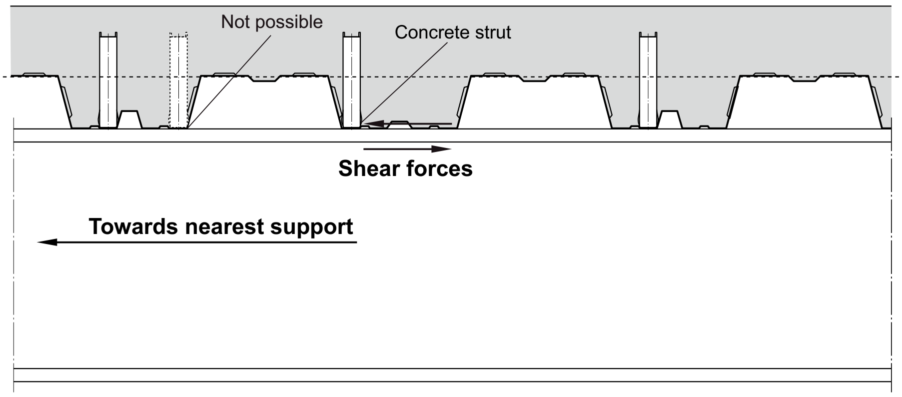


Figure 36: Stress transmission in concrete slab

Load transfer between X-HVBs and the slab is accomplished predominantly by a concrete strut, as illustrated in **Figure 36**.
In addition, when steel decking has narrow ribs and/or stiffeners, the X-HVB should be positioned on the favorable side of the rib, which is towards the nearest beam support, as per **Figure 36**, to allow sufficient load transfer.

Positioning the X-HVB in relation to the supporting beam: The X-HVBs may be placed parallel or transverse to the supporting beam. If possible, X-HVB orientation parallel to the axis of the beam is preferred.

Positioning the X-HVB in relation to the decking profile: The X-HVBs may be placed parallel or perpendicular to the profile ribs.

Minimum distance to the edge of the beam: The X-HVBs can be set flush with the edge of the beam flange, if required.

5.2 Solid concrete slab without steel decking

In addition to the rules mentioned previously, the X-HVBs should be placed longitudinally, parallel to the beam, and opposing each other, as shown in **Figure 37** and **Figure 38**. The minimum longitudinal distance between the anchorage legs is 100 mm and the shear connectors must be spaced at a maximum of 4 times the total concrete thickness or 600 mm, whichever is smaller.

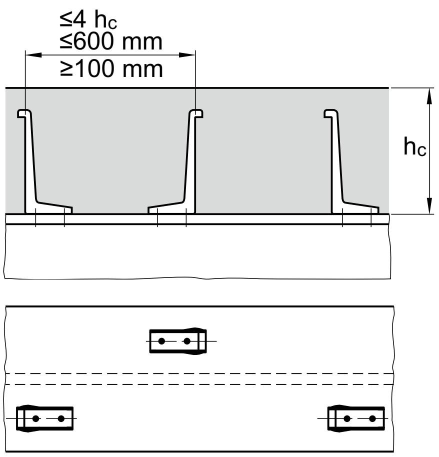


Figure 37: Solid concrete slab with one X-HVB per row

In case of multiple rows (parallel to the beam axis), X-HVBs must be placed facing the same direction in each row and alternately from row to row (**Figure 38**).
The minimum distance between adjacent X-HVBs is 50 mm (**Figure 39**).

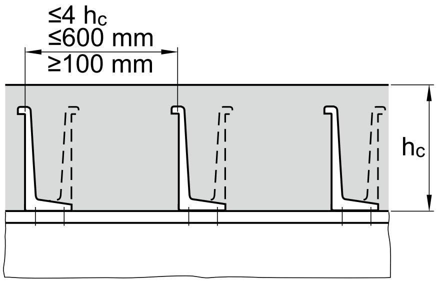


Figure 38: Spacing in concrete solid slab with multiple rows of X-HVBs

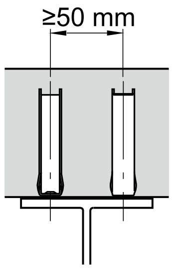


Figure 39: Minimum spacing between shear connectors for concrete slabs without steel decking

5.3 Concrete slab with steel decking – ribs parallel to beam

In general, the ribs of steel decking are parallel to the primary beam. Ideally, the X-HVBs should also be placed parallel to the beam and opposite each other.

When only one X-HVB is placed on the flange it should be centered relative to both the supporting beam and the decking rib and ensure a minimum b_o of 60 mm (**Figure 40**).

However, when profiles have stiffeners between ribs, placement of the X-HVB should alternate between opposite to each other and positions to the left and right of the web (**Figure 41**).

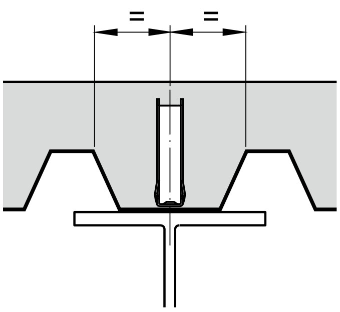


Figure 40: Shear connector centered on the flange

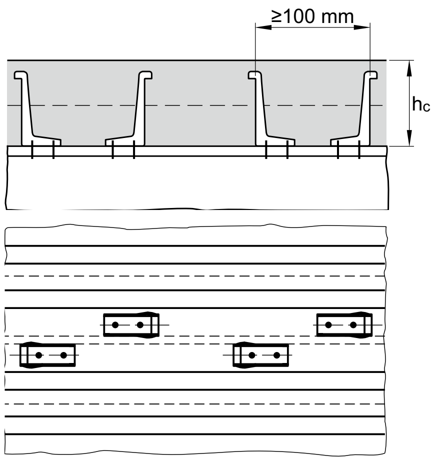


Figure 41: Minimum distance between X-HVBs

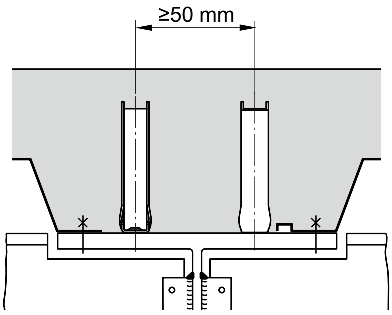


Figure 42: Minimum distance between X-HVBs

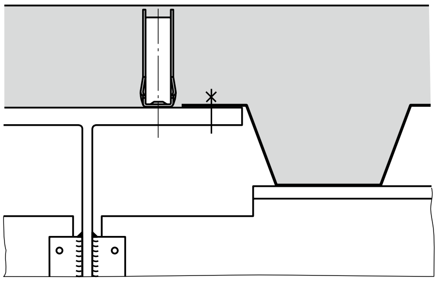


Figure 43: Detail of main beam and secondary beam

When more than one X-HVB is placed parallel on the flange, the minimum distance between the X-HVBs should be 50 mm (**Figure 42**).

