



## TECHNICAL GUIDE

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## Punching shear strengthening with Hilti HIT-Punching Shear according to SIA 262:2017

### 1. Introduction

In 2024-25, Hilti AG conducted a qualification project for the post-installed (PI) “HIT-Punching Shear” strengthening system with HIT-RE 500 V4 aimed at the structural strengthening of reinforced concrete (RC) suspension slabs and foundations deficient in punching shear resistance. The qualification included full-scale tests and assessments under static and quasi-static loads. This extensive experimental campaign led to the issuance of the general construction technique permit (*allgemeine Bauartgenehmigung*) number **aBG Z-15.5-387** [1], which is valid in Germany for Hilti’s new PI strengthening solution.

The **aBG Z-15.5-387** [1] provides a design procedure based on **DIN EN 1992-1-1:2011** [2] integrated with the German National Annex **DIN EN 1992-1-1/NA:2013** [3]. This procedure was developed by calibrating experimental results according to the general reliability requirements of the Eurocodes. The resulting design equations align fully with the punching shear resistance model adopted in **DIN EN 1992-1-1:2011** [2].

Building on this background, the present document serves as a supplementary guide to use the aBG for designing the HIT-Punching Shear strengthening intervention in Switzerland. It compares the design equations for the PI solution detailed in **aBG Z-15.5-387** with the requirements of **SIA 262:2017** [4], adapting equations or parameters where necessary to meet the safety standards and concrete detailing rules of the Swiss design standard.

### 2. Key differences between DIN EN 1992-1-1/NA and SIA 262 for punching shear design

In **DIN EN 1992-1-1/NA:2013** [3], the design equations for RC members with punching shear reinforcement are derived from a model that is similar to the approach for shear resistance in beams and slabs, where a strength coefficient,  $C_{Rd,c}$ , multiplies an semi-empirical expression that accounts for the key influencing parameters (i.e., effective depth  $d$ , flexural reinforcement ratio  $\rho_l$ , and the characteristic concrete strength  $f_{ck}$ ). On the other hand, **SIA 262:2017** [4] is based on a mechanically-based model, known as the Critical Shear Crack Theory (CSCT), in which the opening of the critical shear crack largely determines the punching resistance, with the crack width proportional to the product of the slab’s rotation and effective depth.

**SIA 262:2017** [4] offers designers the choice between simplified and detailed methods to determine the punching shear resistance of concrete members with punching shear reinforcement. These methods incorporate or are directly based on the different Levels of Approximation from the **fib Model Code 2010** [5]. For a shear-reinforced member, the contributions to the combined resistance from concrete and steel reinforcement is not constant, unlike in [2] and [3], as the larger the slab rotation, the less the concrete contribution relative to the steel contribution.

### 3. Differences in the Punching Shear formulations in DIN EN 1992-1-1:2011 + NA and SIA 262:2017

In both standards, the overall resistance to punching shear is given by the sum of the contributions due to concrete,  $V_{Rd,c}$ , and steel reinforcement,  $V_{Rd,s}$ ; however, unlike in **DIN EN 1992-1-1:2011** [2], the control section

used for the verifications for punching shear in **SIA 262:2017** [4] is closer to the edge of the loaded area, say at  $0,5d_{ef}$  instead of  $2,0 d_{ef}$ , where  $d_{ef}$  is the effective depth of the slab.

Furthermore, the combined influence of eccentricity (from bending moments and the from the differences between the centroids of the column and the area bound by the control section,  $u_{crit}$ ) is captured differently in the two standards: in **DIN EN 1992-1-1:2011** [2], a load increase factor,  $\beta$ , amplifies the design punching shear force,  $V_{Ed}$ ; in **SIA 262:2017** [4], the perimeter of the control section is reduced by the factor  $k_e$ . Both factors effectively increase the design shear stress,  $\tau_{Ed}$ . For brevity, Table 1 summarises the key design formulations in the two standards.

