ICC-ES Evaluation Report

ESR-3799

Reissued September 2023

Subject to renewal September 2024

DIVISION: 03 00 00 - CONCRETE Section: 03 15 00—Concrete Accessories	REPORT HOLDER: LEVIAT GmbH	EVALUATION SUBJECT: HALFEN INSULATED CONNECTIONS (HIT)	

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2015 *International Building Code*® (IBC)
- 2015 *International Residential Code*® (IRC)

Property evaluated:

- Structural
- Fire resistance

2.0 USES

The Halfen Insulated Connections (HIT) are load bearing assemblies used as a thermal break to minimize thermal bridging when connecting external reinforced cast-in-place concrete slabs to internal cast-in-place reinforced concrete slabs. The HIT are intended to transfer bending moments, or shear forces, or a combination of bending moments and shear forces.

3.0 DESCRIPTION

See Figure 1 for description of nomenclature.

3.1 HIT-HP/SP:

The HIT-HP and HIT-SP includes an insulating layer of mineral wool with thickness of 80 mm (3.15 inch for HP) or 120 mm (4.72 inch for SP). A casing box made of a proprietary plastic material fixes all load bearing members and encases the insulating material within the connection. The HIT depends on internal forces to be transferred through the joint, and is intended for connecting reinforced concrete slabs. The HIT transmits forces to the adjacent components by bond and surface pressure.

3.2 HIT-HP/SP MVX, ZVX, ZDX, and DD:

The HIT-HP/SPs are available in three different types: MVX, ZVX and ZDX, and DD.

3.2.1 HIT-HP/SP MVX (HIT-HP MVX, HIT-SP MVX): The MVX is used to resist bending moments and shear forces. The MVX consists of steel tension reinforcing bars and compression shear bearings. The steel tension reinforcing bars are embedded in the concrete and the compression shear bearings bear against the concrete outside of the insulation joint. The MVX is used for connecting reinforced concrete slabs under several conditions including connections between slabs with and without an offset, either vertically up or down, and connections between slabs and walls respectively. Additional sub-types of MVX include –OD (offset down) and –OU (offset up). See Figures 2 and 4 for depictions of MVX and Tables 4 and 5 for dimensions and design parameters. HIT-HP/SP MVX…ES is a multi-part connection with plastic casings that are site assembled.

3.2.2 HIT-HP/SP ZVX and HIT-HP/SP ZDX (HIT-HP ZVX, HIT-SP ZVX, HIT-HP ZDX, HIT-SP ZDX): The ZVX and ZDX are used to resist only shear forces. The ZVX and ZDX consist of steel shear reinforcing bars and compression shear bearings. The shear reinforcing bars are embedded in the concrete and the compression shear bearings bear against the concrete outside of the insulation joint. See Figures 5 and 6 for depictions of ZVX and ZDX and Table 7 for dimensions and design parameters.

3.2.3 HIT-HP/SP DD (HIT-HP DD, HIT-SP DD): The DD is used to resist both positive and negative bending moments and shear forces. The DD consists of steel tension reinforcing bars, steel shear reinforcing bars, and steel compression reinforcing bars, without compression shear bearings. All steel reinforcing bars are embedded in the concrete. See Figure 3 for depictions of DD and Table 6 for dimensions and design parameters.

3.3 Materials:

The HIT consists of the following materials:

3.3.1 Compression Shear Bearing (CSB): Compression shear bearings (CSB) are made of proprietary high strength fiber reinforced mortar. The end faces have a specific geometry to facilitate movement between the external and internal concrete slabs. See Figure 7 for depiction of the double symmetric compression shear bearing and Table 1 for dimensions.

3.3.2 Thermal insulation material: Thermal insulation material consists of mineral wool according EN 13162 with CE mark, classified as Euro Class A1 according to EN 13501-1.

3.3.3 Steel reinforcing bars: Tension and compression reinforcing bars consist of a stainless steel bar or a welded bar connection, which is a combination of carbon steel bars welded on each side of a stainless steel bar. The stainless steel bar is in the insulating joint for a minimum length of 100 mm (3.94 in.) within the adjacent components. See Figure 8a and 8b for depictions of tension and compression reinforcing bar configurations, and Table 2 for diameter combinations of tension and compression reinforcing bars.

Shear reinforcing bars consist of a stainless steel bar or a welded bar connection, which is a combination of carbon steel bars welded on each side of a stainless steel bar. The stainless steel bar is in the insulating joint for a minimum length of 100 mm (3.94 in.) within the adjacent components. See Figure 9 for depictions of shear reinforcing bar configurations, and Table 3 for dimensional variations of shear reinforcing bars.

3.3.3.1 Stainless Steel Bars: Stainless steel bars comply with EN10088-1 B500 NR or equivalent ASTM A955 with yield strength ≥ 500 N/mm² (72,520 psi) or stainless steel Grade S690 with yield strength ≥ 690 N/mm² (100,080 psi), material no. 1.4571 or 1.4362 or 1.4462. Compression load buckling capacities of compression bars for use in design of HIT-HP DD or HIT-SP DD connections must comply with Table 6.

Headed bars comply with ASTM A970.

3.3.3.2 Carbon Steel Bars: Carbon steel bars comply with EN1992-1-1 B500B or equivalent ASTM A615 / A706 with yield strength ≥ 500 N/mm² (72,520 psi).

3.3.3.3 **Welded Bar Connections:** Welded bar connections are flash butt welded using process 24 according to EN ISO 17660-1, and comply with AWS D1.4/D1.4M *Structural Welding Code-Reinforcing Steel and Section 1705.3.1 of the IBC.*

See Figures 16, 17a and 17b for reinforcement layouts for Halfen HIT Insulated Connections.

3.3.4 Plastic casings: Plastic casings are made of polyvinylchloride (PVC) according to EN ISO 1163 and are used to enclose and protect the thermal insulation material. The function of the plastic cover is to protect the insulation from damage during handling and installation. The plastic casing does not contribute to the load bearing capacity of the HIT. Plastic shape casings of the compression shear bearings are made of High Density Polyethylene or Polypropylene.

3.3.5 Concrete: Normal weight concrete must comply with ACI 318 with minimum compressive strength f'_c = 20 N/mm² (2900 psi).

4.0 DESIGN AND INSTALLATION

4.1 Design: Design of reinforced cast-in-place concrete floor slabs and reinforced cast-in-place concrete balconies must comply with ACI 318.

Structural analysis of the HITs must be performed using strut and tie models according to Figures 10 - 13. Design calculations for controlling limit states including bending moment, shear, tension in steel reinforcement, concrete edge failure and bearing resistance must be in accordance with Figures 10, 11a – 11d, 12 and 13.

Design calculations for bending deformations and rotation of HIT joints must be calculated in accordance with procedures in Figure 14 and Table 8, Figure 15 and Tables 9 and 10. Expansion joints must be arranged at right angles to the insulation layer. Expansion joint spacing is shown in Table 11 and depicted in Figure 18.

Definitions of terms for design calculations and strut and tie models [units in N (lbf), mm (in.)]

h element height

b_{Unit} unit width of HIT

d effective depth of the slab (floor and balcony)

n_{CSB} number of CSB

h_{CSB} height of CSB [83 mm (3.27 in.)]

c_{CSB} concrete cover of CSB [15 mm (0.59 in.)]