If the dimensions indicated above are not possible, it is recommended that the steel decking on the flange of the beam is separated in order to accommodate X-HVB installation. The steel decking is then fastened to the flange with suitable Hilti fasteners, e.g. X-ENP-19 L15 (**Figure 42**).

When the primary beams are not the same height as the secondary beams, separation of the steel decking is always necessary. The separated steel decking must be directly fastened to the flange with suitable Hilti fasteners, e.g. X-ENP-19 L15.
The X-HVBs can be placed between the nails or directly over the beam (**Figure 43**).

5.4 Concrete slab with steel decking – ribs transverse to beam

The shear connector may be placed **parallel** or **transverse** to the supporting beam.

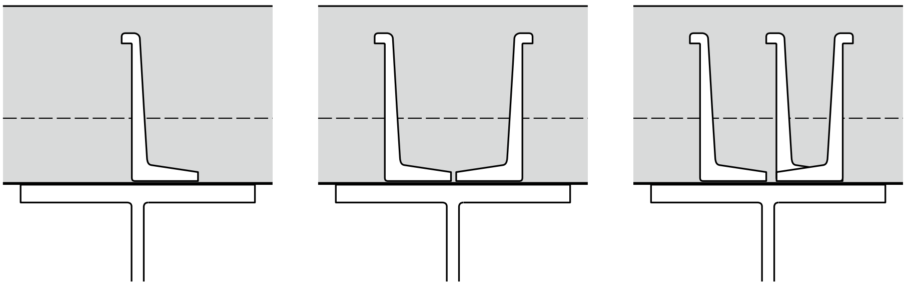


Figure 44: X-HVB perpendicular to supporting beam

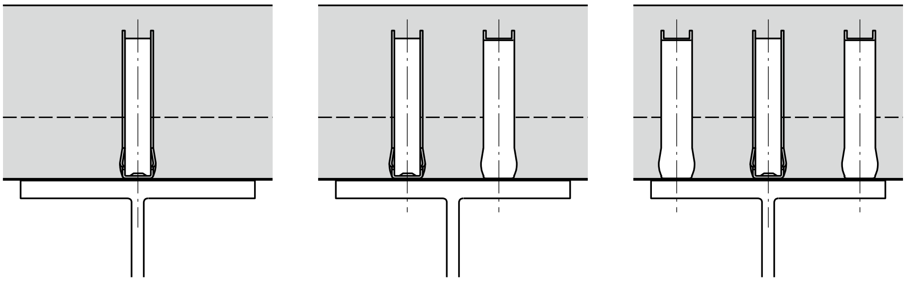


Figure 45: X-HVB parallel to supporting beam

5.4.1 One X-HVB per rib

When the X-HVBs are placed perpendicular to the supporting beam (**Figure 44** and **Figure 46**), the X-HVB should, preferentially, be located at the middle of the valley, as indicated in **Figure 46**.

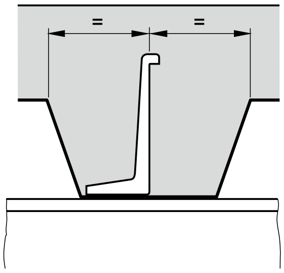


Figure 47: One X-HVB per rib, parallel to supporting beam

Figure 46: One X-HVB per rib, perpendicular to the supporting beam

When X-HVBs are placed parallel to the supporting beam, the X-HVB should be placed over the web and the anchorage leg should be centered.

For steel decking with stiffeners, where the X-HVB is perpendicular to the supporting beam (**Figure 48**), it should be placed next to the indents. When the X-HVB is parallel to the supporting beam the anchorage leg should face the indent (**Figure 49**).

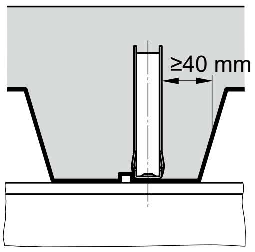


Figure 48: Decking with indentations, X-HVB perpendicular to supporting beam

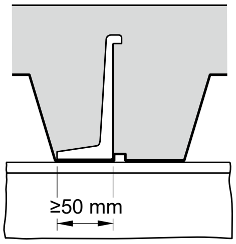


Figure 49: Decking with indentations, X-HVB parallel to supporting beam

5.4.2 Two X-HVBs per rib

The shear connectors must be aligned in the middle of the valley, with the anchorage legs facing outwards (**Figure 50**).

Figure 50: Two shear connectors per rib

The shear connectors should be arranged symmetrical to the beam's central axis (**Figure 50**).

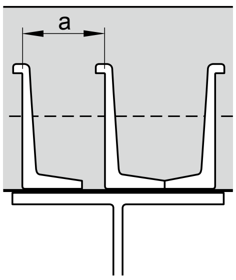


Figure 51: Minimum distance between X-HVB anchorage legs

5.4.3 Three X-HVBs per rib

For X-HVB positioning in decking with ribs transverse to the supporting beam (typically secondary beams), two types of profiled decks can be distinguished according to their b_o / h_p relation. The minimum distance between anchorage legs, governed by this classification, is indicated in **Table 11**.