Table 1: Key expressions for punching shear design according to DIN EN 1992-1-1/NA:2013 and SIA 262:2017

Design standard	DIN EN 1992-1-1/NA:2013	SIA 262:2017
Distance of the Control Section, $u_{crit}$ , from the loaded area is set at:	$2,0d_{ef}$	$0,5d_{ef}$
Factor for eccentric shear distribution:	$\beta$	$k_e$
Reduced control perimeter from eccentric shear:	-	$u_{red} = k_e \cdot u_{crit}$
Design punching shear force, $V_{Ed}$ [kN]	$\beta \cdot V_{Ed}$	$V_{Ed}$
Punching Shear resistance without shear reinforcement ( <b>slabs</b> ), $V_{Rd,c}$ [kN]	$\left( \max \left[ C_{Rd,c} k (100 \rho_l f_{ck})^{\frac{1}{3}}, v_{min} \right] + k_1 \sigma_{cp} \right) u_{crit} d_{ef}$	$k_r \cdot \tau_{cd} \cdot d_{ef} \cdot u_{red}$
Punching Shear resistance without shear reinforcement ( <b>foundations</b> ), $V_{Rd,c}$ [kN]	$\left( \max \left[ C_{Rd,c} k (100 \rho_l f_{ck})^{\frac{1}{3}}, v_{min} \right] \cdot \frac{2d_{ef}}{a_{crit}} \right) u_{crit} d_{ef}$	$k_r \cdot \tau_{cd} \cdot d_{ef} \cdot u_{red}$
Punching shear resistance provided by reinforcement $V_{Rd,s}$ [kN]	$1,5 \left( \frac{d_{ef}}{s_r} \right) \cdot A_{sw} \cdot f_{ywd,ef}$	$k_{pi} \cdot \Sigma A_{sw} \cdot k_e \cdot \sigma_{swd}$
Combined resistance to Punching Shear resistance with shear reinforcement, $V_{Rd,cs}$ [kN]	$0,75V_{Rd,c} + V_{Rd,s}$	$V_{Rd,c} + V_{Rd,s}$
Maximum resistance of the Compression Strut, $V_{Rd,max}$ [kN]	$\begin{cases} k_{max} \cdot V_{Rd,c} \\ k_{max} = 1,4 \end{cases}$	$\begin{cases} 2,0 \cdot k_r \cdot \tau_{cd} \cdot d_{ef} \cdot u_{red} \leq \\ 3,5 \cdot \tau_{cd} \cdot d_{ef} \cdot u_{red} \end{cases}$

## 4. Adjustments to SIA 262:2017 for use with the HIT-Punching Shear strengthening system

Since the results of the experimental campaign correlate well with both [2] and [4], designing to [4] with the Hilti HIT-Punching Shear strengthening system requires minor modifications that are marked in **red** throughout this section.

### 4.1 Resistance verification without punching shear reinforcement

Verifications for punching shear resistance in [4] are conducted by first evaluating the resistance without punching shear reinforcement, i.e., the concrete contribution, at the control section,  $u$ , set at  $0,5 d_{ef}$  from the face of the support. If the support does not penetrate the slab, as illustrated in [Figure 20](#) in [4], the effective depth,  $d_v$ , and the control section,  $u$ , in [Equation 57](#) [4] are replaced with  $d_{ef}$  and  $u_{red}$  from Table 1, respectively.

$$V_{Rd,c} = k_d k_r \tau_{cd} d_{ef} u_{red} \quad (\text{kN}) \quad (\text{Eq. 1})$$

where:

$k_d$ : The reduction of the concrete resistance when using strengthening element diameter M16 in slabs with an effective depth,  $d_{ef} \leq 280 \text{ mm}$ , is provided by:

$$k_d = \begin{cases} 0.95, & \text{M16 and } d_{ef} \leq 280 \text{ mm} \\ 1.00, & \text{standard cases} \end{cases}$$

The reduction in the concrete resistance is attributed to a larger residual cover,  $c_{res}$ , required for the M16 rod in thinner slabs – 40 mm instead of 35 mm – to prevent spalling of the concrete on the opposite side when drilling (see Table 4). In such scenarios, the larger residual cover may increase the likelihood that the critical shear crack easily passes above tip of the rod. This also has an impact on the second coefficient,  $k_{pi}$ , when verifying resistance in the shear-reinforced zone (see Section 4.2 below).

$$\tau_{cd} = \frac{0.3\eta_t \sqrt{f_{ck}}}{\gamma_c}: \text{ design shear strength of concrete,} \quad (\text{N/mm}^2) \quad (\text{Eq. 3}) [4]$$

$f_{ck}$ : characteristic compressive strength of concrete, in MPa, from Table 3 [4].

$\gamma_c$ : Partial safety factor for concrete, from Clause 2.3.2.6 [4].