$V_{CSB,d}$ 16,000 N (3,600 lbf)

$c_{nom,s}$ concrete cover of the tension reinforcing bars

$d_{s,1}$ diameter of the tension / compression reinforcing bars

$d_{s,2}$ diameter of the stainless steel part of the tension / compression reinforcing bars

□$_{SB}$ inclination of shear reinforcing bar

d_{SB} diameter of the shear reinforcing bar

$c_{v,l}$ concrete cover of reinforcement of the slabs

$c_{nom,o}$ concrete cover of the steel reinforcing bars at the top

$c_{nom,u}$ concrete cover of the steel reinforcing bars at the bottom

f_y yield stress of the reinforcing steel

f'_c compressive strength of the concrete

s_{joint} expansion joint spacing

4.2 Fire resistance: HITs are classified by fire testing in conformance with EN 13501-2, EN 1365-2, EN 1365-5 and ASTM E119 as 2-hour fire resistance rated assemblies when installed with a minimum concrete slab thickness of 160 mm (6.3 in.), and reinforcing steel cover requirements as shown in Tables 4, 5, 6 and 7.

5.0 INSTALLATION:

HITs must be installed in accordance with this evaluation report and the manufacturer's installation instructions. If there is a conflict, this evaluation report governs. IBC code requirements for special inspection of reinforcement including Section 1705.1.1, Section 1705.3.1 and Table 1705.3 of the IBC must be followed.

6.0 CONDITIONS OF USE

The HITs described in this report comply with, or are a suitable alternative to what is specified in, those codes listed in Section 1.0 of this report, subject to the following conditions:

6.1 Design of reinforced concrete floor slabs and balconies must comply with ACI 318.

6.2 Design and installation of the HIT connections must be in accordance with this evaluation report and the manufacturer's installation instructions. If there is a conflict, this report governs.

6.3 Project site special inspection must conform to Section 1705.1.1, Section 1705.3.1 and Table 1705.3

of the IBC and applicable portions of ACI 318 as noted in Table 1705.3 of the IBC, including specific requirements for the Halfen Insulated Connections HIT.

6.4 The HITs may be used in structures assigned to Seismic Design Categories (SDC) A – F.

6.5 Dynamic actions causing fatigue are outside the scope of this evaluation report.

6.6 Thermal resistance is outside the scope of this evaluation report.

6.7 Impact sound insulation properties are outside the scope of this evaluation report.

6.8 Complete construction documents, including plans and calculations verifying compliance with this evaluation report, must be submitted to the code official for each project at the time of permit application. The construction documents and calculations must be prepared and sealed by a registered design professional.

7.0 EVIDENCE SUBMITTED

Data in accordance with ICC-ES Acceptance Criteria for Load Bearing Thermal Break Assemblies Installed Between Concrete Balconies and Concrete Floors (AC464), dated June 2017.

8.0 IDENTIFICATION

8.1 HIT product packaging includes the product name and nomenclature, the evaluation report number (ESR-3799), and the Halfen name or identifying mark.

8.2 The report holder's contact information is the following:

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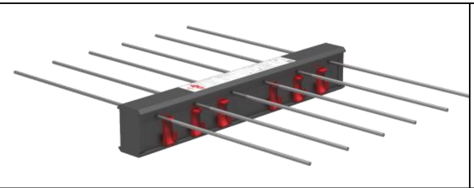
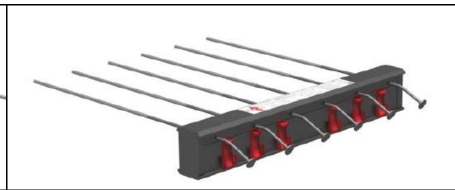
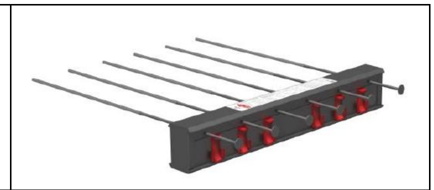
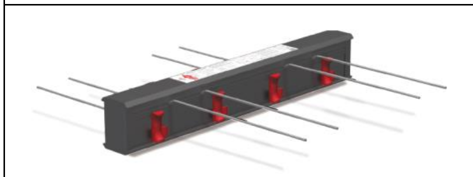
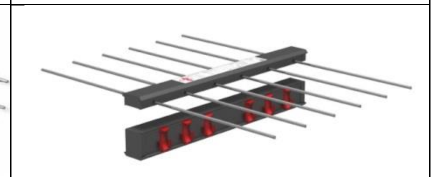
		
HIT–HP/SP MVX	HIT–HP/SP MVX-...-OU	HIT–HP/SP MVX-...-OD
		
HIT-HP/SP ZVX	HIT-HP/SP DD	HIT–HP/SP MVX … ES

Examples:

HIT-HP MVX -0804 -20 -100-35

HIT-SP MVX -0804 -25 -100-35 -ES

HIT-HP ZVX -0804 -18 -100-30 -06

HIT-HP ZDX -0804 -18 -100-30 #3, #4

HIT-HP DD -1006 -22 -100-30 -10

① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

	HIT-HP/SP MVX	HIT-HP/SP ZVX and HIT-HP/SP ZDX	HIT-HP/SP DD
①	Product group type		
②	Joint thickness: 80 mm (3.15 in., HP) or 120 mm (4.72 in., SP)		
③	Load type: bending moments and ± shear force	Load type: ZVX: shear force in one direction, ZDX: shear force in both direction	Load type: ± bending moments and ± shear force
④	Number of tension bars	Number of shear bars	Number of tension / compression bars
⑤	Number of CSB	Number of CSB	Number of shear bars
⑥	Element height [cm]		
⑦	Element width [cm]		
⑧	Concrete cover [mm]		
⑨	Additional information e.g.: ES – multipart solution[1] OU / OD: offset solution	Diameter of shear bars [mm] or #3, #4	Diameter of shear bars [mm] or #3, #4