The X-HVBs placed near the edges of the beams should face the exterior, and the shear connector in the middle should be aligned with the beam's web.

b_0/h_p	a
$b_0/h_p \geq 1,8$	a ≥ 50 mm
$b_0/h_p < 1,8$	a ≥ 100 mm

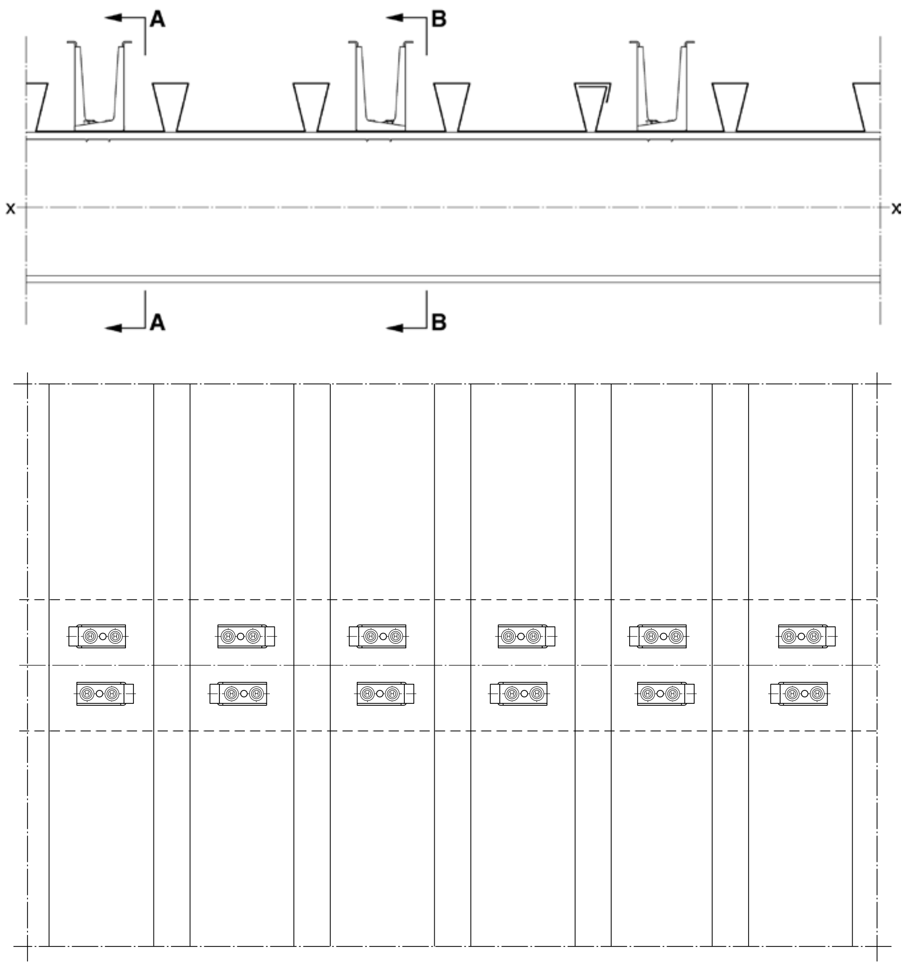
Table 11: Minimum distance, a between X-HVB anchorage legs

Please contact your local Hilti representatives if more than three X-HVBs per rib are necessary.

5.5 Examples of commercial steel decks

5.5.1 Holorib HR 51/150

Two X-HVBs per rib



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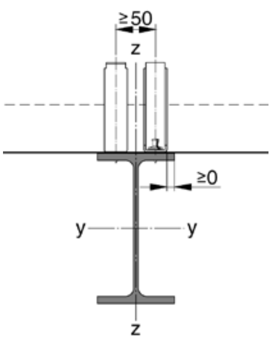
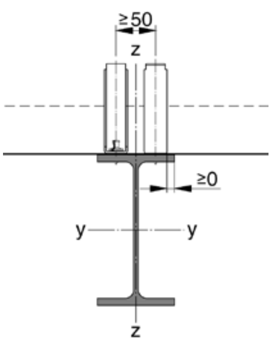
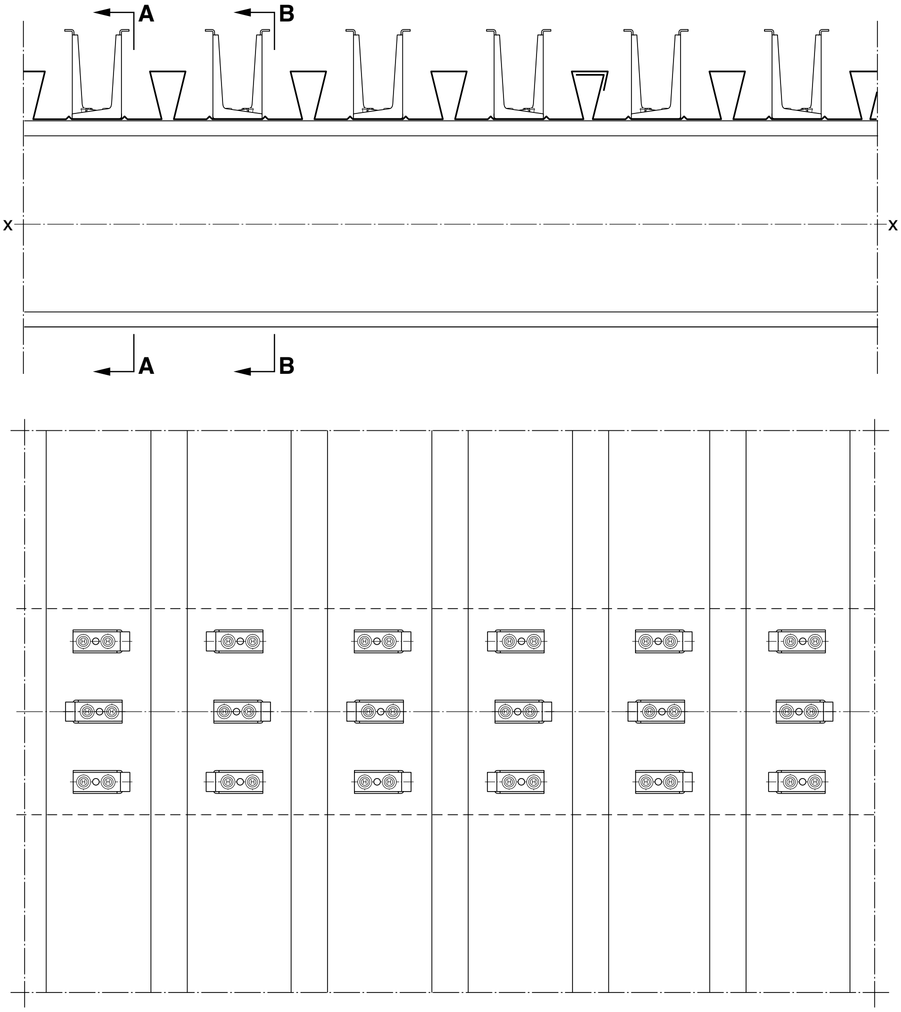