$\eta_t$ : the coefficient for concrete strength accounting for duration of exposure and age of the concrete. From Clause 4.2.1.3 [4], this value can be either 0.85, 1.0, or 1.2.

$$k_r = \frac{1}{0.45 + 0.18 k_g \psi d_{ef}} \leq 2: \text{ coefficient accounting for the slab rotation} \quad (\text{Eq. 58}) [4]$$

$$k_g = \frac{48}{16 + D_{max}}: \text{ coefficient for the effect of aggregate interlock} \quad (\text{Eq. 37}) [4]$$

$D_{max}$ : maximum size of the aggregate

$$\text{Coefficient for slab rotation (determined for each axes), } \psi = 1.5 \cdot \frac{r_s}{d_{ef}} \cdot \frac{f_{yd}}{E_s} \cdot \left( \frac{m_{sd}}{m_{Rd}} \right)^{3/2} \quad (\text{rads}) \quad (\text{Eq. 59}) [4]$$

- $r_s$ : Distance from the axis of the support to the point of contraflexure
- $f_{yd}$ : Yield strength of the flexural reinforcement
- $E_s$ : Elastic modulus of the flexural reinforcement
- $m_{sd}$ : Bending moment in the support strip
- $m_{Rd}$ : Resistance to bending in the support strip that, according to rigid-plastic theory, may be considered as:

$$m_{Rd} = \rho \cdot d^2 \cdot f_{yd} (1 - 0.5\rho \cdot f_{yd}/f_{cd}) \quad (\text{kNm/m}) \quad (\text{Eq. 19}) [6]$$

The slab rotation in Eq. 59 [4] may be evaluated for each direction according to one of three Levels of Approximation (LOA):

- **LOA 1** applies to regularly supported slabs with a span ratio  $0.5 \leq L_x/L_y \leq 2.0$ , and without large plastic redistribution,  $m_{sd}/m_{Rd} = 1.0$ , and  $r_s = 0.22L_x$  or  $0.22L_y$  ( $L_x$  and  $L_y$  are the span lengths in  $x$ - and  $y$ -direction, respectively).
- **LOA 2** follows the same steps as LOA 1, except that the bending moment in the support strip,  $m_{sd}$ , is determined by either Eq. 61, 62, 63, or 64 [4]. The width of the support strip is determined by:

$$b_s = 1.5 \sqrt{r_{sx} \cdot r_{sy}} \leq l_{min}, \text{ where } l_{min} = \min(L_x; L_y) \quad (\text{mm}) \quad (\text{Eq. 60}) [4]$$

- **LOA 3** applies to slabs with complex geometries where the span ratio  $L_x/L_y < 0.5$  or  $L_x/L_y > 2.0$ ,  $m_{sd}$  is determined by either [Eq. 61](#), [62](#), [63](#), or [64](#) [4], and  $r_s$  is determined by detailed analysis, e.g., using a finite element model. The factor 1.5 in [Eq. 59](#) [4] is replaced by 1.2. For edge and corner columns,  $r_{s,min} \geq 0.67b_{sr}$ , where  $b_{sr} \leq b_s$  according to [Figure 24](#) [4].

## 4.2 Resistance verification with the HIT-Punching shear strengthening system

Where punching shear reinforcement is required, the combined resistance,  $V_{Rd}$ , from the contributions of concrete,  $V_{Rd,c}$ , and HIT-Punching shear strengthening system,  $V_{Rd,s}$ , must not be less than the design shear force,  $V_{Ed}$ :

$$V_{Rd} = V_{Rd,c} + V_{Rd,s} \geq V_{Ed}$$

The resistance required from strengthening system may be rewritten as:  $V_{Rd,s} = V_{Rd} - V_{Rd,c}$  (kN) ([Eq. 65](#)) [4]

where the contribution from the strengthening system is:  $V_{Rd,s} = k_{pi}(\sum A_{sw} \cdot k_e \cdot \sigma_{swd})$  (kN) ([Eq. 2](#))

A minimum resistance from the strengthening system must be provided to ensure sufficient deformation capacity:

$$V_{Rd,s} \geq 0.5V_{Ed} \quad (\text{kN}) \quad (\text{Eq. 66}) [4]$$

Combining the above equations, the minimum steel area of PI elements required to satisfy the punching shear verification may be evaluated by:

$$\sum A_{sw} = \frac{\max(0.5V_{Ed}; V_{Ed} - V_{Rd,c})}{k_{pi} \cdot k_e \cdot \sigma_{swd}} \quad (\text{mm}^2) \quad (\text{Eq. 3})$$