1. Halfen Insulated Connection HIT-MVX…ES is a multi-part connection with plastic casings that are site assembled.

FIGURE 1—HIT NOMENCLATURE

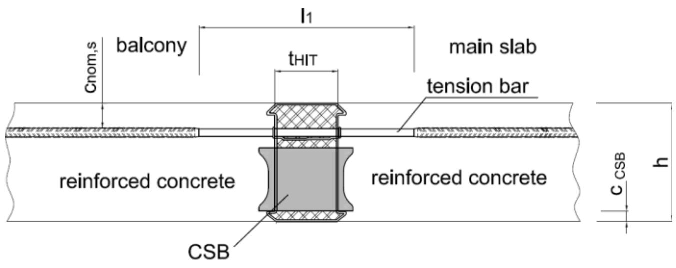


FIGURE 2—HIT-HP/SP MVX

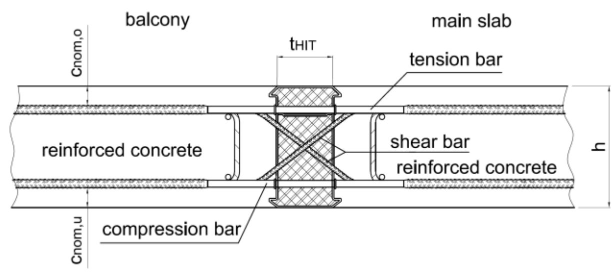


FIGURE 3—HIT-HP/SP DD

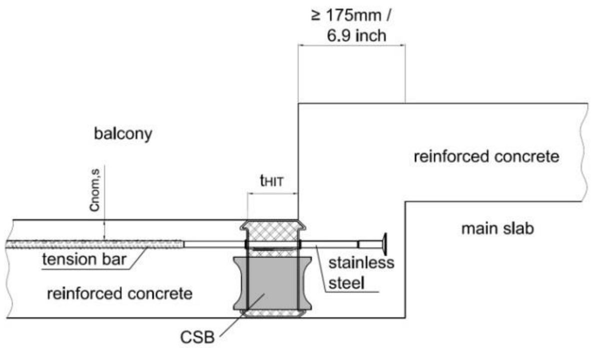


FIGURE 4A—HIT-HP/SP MVX-…-OD

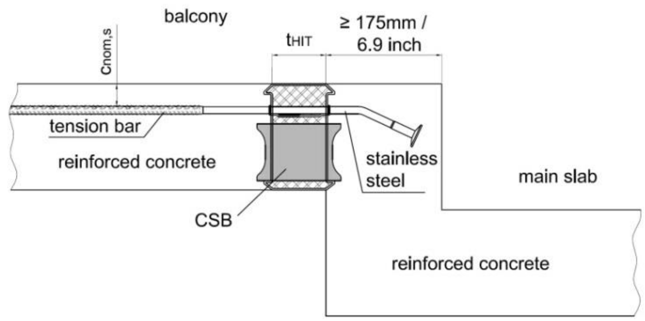


FIGURE 4B—HIT-HP/SP MVX-…-OU

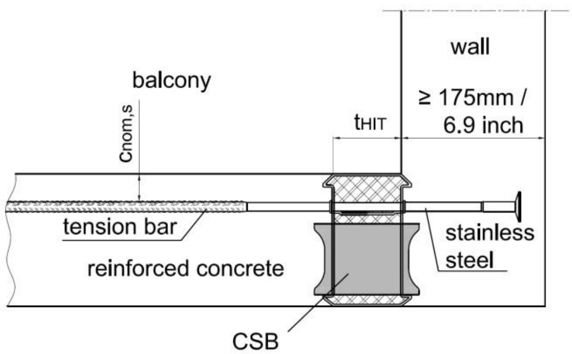


FIGURE 4C—HIT-HP/SP MVX-…-OD

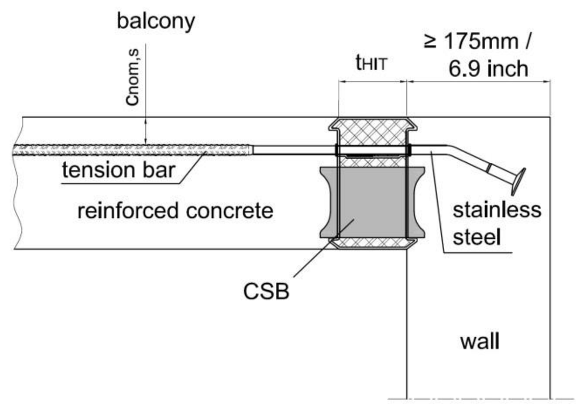


FIGURE 4D—HIT-HP/SP MVX-…-OU

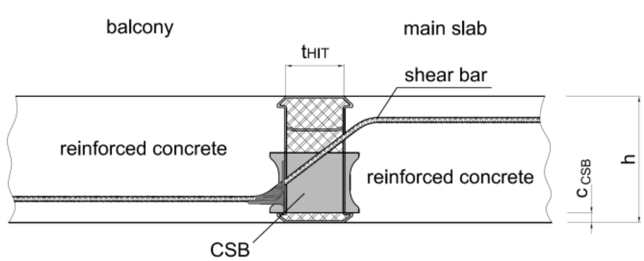


FIGURE 5—HIT-HP/SP ZVX

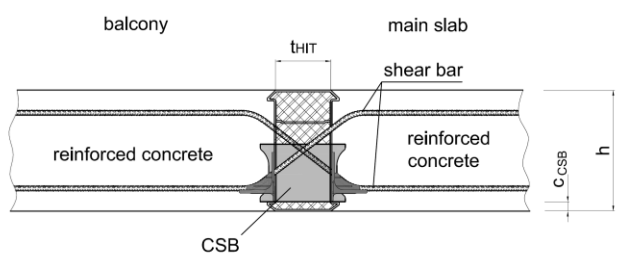


FIGURE 6—HIT-HP/SP ZDX

Compression Shear Bearing (CSB)

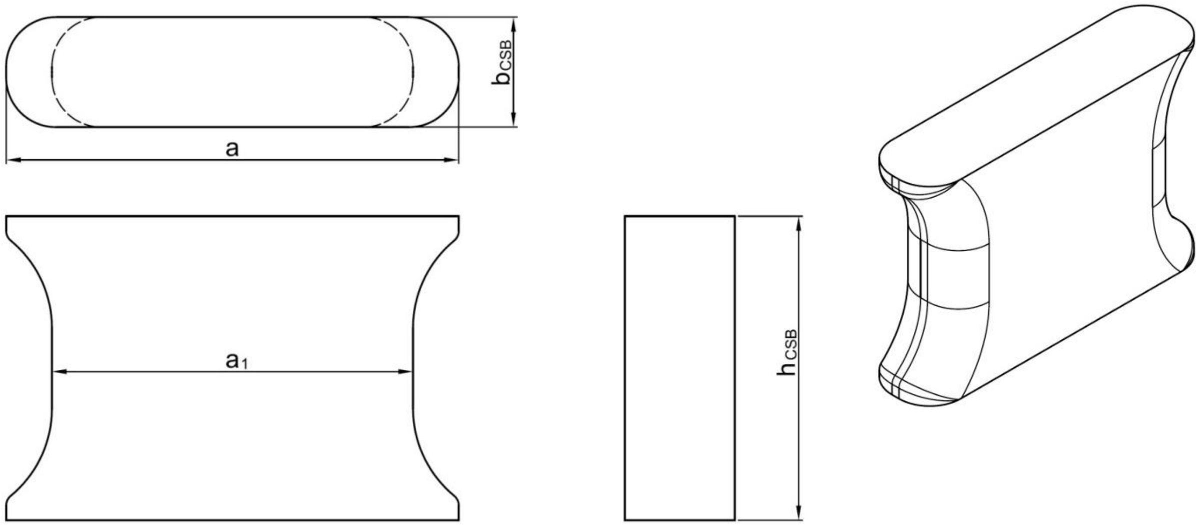
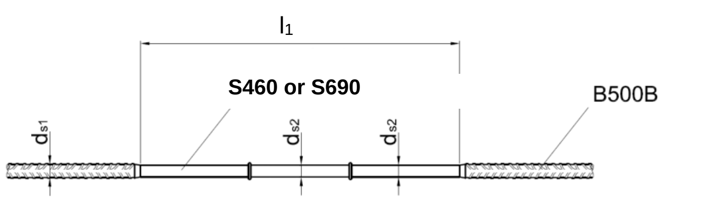


FIGURE 7—DOUBLE SYMMETRIC COMPRESSION SHEAR BEARING (CSB)

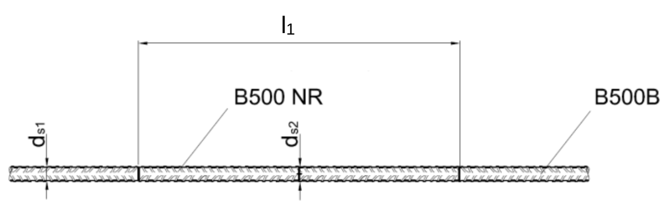
TABLE 1—DIMENSIONS OF HIT-HP/SP COMPRESSION SHEAR BEARING (CSB)

Parameter	HIT-HP	HIT-SP
h_{CSB}	83mm (3.27 in.)	
b_{CSB}	30mm (1.18 in.)	
a	123.6mm (4.87 in.)	163.6mm (6.44 in.)
a_1	98.6mm (3.88 in.)	138.6mm (5.46 in.)