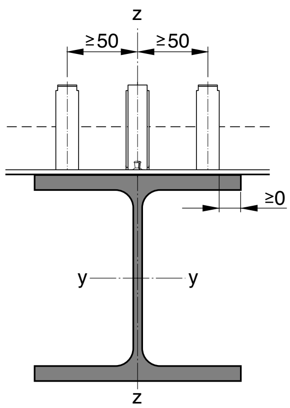
Section B-B



Three X-HVBs per rib



Section A-A



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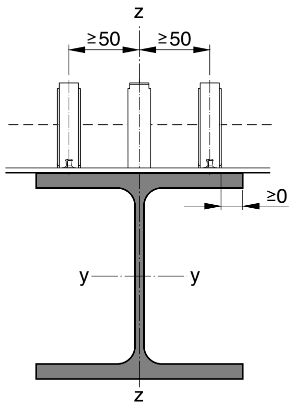

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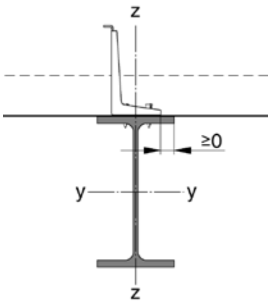

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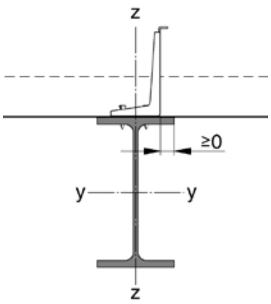
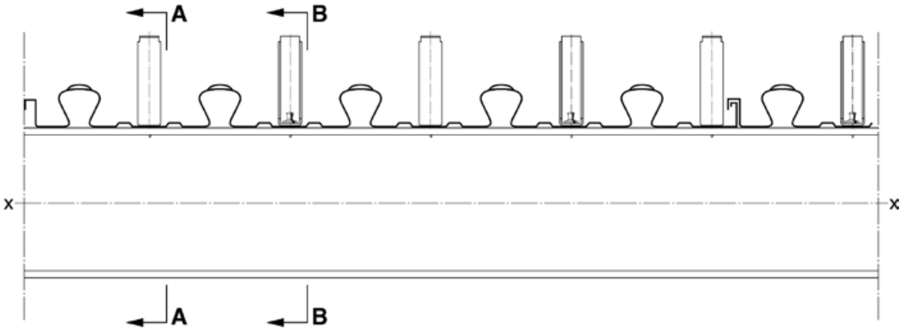
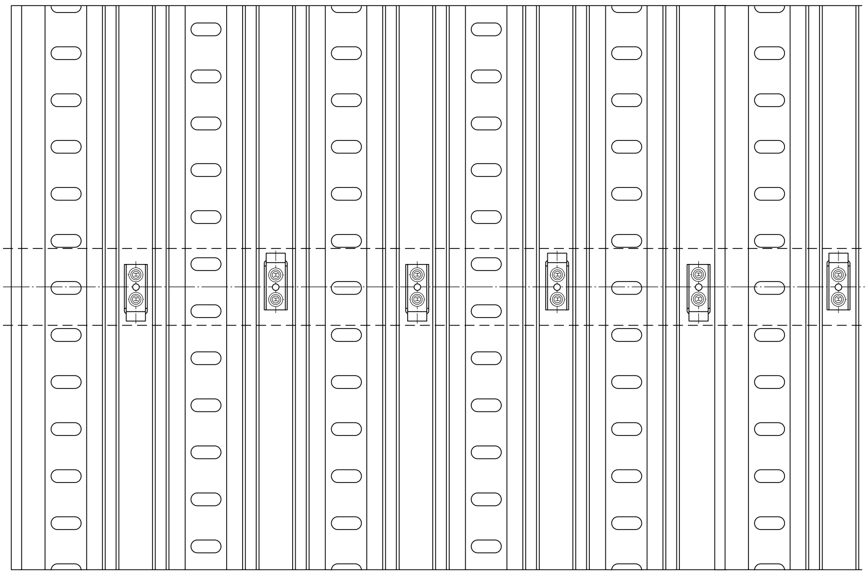