$k_{pi}$ : derived from a statistical evaluation of the ratio of the experimental to calculated resistance values at the characteristic and design levels for **SIA 262:2017** and **DIN EN 1992-1-1/NA:2013**. Due to the low coefficient of variation when using the design equations according to SIA 262:2017 to interpret the experimental results, and a comparatively higher level of safety in SIA 262:2017 compared to DIN EN 1992-1-1/NA:2013, this parameter is reduced below 1,0 only in specific cases where an M16 rod is installed in slabs with an effective depth,  $d_{ef} \leq 280$  mm:

$$k_{pi} = \begin{cases} 0.59, & M16 \text{ and } d_{ef} \leq 280 \text{ mm} \\ 0.82, & \text{standard cases} \end{cases}$$

$\sum A_{sw}$ : Total cross-sectional area of the strengthening reinforcement intersected by the potential failure plane, determined the area bound between a distance of  $0.35d_{ef}$  &  $1.0d_{ef}$  from the face of the support.

$\sigma_{swd}$ : Similar to [Equation 68](#) [4], the stress activated by the effective slab rotation,  $\Delta\psi$ , in the strengthening reinforcement perpendicular to the concrete surface is evaluated by:

$$\sigma_{swd} = \frac{E_{sw} \cdot \Delta\psi}{6} \cdot \left( 1 + \frac{f_{bd}}{f_{ywd}} \cdot \frac{d_{ef}}{\phi_{sw}} \right) \leq f_{ywd} \quad (\text{N/mm}^2) \quad (\text{Eq. 4})$$

- $f_{bd}$ : bond strength associated with the concrete class, determined from [Table 19](#) [4] or [Eq. 103](#) [4]
- $f_{ywd}$ : design yield strength of HIT-Punching Shear strengthening system, i.e., **390 MPa** from [Table 13](#) [1]
- $\phi_{sw}$ : nominal diameter of each rod used in the strengthening system (e.g., 12 mm for an M12 threaded rod)
- $E_{sw}$ : elastic modulus of the strengthening reinforcement: **200 GPa** for the Hilti HAS(-U) 8.8 carbon steel and A4 stainless steel rods

$\Delta\psi$ : effective slab rotation activated by the HIT-Punching Shear strengthening system after strengthening, calculated as the difference between the slab rotation at the Ultimate Limit State (ULS),  $\psi(V_{ULS})$ , i.e., under the maximum load that can be allowed on the slab, and at the quasi-permanent loading state during installation,  $\psi(V_{inst})$ , which may be calculated using the corresponding load factors ( $\psi_0$ ,  $\psi_1$ , or  $\psi_2$ ) found in Table 2 of Annex A in SIA 260 [7] or directly estimated based on the known conditions of the slab when the strengthening intervention is executed.

### 4.3 Verification of the maximum punching shear resistance and resistance outside the shear-reinforced zone

Similar to Eq. 69 [4], the maximum punching shear resistance is limited to the following condition to avoid crushing of the concrete struts near the support:

$$V_{Rd,max} = k_d \cdot (2.0 \cdot k_r \cdot \tau_{cd} \cdot d_{ef} \cdot u_{red}) \leq k_d \cdot (3.5 \cdot \tau_{cd} \cdot d_{ef} \cdot u_{red}) \quad (\text{kN}) \quad (\text{Eq. 5})$$

The extent of the shear-reinforced zone is determined by evaluating the punching shear resistance outside the shear-reinforced zone, which may be determined iteratively or according to the following condition:

$$V_{Ed} \leq V_{Rd,c,out} = k_r \tau_{cd} d_{ef,out} u_{out} \quad (\text{kN}) \quad (\text{Eq. 6})$$

- $d_{ef,out}$ : effective depth of the slab or foundation at the outer perimeter reduced by the residual cover,  $c_{res}$ , analogous to Clause 4.3.6.5.9 and Figure 25 [4].
  - Thus,  $d_{ef,out} = d_{ef} - c_{res}$
- $u_{out}$ : outer perimeter where reinforcement is no longer required, set at  $0.5d_{ef}$  from the reinforcing perimeter furthest from the face of the support, according to Clause 4.3.6.5.9 and Figure 25 [4].
  - **Note:**  $u_{out}$  is typically modified by  $k_{e,out}$ , that accounts for the eccentricity of the outer perimeter from the centroid of the support.
  - Thus,  $u_{out,mod} = u_{out}/k_{e,out}$ , where  $k_{e,out}$  may be determined by  $k_{e,out} = 1/(1 + e_u/2r_{out})$  and  $r_{out}$  is the distance from the centre of the support to  $u_{out}$ .