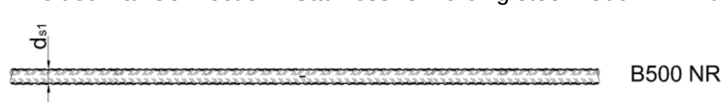
Tension and Compression Bars



1) Welded Bar Connection - Stainless steel round steel S460 or S690 with B500B[1] reinforcing steel



2) Welded Bar Connection - Stainless reinforcing steel B500 NR[1] with B500B[1] reinforcing steel



3) Stainless reinforcing steel B500 NR[1]

FIGURE 8A—TENSION / COMPRESSION REINFORCING BAR VARIATIONS FOR HIT-HP/SP

Note 1: B500B and B500NR reinforcing steel shown. Equivalent ASTM A615 / A706 and ASTM A955 reinforcing steel respectively may also be used.

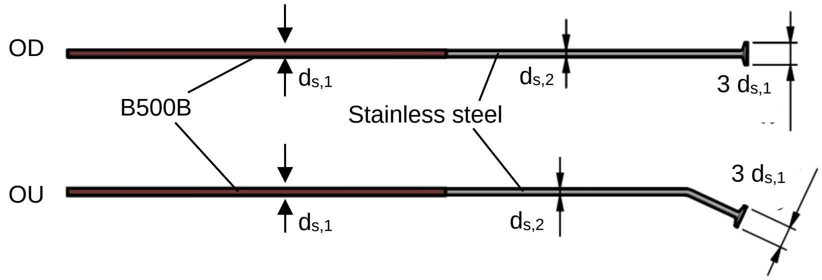
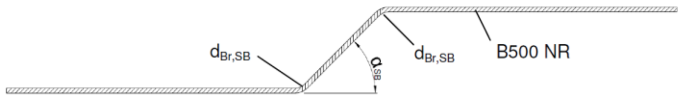


FIGURE 8B—TENSION / COMPRESSION REINFORCING BAR VARIATIONS FOR HIT-HP/SP MVX-…- OU OR HIT-HP/SP MVX-…-OD

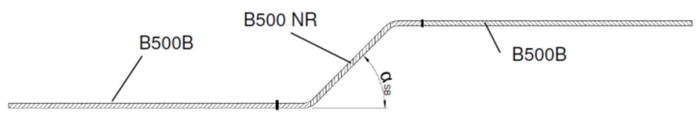
TABLE 2—DIAMETER COMBINATIONS OF HIT-HP/SP TENSION / COMPRESSION REINFORCING BARS[1]

d_{s1} (B500B, B500 NR)	d_{s2} (stainless round steel S 690)	d_{s2} (stainless round steel S 460, B500 NR)
6 mm (0.24 in.)	-	6 mm (0.24 in.)
8 mm (0.31 in.)	≥ 7 mm (0.28 in.)	8 mm (0.31 in.)
10 mm (0.39 in.)	≥ 8.5 mm (0.33 in.)	10 mm (0.39 in.)
12 mm (0.47 in.)	≥ 10.5 mm (0.41 in.)	12 mm (0.47 in.)
14 mm (0.55 in.)	-	14 mm (0.55 in.)
16 mm (0.63 in.)	-	16 mm (0.63 in.)
20 mm (0.79 in.)	-	20 mm (0.79 in.)
#3 (0.375 in,)	-	#3 (0.375 in.)
#4 (0.500 in.)	≥ 10.5 mm (0.41 in.)	#4 (0.500 in.)
#5 (0.625 in.)	-	#5 (0.625 in.)
#6 (0.750 in.)	-	#6 (0.750 in.)

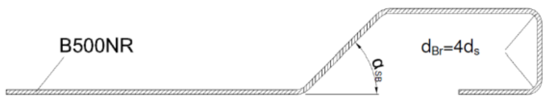
Shear Bars



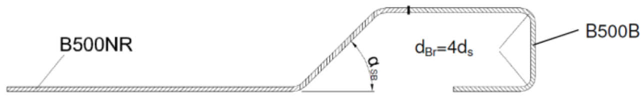
a) Stainless reinforcing steel B500 NR[1]



b) Welded Bar Connection - Stainless reinforcing steel B500 NR[1] in combination with B500B[1] (embedment length of B500 NR of 10 cm (3.9 in.) in the adjacent concrete)



c) Stainless reinforcing steel B500 NR[1], with loop in upper leg of shear reinforcing bar



d) Welded Bar Connection - Stainless reinforcing steel B500 NR[1], with loop in upper leg made of B500B[1] (embedment length of B500 NR[1] of 10 cm (3.9 in.) in the adjacent concrete) in upper leg of shear reinforcing bar

FIGURE 9—SHEAR REINFORCING BAR VARIATIONS FOR HIT-HP/SP

Note 1: B500B and B500NR reinforcing steel shown. Equivalent ASTM A615 / A706 and ASTM A955 reinforcing steel respectively may also be used.

TABLE 3—DIMENSIONAL VARIATIONS OF HIT-HP/SP SHEAR REINFORCING BARS[1]

d_{SB} (B500B, B500 NR)	$d_{Br,SB}$ bending diameter	α_{SB} [°]
6 mm (0.24 in.)	6 d_s	30 – 60
8 mm (0.31 in.)		
10 mm (0.39 in.)		
12 mm (0.47 in.)		
#3 (0.375 in.)		
#4 (0.500 in.)		

Note 1: B500B and B500NR reinforcing steel shown. Equivalent ASTM A615 / A706 and ASTM A955 reinforcing steel respectively may also be used.

Dimensions and Design Parameters

TABLE 4—DIMENSIONS AND DESIGN PARAMETERS FOR HIT HP/SP MVX

Parameter	Dimensions
Element height h	160 mm (6.3) $\leq$ h $\leq$ 350 mm (13.8 in.)
Number of Compression Shear Bearings (CSBs) per one meter (39.4 in.) element n_{CSB}	≥ 2 (for h ≤ 300 mm (11.8 in.)) ≥ 4 (for h ≤ 350 mm (13.8 in.)) ≤ 12
Concrete cover of the compression shear bearings c_{CSB}	≥ 15 mm (0.59 in.)
Axial distance of the compression shear bearings to the lateral component edge	≥ 80 mm (3.15 in.)
Axial distance of the compression shear bearings	≥ 75 mm (2.95 in.) ≤ 600 mm (23.6 in.) (for n_{CSB} = 2) ≤ 400 mm (15.7 in.) (for n_{CSB} = 3) ≤ 300 mm (11.8 in.) (for n_{CSB} ≥ 4)
Number of tension bars per one meter (39.4 in.) element n_{TB}	≥ 2 (for h ≤ 300 mm (11.8 in,)) ≥ 4 (for h ≤ 350 mm (13.8 in.))
Diameter of the tension bars $d_{s,1}$	≤ 20 mm (0.79 in.)
Concrete cover of tension bars $c_{nom,s}$	≥ 30 mm (1.18 in.)
Axial distance of the tension bars to the lateral component edge	≥ 50 mm (1.97 in.)
Axial distance of the tension bars	≤ 600 mm (23.6 in.) (for n_{TB} = 2) ≤ 400 mm (15.7 in.) (for n_{TB} = 3) ≤ 300 mm (11.8 in.) (for n_{TB} ≥ 4)

TABLE 5—DIMENSIONS AND DESIGN PARAMETERS FOR HIT HP/SP MVX (-OD, -OU) – (HEIGHT OFFSET)