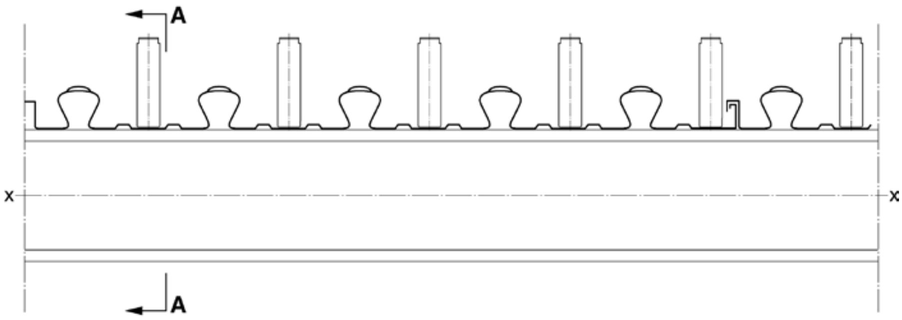
5.5.2 COFRASTRA 40

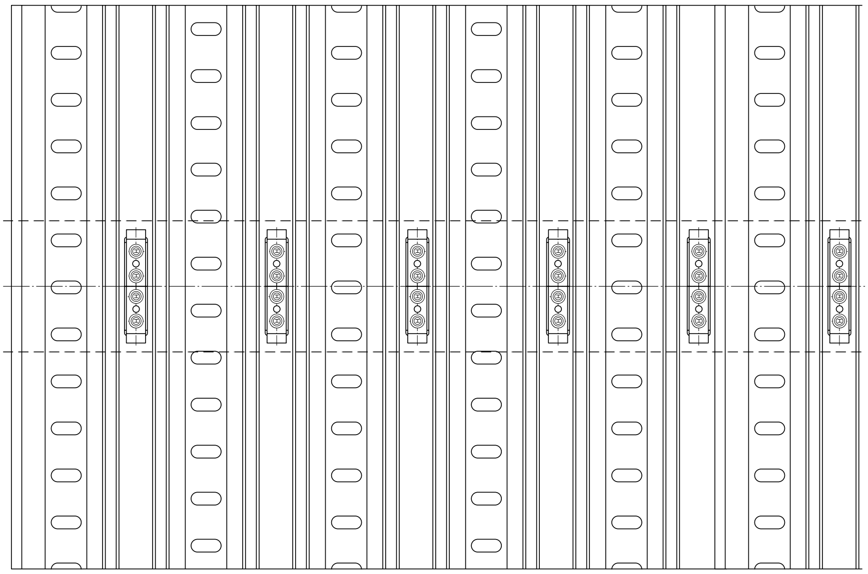
One X-HVB per rib





Two X-HVBs per rib





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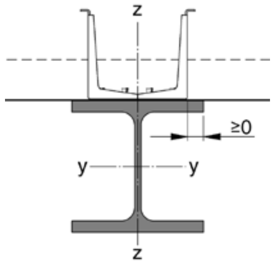

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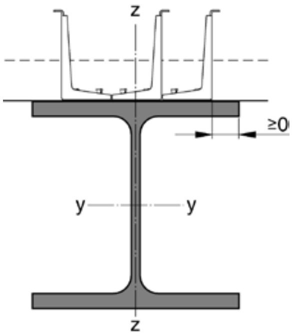

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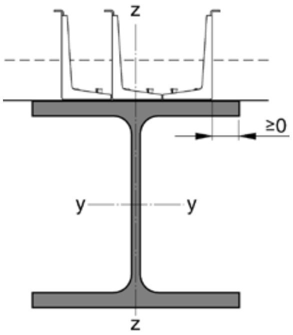
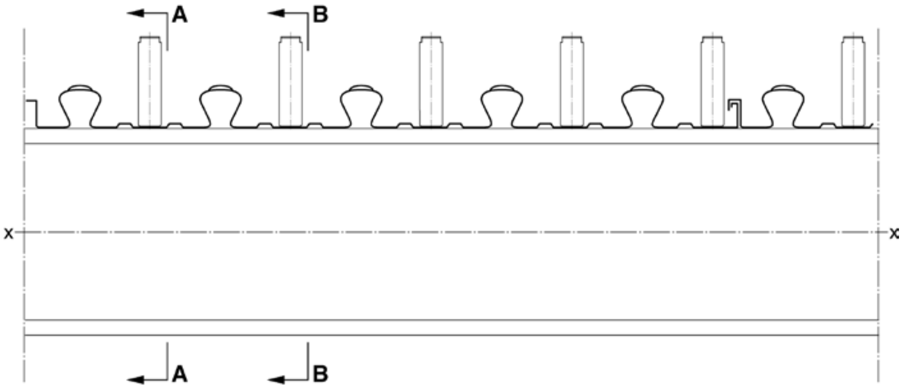
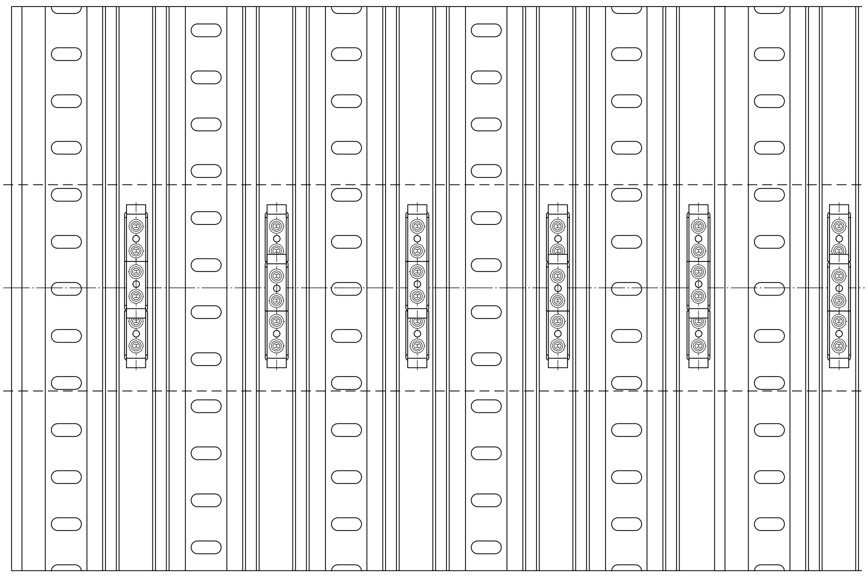
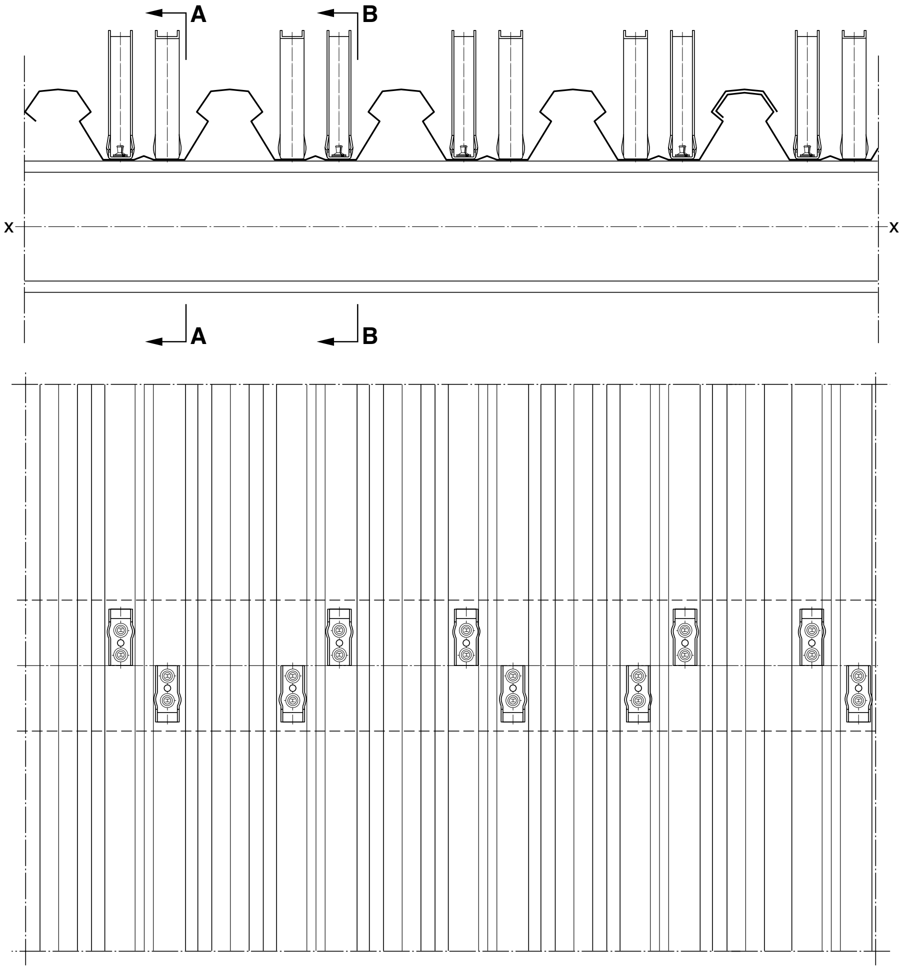