### 4.4 Detailing rules: Limits on positioning and on maximum and minimum spacing

The sections strengthened with the Hilti HIT-Punching Shear strengthening system were designed and detailed according to [3], in which the spacing of the first reinforcing perimeter,  $s_0$ , from the support face is positioned between  $0.3d_{ef} \leq s_0 \leq 0.5d_{ef}$ , where exceeding the upper limit should generally be avoided as it would pose the risk that the critical crack can fully develop without been intercepted by the PI steel elements. Spacing between subsequent reinforcing perimeters,  $s_r$ , is typically greater than or equal to  $s_0$ , but must not be less than the minimum spacing between two strengthening elements,  $s_{min}$ , from Table 3.

According to [4], only the strengthening reinforcement,  $\sum A_{sw}$ , positioned between  $0.35d_{ef}$  and  $1.0d_{ef}$  contributes to the overall punching shear resistance described by Eq. 2 of this document. Thus, similar to Figure 39 and Table 20 of [4],  $s_0$  and  $s_r$  for the HIT-Punching Shear strengthening system are linked to the effective depth,  $d_{ef}$ , of the slab or foundation in Table 2.

Table 2: Minimum & maximum radial spacing for slabs and foundations for the HIT-Punching Shear strengthening system

Effective static depth, $d_{ef}$ [mm]	Spacing from the loaded area to the first reinforcing perimeter, $s_0$	Spacing between the first, second, and subsequent perimeters, $s_r$
160-180	$0.35d_{ef} \leq s_0 \leq 0.5d_{ef}$	$s_{min} \leq s_r \leq 0.66d_{ef}$
181-340		$s_{min} \leq s_r \leq 0.75d_{ef}$
341-1100		$s_{min} \leq s_r \leq 200 + d_{ef}/6$

Apart from the general rule of spacing between adjacent bars to permit even distribution of the concrete and aggregates during pouring of concrete, no specific minimum spacing,  $s_{min}$ , applies to punching shear reinforcement in [3] and [4]. However, a relatively larger spacing between adjacent post-installed strengthening elements is required to avoid splitting the concrete between the elements, which derives from the experimental campaign and is defined in Table 3. Additionally, while the minimum spacing also applies to the tangential spacing,  $s_t$ , between adjacent strengthening elements in each reinforcing perimeter, the maximum must not exceed the limits defined in Table 3.

Table 3: Minimum radial & tangential spacing and maximum tangential spacing for slabs and foundations

Strengthening element	Minimum radial and tangential spacing, $s_{min}$ [mm]	Tangential spacing between adjacent elements:	
		In the first two reinforcing perimeters	In the third perimeter and beyond
M12	72	$s_{min} \leq s_t \leq 1.5d_{ef}$	$s_{min} \leq s_t \leq 2.0d_{ef}$
M16	96		
M20	120		
M24	144		

Table 20 of [4] also links the diameter to the punching shear reinforcement to the effective depth, which are replaced by limits in Table 4 for the Hilti HIT-Punching Shear strengthening system. Furthermore, Clause 5.5.3.11 of [4] requires a maximum cover of  $c_v = d_v/6$  between the tip of the punching shear reinforcement and the compression face of the slab; however, if this condition cannot be met – for instance, due to larger cover required the exposure class – then the punching resistances,  $V_{Rd,c}$  and  $V_{Rd,s}$ , must be reduced by 30%.

For the Hilti HIT-Punching Shear strengthening system,  $c_v$  is independent of the exposure class and instead is described by a fixed value of  $c_{res}$  in Table 4, which is required to avoid spalling of the concrete while drilling and is maintained irrespective of the section thickness,  $h$ . Reduction to the punching resistance is not required since tests were conducted satisfactorily with the smallest permissible effective depth of  $d_{ef} = 160\text{ mm}$  that corresponds to the largest ratio of  $c_{res}/d_{ef}$ , for the most critical installation condition, i.e., from the compression face of the section.