Parameter	Dimensions
Embedment depth of anchor heads	≥ 145 mm (5.7 in.)
Concrete cover of anchor heads to the axis of the bar	≥ 60 mm (2.36 in.)
Concrete cover of anchor heads to the lateral component edge	≥ 60 mm (2.36 in.)
Mandrel diameter of headed tension bars	≥ 4 $d_{s,1}$
diameter of headed tension bars $d_{s,1}$	≤ 12 mm (0.5 in.)
Number of headed tension bars per one meter (39.4 in.) element	≥ 2 (for h ≤ 300 mm (11.8 in.) ≥ 4 (for h ≤ 350 mm (13.8 in.) ≤ 12
Diameter of anchor head	≥ 3 $d_{s,1}$

TABLE 6—DIMENSIONS AND DESIGN PARAMETERS FOR HIT HP/SP DD

Parameter	Dimensions
Element height h	160 mm (6.3 in.) ≤ h ≤ 350 mm (*13.8 in.)*
Number of tension and compression bars per one meter (39.4 in.) element	≥ 2
Diameter of the tension and compression bars $d_{s,1}$	≤ 20 mm (≤ *0.79 in.)*
Concrete cover of tension and compression bars $c_{nom,o}$ ($c_{nom,u}$)	≥ 30 mm (≥ *1.18 in.)*
Axial distance of the tension and compression bars to the lateral component edge	≥ 50 mm (≥ *1.97 in.)*
Axial distance of the tension and compression bars	≤ 600 mm (23.6 in.) (for n_{TB} = 2) ≤ 400 mm (15.7 in.) (for n_{TB} = 3) ≤ 300 mm (11.8 in.) (for n_{TB} ≥ 4)
Number of shear bars per one meter (39.4 in.) element n_{SB}	≥ 2 (for d_{SB} ≤ 8 mm (0.31 in.)) ≥ 4 (for d_{SB} > 8 mm (0.31 in.))
Diameter of the shear bars d_{SB}	≤ 12 mm or #4
Bending diameter of shear bars	≥ 6 d_{SB}
Axial distance of the shear bars to the lateral component edge	≥ 6 d_{SB}
Axial distance of the shear bars	≥ 6 · d_{SB} (average) and ≥ 4 · d_{SB} (minimum)
Angle of the shear bars	30° ≤ α_{SB} ≤ 60°
Vertical offset between the shear bars and longitudinal reinforcement	s_{SB} ≤ 100 mm (3.94 in.)
Compression load buckling capacity of compression steel bars, F_{Rd}: 8 mm (0.31 in.) diameter bar, B500 NR 10 mm (0.39 in.) diameter bar, B500 NR 12 mm (0.47 in.) diameter bar, B500 NR 10.5 mm (0.41 in.) diameter bar, S690	 19.0 kN (4,270 lbf) 34.1 kN (7,663 lbf) 49.2 kN (11,056 lbf) 49.2 kN (11,056 lbf)

TABLE 7—DIMENSIONS AND DESIGN PARAMETERS FOR HIT HP/SP ZVX AND HIT HP/SP ZDX

Parameter	Dimensions
Element height h	160 mm (6.3 in.) ≤ h ≤ 350 mm (13.8 in.)
Number of compression shear bearings per one meter (39.4 in.) element n_{CSB}	≥ 2 ≤ 12
Concrete cover of the compression shear bearings c_{CSB}	≥ 15 mm (0.59 in.)
Axial distance of the compression shear bearings to the lateral component edge	≥ 80 mm (3.15 in.)
Axial distance of the compression shear bearings	≥ 75 mm (2.95 in.)
Number of shear bars per one meter (39.4 in.) element n_{SB}	≥ 2 (for d_{SB} ≤ 8 mm (0.31 in.)) ≥ 4 (for d_{SB} > 8 mm (0.31 in.))
Diameter of the shear bars d_{SB}	≤ 12 mm or #4
Bending diameter of shear bars	≥ 6 d_{SB}
Axial distance of the shear bars to the lateral component edge	≥ 6 d_{SB}
Axial distance of the shear bars	≥ 6 d_{SB} (average) and ≥ 4 d_{SB} (minimum)
Angle of the shear bars	30° ≤ α_{SB} ≤ 60°
Vertical offset between the shear bars and longitudinal reinforcement	s_{SB} ≤ 100 mm (3.94 in.)

HIT-HP/SP MVX with Compression Shear Bearing (CSB)

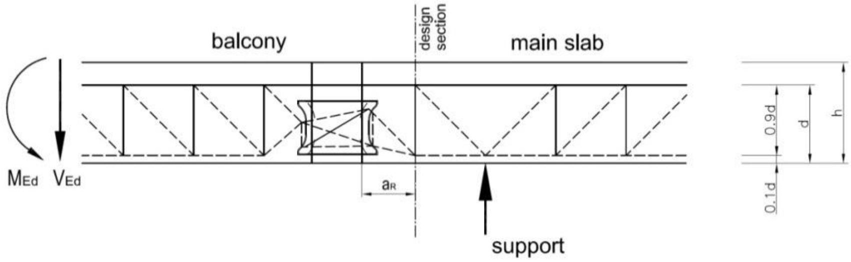


FIGURE 10—STRUT AND TIE MODEL AND DESIGN SECTION FOR HIT-HP/SP MVX WITH COMPRESSION SHEAR BEARING

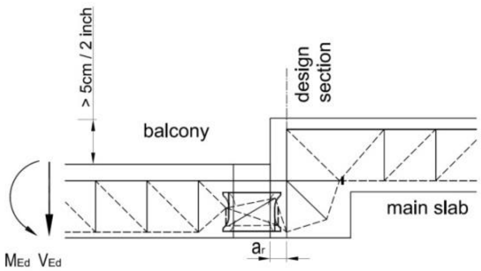


FIGURE 11A—STRUT AND TIE MODEL HIT-HP/SP MVX-…-OD

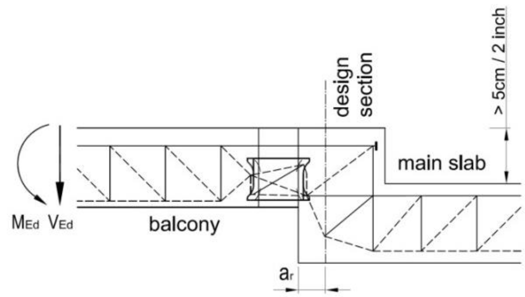


FIGURE 11B—STRUT AND TIE MODEL HIT-HP/SP MVX-…-OU

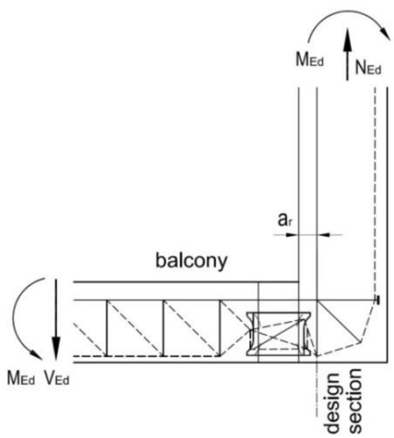


FIGURE 11C—STRUT AND TIE MODEL HIT-HP/SP MVX-…-OD (WALL CONNECTION)

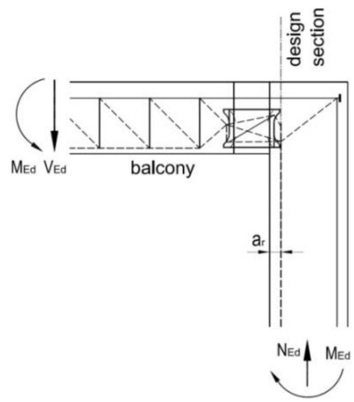


FIGURE 11D—STRUT AND TIE MODEL HIT-HP/SP MVX-…-OU (WALL CONNECTION)

1. <u>Design Calculation Procedure for Bending Moment Limit State:</u>

Distance between design section and component edge HIT-HP/SP MVX

a_r = 96 mm – 0.1 · d ($a_r \approx$ 80 mm) (a_r = 3.8 in. – 0.1 · d) ($a_r \approx$ 3.15 in.)