Three X-HVBs per rib

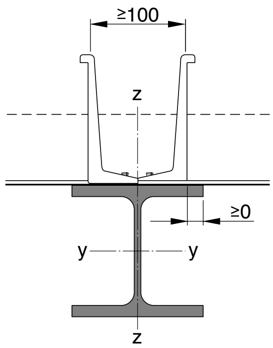




5.5.3 COFRASTRA 70
Two X-HVBs per rib



Section A-A



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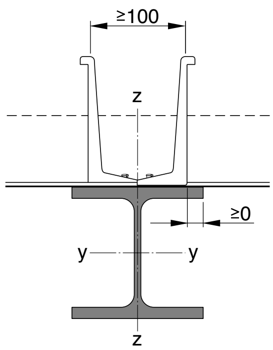
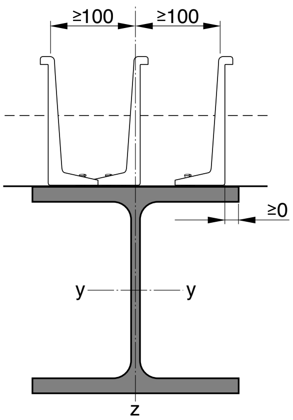
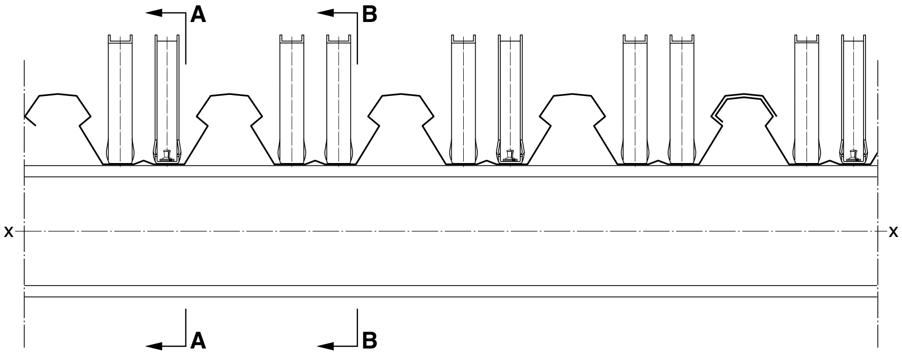


Section A-A



Three X-HVBs per rib



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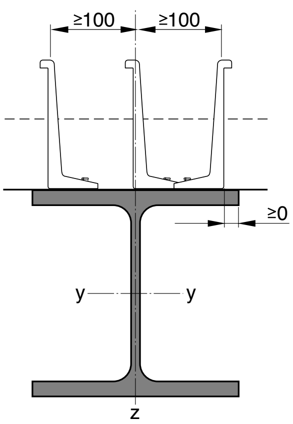

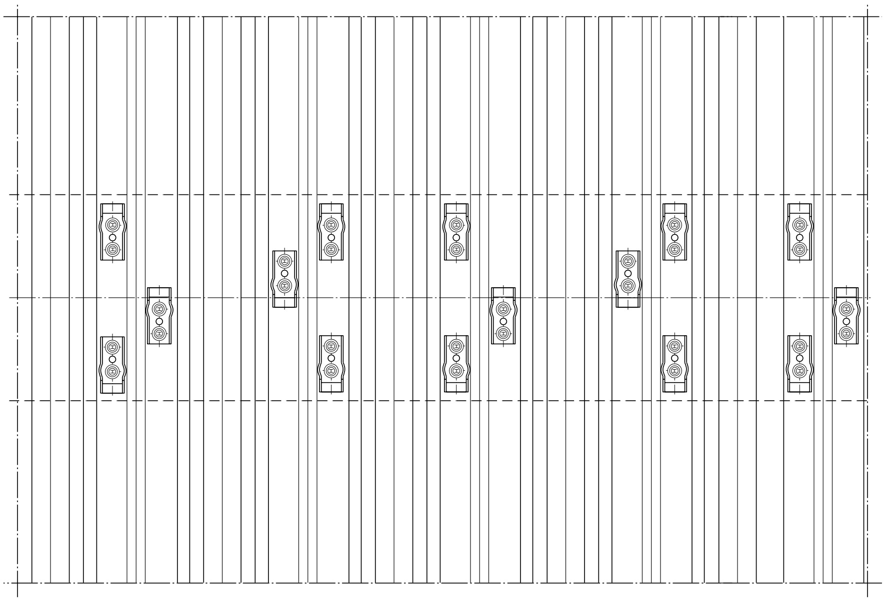

5.6 X-HVB positioning in rehabilitation projects

In rehabilitation projects with thin concrete solid slabs, in order to allow close X-HVB spacing on flanges with narrow width of about 50 mm, "duck walk" positioning is recommended: the center of the X-HVB base is positioned in the middle of beam's top surface, and the X-HVBs are alternately obliquely oriented relative to the longitudinal axis of the beam **(Figure 52)**.
In the common case of uniformly distributed loads, the X-HVBs are located symmetrically and the heads are pointing toward the nearest support **(Figure 53)**.