In the ultimate limit state, a ratio between bending moment M_{Ed} and shear force V_{Ed} of at least

$$\frac{M_{Ed}}{V_{Ed}} \geq 0.15[\,m\,] \left(\frac{M_{Ed}}{V_{Ed}} \geq 0.492[\,ft\,] \right)$$ shall apply.

Determination of internal forces resulting from moment / shear force interaction

Concrete compression zone height of compression shear bearing:

$$x_c = Max \begin{cases} d_{CSB} - \sqrt{(d_{CSB})^2 - \dfrac{|M_{Ed}|}{\beta_{c1,M} \cdot n_{CSB}}} \\ \dfrac{h_{CSB}}{2} - \sqrt{\left(\dfrac{h_{CSB}}{2}\right)^2 - \dfrac{|V_{Ed}|}{\beta_{c2,V} \cdot n_{CSB}}} \end{cases} \leq h_{CSB} \quad \text{(units in N (lbf) and mm (in.))}$$

where: $d_{CSB} = h - c_{nom,s} - \dfrac{d_{s,1}}{2} - c_{CSB}$

Concrete compressive force F_{cd} (negative) and steel tensile force F_{sd} (positive):

$-F_{cd} = F_{sd} = 2 \cdot x_c \cdot n_{CSB} \cdot \beta_{c1,M}$ (units in N (lbf) and mm (in.))

Maximum transferable shear force V_{Rd} in the design section: $V_{Rd} = \text{Min} \begin{cases} n_{CSB} \cdot V_{CSB,d} \\ |F_{cd}| \cdot \dfrac{(h_{CSB} - x_c)}{a_{CSB}} \end{cases}$

Verification**:** Shear load: $|V_{Ed}| \leq V_{Rd}$ Moment load: $M_{Ed} \leq M_{Rd}$

Verification of required tension bar reinforcement: $A_{s,req} = \dfrac{F_{sd}}{f_{yd}}$ where $f_{yd} = f_y / 1.15$

2. Design Calculation Procedure for Concrete Edge Failure Limit State:

Verification of concrete edge failure HIT-HP/SP MVX

Actions in the design section: $F_{c,Ed} = 0.25 \cdot |F_{cd}| + |V_{Ed}|$

Bearing resistance: $F_{c,Rd} = a_{Rd} \cdot (f_c')^{\frac{1}{4}} \cdot b_{eff} \cdot \psi_{BK}$

where: $b_{eff} = n_{CSB} \cdot 137[mm] \leq b_{Unit}$ $(b_{eff} = n_{CSB} \cdot 5.4[in.] \leq b_{Unit})$

$\psi_{BK} = 1.0$ general

$\psi_{BK} = 0.7$ applicable to HIT-HP/SP MVX-…-OD (Balcony offset downward, see Figures 4a and 4c)

Verification: $F_{c,Ed} \leq F_{c,Rd}$

When designing the adjacent slabs of HIT-HP/SP MVX, the following loads shall be considered:

Main slab: $M_{Ed,slab} = \text{Max} \begin{cases} M_{Ed} \\ F_{cd} \cdot z_1 \end{cases}$ in the design section

where $z_1 = d - ½ \cdot x_c - c_{CSB}$

Balcony slab: $M_{Ed,balcony} = M_{Ed,slab} - |V_{Ed}| \cdot a_{CSB}$

3. Design Calculation Procedure for Tension in Steel Reinforcement Limit State:

Design of the tensile splitting reinforcement

Horizontal tensile splitting reinforcement: $F_{Sp,h} = \dfrac{|F_{cd}|}{4 \cdot n_{CSB}} \cdot \left(1 - \dfrac{c}{e}\right)$

Vertical tensile splitting reinforcement: $F_{v,cal} = F_{Sp,v} + V_{Ed}$

where: $F_{Sp,v} = \dfrac{|F_{cd}|}{4} \cdot \left(1 - \dfrac{x_c}{x_c + c}\right)$

V_{Ed} internal shear force in the design section

c = 30mm (1.18 in.)

$e = \begin{cases} e_{max,\,CSB} & \text{axis distance of CSB} \\ 2 \cdot e_{CSB,edge} & \text{edge distance of CSB} \end{cases} \leq 120\,mm\ (4.72\ in.)$

HIT-HP/SP ZVX and HIT-HP/SP ZDX

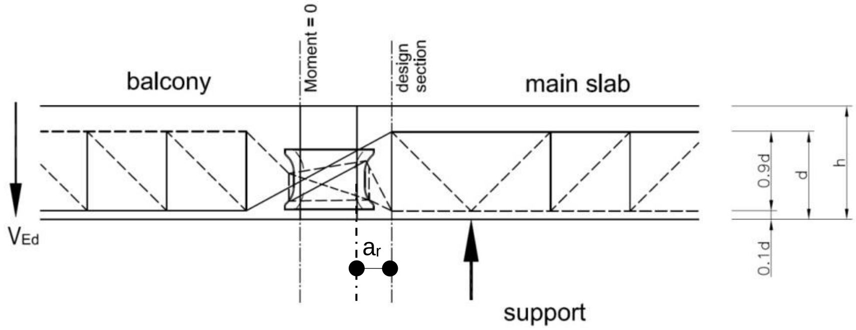


FIGURE 12: STRUT AND TIE MODEL FOR HIT-HP/SP ZVX AND HIT- HP/SP ZDX[1] WITH COMPRESSION SHEAR BEARINGS

1. For HIT-HP/SP ZDX, balcony and main slab positions are reversed.

The design action V_{Ed} is to be calculated at the defined position of the joint (Moment = 0), the verification has to be performed at the design section.

4. Design Calculation Procedure for Shear Limit State:

Determination of internal force HIT-HP/SP ZVX and HIT-HP/SP ZDX

Concrete compression zone height of compression shear bearings (units in N (lbf) and mm (in.))

$$x_c = \mathrm{Max}\begin{cases} \left(\frac{h_{CSB}}{2} + \frac{a_{CSB}}{2}\cdot\tan\alpha_{SB}\right) - \sqrt{\left(\frac{h_{CSB}}{2} + \frac{a_{CSB}}{2}\cdot\tan\alpha_{SB}\right)^2 - \frac{|V_{Ed}|}{\beta_{c2,V}\cdot n_{CSB}}} \\ \frac{\left(V_{Ed} - n_{CSB}\cdot V_{CSB,d}\right)}{2\cdot n_{CSB}\cdot\beta_{c1,M}\cdot\tan\alpha_{SB}} \end{cases} \le h_{CSB}$$

Verification of required shear reinforcement bar:

$$A_S = \frac{F_{SB,d}}{f_{yd}} \qquad \text{where: } F_{SB,d} = \frac{-F_{cd}}{\cos\alpha_{SB}} \text{ and } f_{yd} = f_y / 1.15$$

For determining F_{cd}, see Design Calculation Procedure 1 on page 9.

5. Design Calculation Procedure for Concrete Edge Failure Limit State:

Verification of concrete edge failure HIT-HP/SP ZVX and HIT-HP/SP ZDX:

Actions in the design section: $F_{c,Ed} = 0.25\cdot|F_{cd}| + |V_{Ed,CSB}|$

where: $V_{Ed,CSB} = F_{cd}\cdot\frac{\mathrm{Max}(h_{CSB} - x_c;\ 0.5\cdot h_{CSB})}{a_{CSB}}$

Bearing resistance: $F_{c,Rd} = a_{Rd}\cdot(f'_c)^{\frac{1}{4}}\cdot b_{eff}$ (units in N (lbf) and mm (in.))

where: $b_{eff} = n_{CSB}\cdot 137[mm] \le b_{Unit}$ ($b_{eff} = n_{CSB}\cdot 5.4[in.] \le b_{Unit}$)

Verification: $F_{c,Ed} \le F_{c,Rd}$

When designing the adjacent slabs of HIT-HP/SP ZVX and HIT-HP/SP ZDX, the following loads shall be considered:

$$M_{Ed,\ main\_slab} = V_{Ed}\cdot t_{HIT}$$

6. **Design Calculation Procedure for Tension in Steel Reinforcement Limit State:**

Design of the tensile splitting reinforcement

See design calculation procedure 3 on page 10.

HIT-HP/SP DD

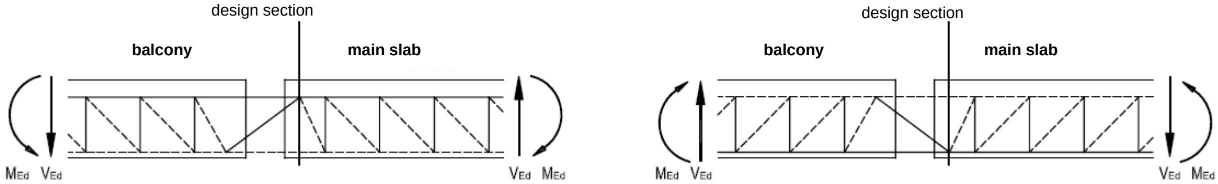


FIGURE 13—STRUT AND TIE MODEL AND DESIGN SECTION FOR HIT-HP/SP DD

7. **Design Calculation Procedure for the ultimate limit state of HIT-HP/SP DD:**

$F_{sd,u} = \frac{M_{Ed}}{z_{DD}}$ (compression reinforcing bars)

$F_{sd,o} = \frac{M_{Ed}}{z_{DD}} - F_{SB,H}$ (tension reinforcing bars)

where: $z_{DD} = h - (c_{nom,o} + c_{nom,u} + d_{s,1})$

$F_{SB,H} = \frac{V_{Ed}}{\tan \alpha_{SB}}$ (horizontal tension forces of the shear reinforcing bars)

$F_{SB,d} = \frac{V_{Ed}}{\sin \alpha_{SB}}$ (shear bars)

Verification of required reinforcement:

$A_s = \frac{F_{(..)}}{f_{yd}}$ where $f_{yd} = f_y / 1.15$ (for tension bars, $F_{(..)} = F_{sd,o}$ and for shear bars, $F_{(..)} = F_{SB,d}$)

$n_s = \frac{F_{sd,u}}{F_{Rd,u}}$ (for compression bars, see Table 6 Compression load buckling capacity, F_{Rd})

Determination of Deformation

8. **Design Calculation Procedure for Determination of Deformation in HIT-HP/SP MVX and HIT-HP/SP DD:**

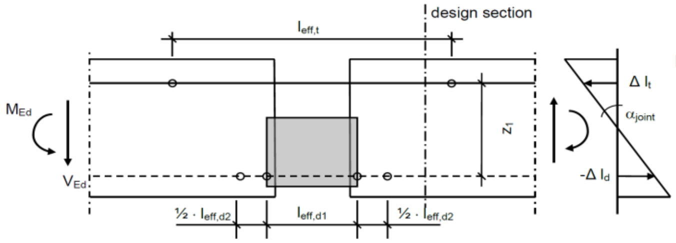


FIGURE 14—HIT-HP/SP MVX

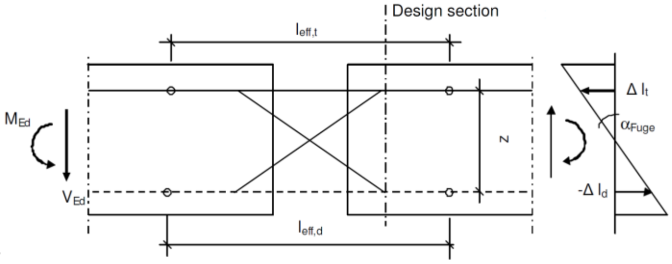


FIGURE 15—HIT-HP/SP DD

	HIT-HP/SP MVX	HIT-HP/SP DD
Angle of rotation in the joint:	$\tan\alpha_{joint} = \frac{\Delta l_t - \Delta l_d}{z_1}$	
Tension bar strain:	$\Delta l_t = \frac{\sigma_{s,t,ds1}}{E_{s,ds1}} \cdot l_{eff,t,ds1} + \frac{\sigma_{s,t,ds2}}{E_{s,ds2}} \cdot l_{eff,t,ds2}$	$\Delta l_t = \frac{\sigma_{s,t,ds1}}{E_{s,ds1}} \cdot l_{eff,t,ds1} + \frac{\sigma_{s,t,ds2}}{E_{s,ds2}} \cdot l_{eff,t,ds2}$
Compression strain:	$\Delta l_d = \frac{-\sigma_{c,d1}}{E_{c,CSB}} \cdot l_{eff,d1} + \frac{-\sigma_{c,d2}}{E_{cm}} \cdot l_{eff,d2}$	$\Delta l_d = \frac{\sigma_{s,d,ds1}}{E_{s,ds1}} \cdot l_{eff,d,ds1} + \frac{\sigma_{s,d,ds2}}{E_{s,ds2}} \cdot l_{eff,d,ds2}$

Where:

- effective length of the tension bar: $l_{eff,t}$ = length of the stainless steel bar section (l_1) + 2·10·d_s
- effective length of the CSB: $l_{eff,d1}$ = total length of the compression shear bearing at half height
- effective length of the slab concrete: $l_{eff,d2}$ =width of the compression shear bearings (= 2 b_{CSB})
- compression stress: $\sigma_{c,d1}$ (for CSB) and $\sigma_{c,d2}$ (for the slab concrete)
- tension stress: $\sigma_{t,ds1}$ (section 1 with diameter d_{s1}) and $\sigma_{t,ds2}$ (section 2 with diameter d_{s2})
- elastic modulus: $E_{(..)}$

Coefficients for elastic compression Δl_d of the compression zone are provided in Table 8. Length of the stainless steel bar section l_1, are provided in Table 9.

TABLE 8—COEFFICIENTS FOR Δl_d

Concrete compressive strength f'_c	20.0 N/mm² *2,900 psi*	20.7 N/mm² *3,000 psi*	24.1 N/mm² *3,500 psi*	≥ 26.9 N/mm² *≥ 3,900 psi*
Δl_d for HIT-HP MVX	0.226 mm *(8.89*10⁻³ in.)*	0.233 mm *(9.16*10⁻³ in.)*	0.266 mm *(10.46*10⁻³ in.)*	0.292 mm *(11.50*10⁻³ in.)*
Δl_d for HIT-SP MVX	0.275 mm *(10.84*10⁻³ in.)*	0.284 mm *(11.18*10⁻³ in.)*	0.326 mm *(12.82*10⁻³ in.)*	0.359 mm *(14.12*10⁻³ in.)*

TABLE 9—VARIOUS DIMENSIONS FOR HIT-HP AND HIT-SP

Parameter	HIT-HP	HIT-SP
t_{HIT}	80mm (3.14 in.)	120mm (4.72 in.)
l_1	280mm (11.0 in.)	320mm (12.6 in.)
a_{CSB}	110mm (4.33 in.)	150mm (5.91 in.)
a_{Rd}	128 (for verification with N and mm)	112 (for verification with N and mm)
	210 (for verification with lbf and in.)	184 (for verification with lbf and in.)