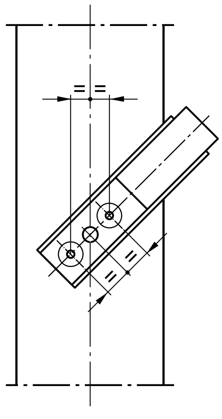

Figure 52: "Duck walk" positioning detail

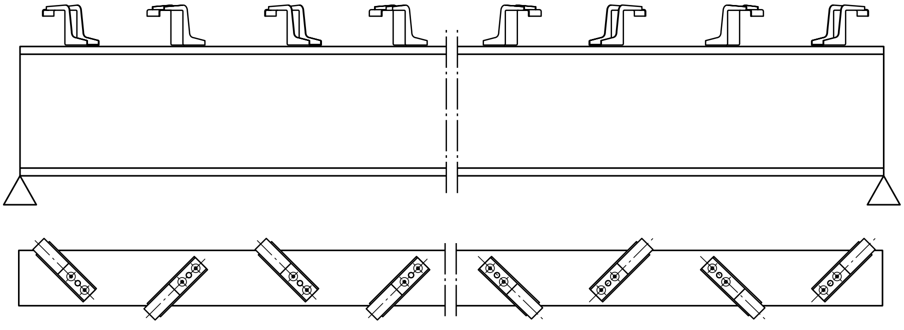

Figure 53: "Duck walk" positioning along the beam

6. Design examples

6.1 Substituting specified welded studs with X-HVB

HOLORIB 51 steel decking with the geometry shown in **Figure 54** is to be used, with ribs transverse to the beam.

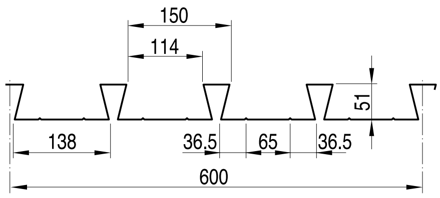

Figure 54: Holorib 51 geometry

This profile is initially designed with holes and one welded shear stud per rib which is to be substituted by the calculated number of X-HVBs.

The design resistance of the welded shear stud is the minimum value of:

$$P_{Rd} = (0.8\, f_u\, d^2/4)/\gamma_V = (0.8\times 450\times 19^2/4)/1.25 = 81.7\ kN$$

and

$$P_{Rd} = \left(0.29\alpha d^2\sqrt{f_{ck}E_{cm}}\right)/\gamma_V = \left(0.29\times 1\times 19^2\sqrt{25\times 31\times 10^3}\right)/1.25 = 73.7\ kN$$

where
$h_{sc}/d>4$, therefore α = 1 (see section 4.8 substituting welded shear studs with X-HVB in design)

The reduction factor k_t is given by:

$$k_t = (0{,}7/\sqrt{n_r})\,(b_0/h_p)\left((h_{sc}-h_p)/h_p\right) = \left(0.7/\sqrt{1}\right)(114/51)\left((100/51)-1\right) = 1.5 \rightarrow 1$$ (not greater than 1)

However, according to table 6.2 of EC1994-1-1, the maximum value for k_t is 0.75.

Hence, $P_{Rd} = 0.75\times 73.7 = 55.3\ kN$

The shear resistance of X-HVB, assuming the X-HVB 110 is used, is:
P_{Rd} = 28 kN (**Table 7**, view section 4. Shear connector design according to EC4)

The reduction factor, k_t is given by:
• Assuming one shear connector per rib,

$$k_t = \frac{0.7}{\sqrt{n_r}}\frac{b_0}{h_p}\left(\frac{h_{sc}}{h_p}-1\right) = \frac{0.7}{\sqrt{1}}\frac{114}{51}\left(\frac{110}{51}-1\right) = 1.81 \rightarrow 1$$

P_{Rd} = 28 kN

Comparing the P_{rd} of welded stud and X-HVB, it is clear that more than one X-HVB is required. In this case, we have to recalculate k_t with $n_r = 2$ ($n_r = 2$ for 2 or more X-HVB per rib).

• Two or three shear connectors per rib,

$$k_t = \frac{0.7}{\sqrt{n_r}}\frac{b_0}{h_p}\left(\frac{h_{sc}}{h_p}-1\right) = \frac{0.7}{\sqrt{2}}\frac{114}{51}\left(\frac{110}{51}-1\right) = 1.28 \rightarrow 1$$

Hence,
P_{Rd} = 28 kN
Number of X-HVB required to substitute a welded stud = 55.3 / 28 = 1.975 = 2
Accordingly, two X-HVBs are necessary to replace one welded stud per rib in this case.

In many cases, as welded studs have been overdesigned initially, simple replacement to ensure the same resistance may promote inefficient use or design.

6.2 Hilti support

Hilti provides excellent engineering support and services.
Please contact your local Hilti representatives if you have any queries on the design and installation of X-HVBs.

7. Special considerations

7.1 Fire resistance

The temperature-dependent characteristic shear resistance of X-HVB shear connectors in a solid slab, in the fire situation, should be determined according to the following expression:

$$P_{fi,Rd} = \left(k_{u,\theta} P_{Rk}\right) / \gamma_{M,fi}$$

Where,
P_{Rk} is the characteristic shear resistance of X-HVB, as provided in the DFTM (section 4.5).
$\gamma_{M,fi}$ is the partial safety factor for shear resistance for the fire situation. As stated in EN1992-1-4, section 2.3. The recommended value for $\gamma_{M,fi}$ is 1.
$k_{u,\theta}$ is the reduction factor for the characteristic resistance of X-HVB, given by:

X-HVB temperature, θ_a	$k_{u\theta,HVB}$
20	1.00
100	1.00
200	1.00
300	0.77
400	0.42
500	0.24
600	0.12
>700	0

Table 12: Reduction factor for the characteristic resistance of X-HVB in DIBt Z-26.4-46

When profiled steel decking is used, the resistance of X-HVB should be further multiplied by the reduction factors which are dependent on decking rib orientation, as present in **4. Shear connector design according to EC4.**

As stated in EN1992-1-4, section 4.3.4.2.5, the temperature of shear connectors, in a fire situation, may be taken as 80% of the temperature of the upper flange of the beam.

When designing for a fire situation, the total characteristic shear resistance of X-HVBs is compared to the longitudinal shear force acting on the beam with fire loading.

Figure 55: Old steel profiles collected on different jobsites in L'Aquila (Italy)

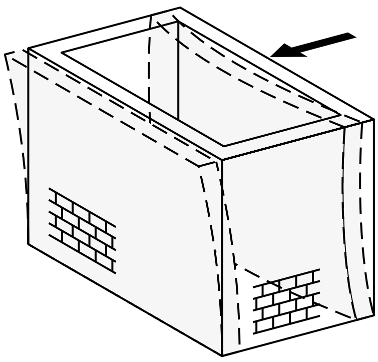

Figure 56: Out-of-plane collapse

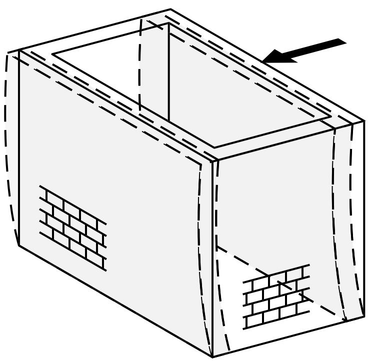

Figure 57: Out-of-plane collapse prevented, rigid diaphragm

7.2 Rehabilitation

At the University of the German Army in Munich, push-out tests with X-HVBs have also been carried out in order to investigate the load-bearing capacity of the shear connectors on old steel beams with a view to issuing a specific jobsite approval. The main finding was that for these old beams the standard load data published within the DFTM is valid and can be used for design of this project.
The French Socotec PX 0091/8 approval specifically addresses the use of Hilti X-HVBs in rehabilitation projects. For more details, please refer to the approval.
Furthermore, in cooperation with the University of Stuttgart, push-out tests have been carried out to investigate the behavior of X-HVBs installed on old steel profiles taken from Italian jobsites from L´Aquila as well as new 6 mm thin steel material representative of many rehabilitation jobs.
Results of the tests indicate similar performance for X-HVBs installed on normal weight concrete and lightweight concrete solid slabs. According to these results, lightweight concrete can be chosen to utilize all benefits related to a lighter structure (reduced self-weight, greater loading capability, better seismic response).
In case of fastening on old steel beams with ultimate strength $F_u \leq 360$ N/mm2 (with a $F_{u,min}$ = 300 N/mm²), a conservative reduction factor (F_{actual}/360) should be taken into account.
Please contact Hilti for detailed information.

7.3 Seismic response

A major source of vulnerability of existing buildings (particularly masonry structures with wooden/steel beam slabs) is associated with local collapse mechanisms (out-of-plane response of the bearing walls). By improving connections between the elements, through new composite slabs interconnected with perimeter walls, you can improve the seismic behavior of the entire building.
For proper seismic improvement, it is extremely important to create diaphragms (slabs) capable of transferring the horizontal actions of the earthquake to the shear-resistant walls. Diaphragms help to constrain the out-of-plane deformation of the walls, preventing the collapse, through keeping the box-like configuration; the stiffness of the diaphragms in their plane influences the distribution of the horizontal forces between different sidewalls. To be able to represent an effective constraint, diaphragms have to be able to transmit forces and tensile stresses and must also be properly connected to the walls, as evidenced by Eurocode 8 - Part 3.

7.4 Deflection control

If the shear connection is only required for deflection control there is no minimum degree of connection. However, maximum allowable connector spacing applies and the steel beam must have sufficient capacity to carry the self weight and all imposed loads.

8. References

8.1 Approvals

France:

- SOCOTEC (2012): Cahier des charges des connecteurs en construction neuve. No. PX 0091/7. December 2012.
- SOCOTEC (2012): Cahier des charges d'utilisation en réhabilitation des connecteurs X-HVB, No. PX 0091/8. December 2012.

Germany:

- Deutsches Institute für Bautechnik (2013): Zulassungsbescheid Z-26.4-46: Hilti Schenkeldübel X-HVB als Verbundmittel. October 2013.

Czech Republic:

- Technical and Test Institute for Construction Prague (2011). Spřahovací prvky Hilti pro spřahování ocelobetonových konstrukcí ve stavebnictví. č.070-041312.

Romania:

- Ministerul Dezvoltării Regionale şi Administrației Publice Consiliul Tehnic Permanent Pentru Contrucții (2013): Procedeu pentru fixarea conectorilor Hilti X-HVB pentru realizarea de elemente strucutrale mixte pentru construcții. AT 016-01/281-2013.

8.2 Literature

Neuer Verbunddübel für Konstruktionen mit Stahl/Beton-Verbund, M. Crisinel, D. Clenin, Schweizer Baublatt 77, 9/85 (C4: VI.2.4.4)

Zur Bemessung von Schenkeldübeln, eines neuen Dübels für Verbundkonstruktionen im Hochbau, F. Tschemmernegg, Bauingenieur 60 (1985) (C4: VI.2.4.5)

The Behaviour and Strength of Steel to Concrete Connection using HVB Shear Connectors (EC4-Design), J.C. Badoux, EPF Lausanne, ICOM 617-4, 6/1989 (C4: VI.2.2.8)

Partial-Interaction Analysis of Composite Beams with Profiled Sheeting and Non-welded Shear Connectors, M. Crisinel, EPF Lausanne, Journal of Constructional Steel Research 15 (1990) 65 – 98 (C4: VI.2.4.11)

Composite beams with profiled-steel sheeting and non-welded shear connectors, D.A.B. Thomas, D.C. O´Leary, Steel Construction Today 1988, 2, 117 – 121

Testing of Continuous Span Composite Slabs with Hibond 55 Profiled Sheeting (HVB 95), B.J. Daniels, M. Crisinel, D.O´Leary, ICOM 229 (C4: VI.2.1.11)

Partial connection of steel and concrete composite beams with HVB shear connectors, K. Peleska, Department of Steel Structures, CVUT Praha, Proceedings of Eurosteel 99 Conference

Powder-actuated fasteners and fastening screws in steel construction, H. Beck, M. Siemers, M. Reuter. Stahlbau-Kalender. Ernst & Sohn (2011).

Figure 58: Hilti Direct Fastening Technology Manual

8.3 Hilti publications

The Hilti Direct Fastening Technology Manual (DFTM) is intended as a guide on how to use and choose suitable and correct direct fastening solutions for each specific application. The DFTM provides all the technical data necessary for the correct utilization of Hilti's direct fastening products and describes the main principles and techniques that have an influence on direct fastening.

8.4 Project references

For up-to-date project references, please refer to your local Hilti website.

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