TABLE 10—FACTORS $\beta_{c1,M}$ AND $\beta_{c2,V}$ FOR HIT-HP AND HIT-SP[1]

Factors $\beta_{c1,M}$ and $\beta_{c2,V}$ for the calculation of HIT-HP / HIT-SP with N and mm							
HIT Type		HIT-HP/SP		HIT-HP		HIT-SP	
concrete compressive strength f'_c		$\beta_{c1,M}$		$\beta_{c2,V}$		$\beta_{c2,V}$	
[N/mm²]	[psi]	[N/mm]*	[lbf/in.]**	[N/mm²]*	[psi]**	[N/mm²]*	[psi]**
20.0	2,900	700	4,000	12.7	1,850	9.3	1,350
20.7	3,000	725	4,140	13.2	1,910	9.7	1,400
24.1	3,500	845	4,820	15.4	2,230	11.3	1,630
≥ 26.9	≥ 3,900	942	5,380	17.1	2,480	12.5	1,820

* for the calculation of HIT-HP / HIT-SP with N and mm
** for the calculation of HIT-HP / HIT-SP with lbf and in.

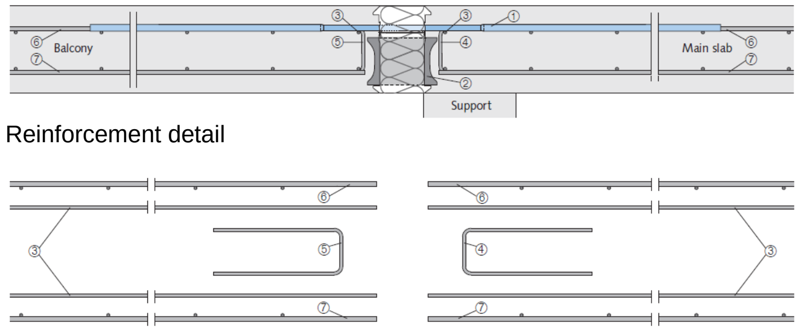
1. Linear interpolation must be used for determination of intermediate values.

TABLE 11—EXPANSION JOINT SPACING[1]

Joint Thickness		Diameter of the Tension Bar in the Joint											
	[mm] [in.]	≤ 9.5 (≤ 0.37)	10 (0.39)	10.5 (0.41)	11 (0.43)	12 (0.47)	14 (0.55)	16 (0.63)	20 (0.79)	#3 (0.38)	#4 (0.50)	#5 (0.63)	#6 (0.75)
HIT-HP	[m] [ft.]	13.5 (44.3)	13.0 (42.7)	12.6 (41.3)	12.2 (40.0)	11.7 (38.4)	10.1 (33.1)	9.2 (30.2)	8.0 (26.2)	13.5 (44.3)	11.1 (36.4)	9.3 (30.5)	8.3 (27.2)
HIT-SP	[m] [ft.]	23.0 (85.3)	21.7 (71.2)	21.2 (69.6)	20.6 (67.6)	19.8 (65.0)	17.0 (55.8)	15.5 (50.9)	13.5 (44.3)	23.0 (85.3	18.8 (61.7)	15.6 (51.2)	14.0 (45.9)

1. Refer to Figure 18 for example of expansion joint spacing, s_{joint}

On-Site Reinforcement



Legend:

① Tension bar
② Double-symmetrical CSB
③ Horizontal transverse tensile reinforcement $A_{s,h}$
④ Vertical tensile splitting reinforcement $A_{s,v}$
⑤ Vertical tensile splitting reinforcement $A_{s,v}$
⑥ Upper connecting reinforcement made of steel bars or mesh
⑦ Lower connecting reinforcement made of steel bars or mesh

FIGURE 16—EXAMPLE OF ON-SITE REINFORCEMENT

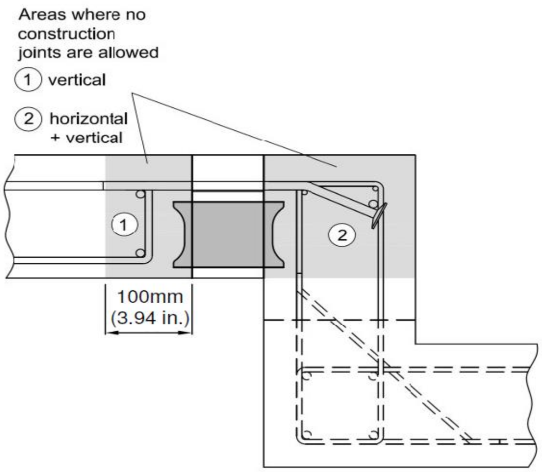


FIGURE 17A—REINFORCEMENT LAYOUT FOR HIT HP/SP MVX-…-OU

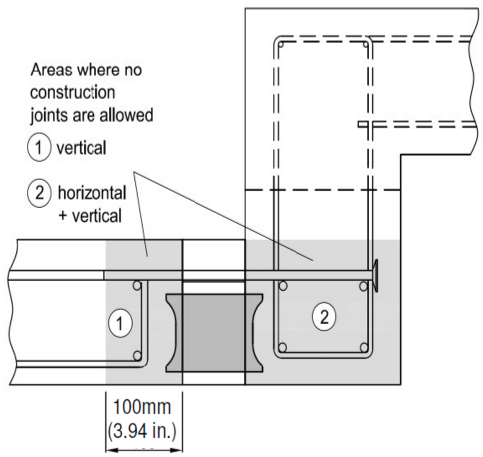


FIGURE 17B—REINFORCEMENT LAYOUT FOR HIT HP/SP MVX-…-OD

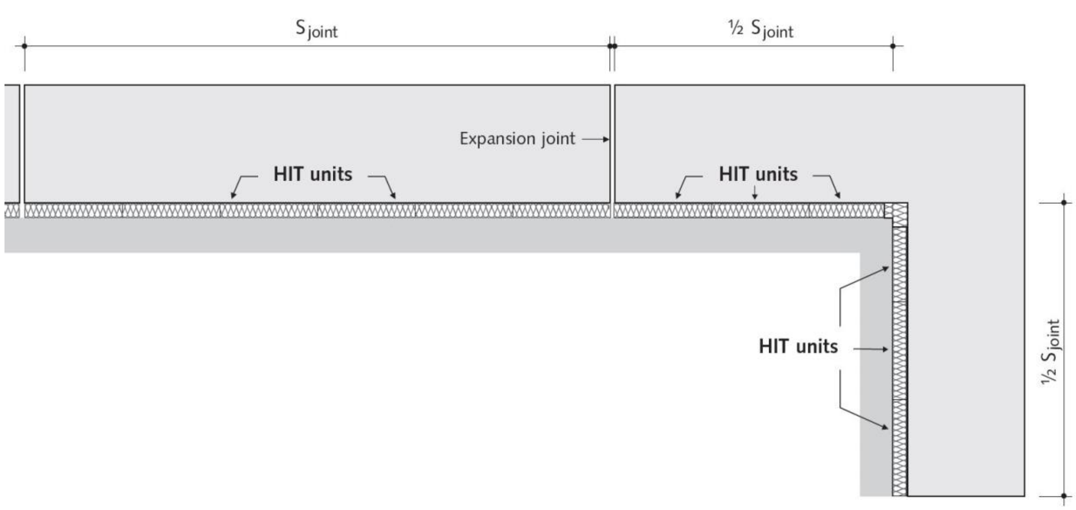


FIGURE 18—EXAMPLE OF EXPANSION JOINT SPACING, s_{joint} (PLAN VIEW)