Table 4: Residual cover and minimum effective depth of the section for each strengthening element size

Size of the threaded rod	M12	M16	M20	M24
Minimum effective depth, $d_{ef,min}$	160	160	350	420
Residual concrete cover, $c_{res}$	35	40	45	60

A worked example in Annex A summarises the design procedure using the [4] in conjunction with [1]. For specific design requirements, please use PROFIS Engineering's *Punching Shear strengthening* module or contact Hilti Engineering support.

## Annex A: Design example of a slab strengthened with the HIT-Punching Shear strengthening system

### 1. Inputs

- Applied factored load:  $g_d + q_d = 20 \text{ kN/m}^2$
- Design support reactions:  $N_{Ed} = 1250 \text{ kN} \ \& \ V_{inst} = 500 \text{ kN}$
- Design bending moments:  $M_{Ed,x} = 50 \text{ kN} \ \& \ M_{Ed,y} = 30 \text{ kN}$
- Column dimensions ( $C_x \times C_y$ ):  $200 \times 600 \text{ mm}$
- Span lengths to adjacent columns ( $L_x \times L_y$ ):  $7000 \times 7000 \text{ mm}$
- Position – **Inner** column:  $k_e = 0.94$  (calculated)
- Slab thickness:  $h = 350 \text{ mm}$
- Effective depth in  $x$  &  $y$ :  $d_x = 317 \text{ mm} \ ; \ d_y = 301 \text{ mm}$
- Slab concrete strength & max aggregate size:  $f_{ck} = 40 \text{ N/mm}^2, D_{max} = 32 \text{ mm}$
- Flexural reinforcement steel strength:  $f_{sk} = 500 \text{ N/mm}^2, \gamma_s = 1.15, E_s = 205 \text{ GPa}$
- Concrete parameters:

$f_{cd}$ [N/mm <sup>2</sup> ]	$\eta_t$ [-]	$\eta_{fc}$ [-]	$\gamma_c$ [-]	$\tau_{cd}$ [N/mm <sup>2</sup> ]	$f_{ctm}$ [N/mm <sup>2</sup> ]	$f_{bd}$ [N/mm <sup>2</sup> ]
20.59	0.85	0.91	1.50	0.931	2.90	2.703

The longitudinal reinforcement ratio is assumed constant per metre width of the slab:

- In  $x$ -direction,  $\rho_{l,x} = \frac{A_{sl,x}}{1000 \cdot d_x} = \frac{2011}{1000 \cdot 317} = 0.634\%$  (from  $\Phi 16$  mm at 100 mm centres)
- In  $y$ -direction,  $\rho_{l,y} = \frac{A_{sl,y}}{1000 \cdot d_y} = \frac{2011}{1000 \cdot 301} = 0.668\%$  (from  $\Phi 16$  mm at 100 mm centres)

### 2. Perimeter definitions

Description	Variable	Value
Column perimeter	$u_0$	1600 mm
Mean effective depth	$d_{ef}$	309 mm
Control perimeter at $0,5d_{ef}$ with reduction from opening	$u_{crit}$	2571 mm
Reduction from openings	$\Delta u_{crit}$	0 mm
Area contained within the control perimeter	$A_{crit}$	442191 mm <sup>2</sup>
Shear-resisting control perimeter	$u_{red}$	2417 mm

Outer perimeter where reinforcement is not required	$u_{out}$	4018 mm
Modified outer perimeter where reinforcement is not required	$u_{out,mod}$	4223 mm

### 3. Design shear force

Design punching shear force is calculated based on the applied load within the control perimeter:

4.3.6.2.6 [4]

$$V_{Ed} = N_{Ed} - (g_d + q_d) \cdot A_c = 1250 - (20 \cdot 0.442) = 1241 \text{ kN}$$

### 4. Load eccentricity parameters

- Eccentricity between the centroids of the control section and the column in  $x$ ,  $\Delta e_x = 0 \text{ mm}$
- Eccentricity between the centroids of the control section and the column in  $y$ ,  $\Delta e_y = 0 \text{ mm}$
- Load eccentricity in  $x$ ,  $|e_{u,x}| = \left| \frac{M_{Ed,y}}{V_{Ed}} - \Delta e_x \right| = \left| \frac{50 \cdot 10^6}{1241 \cdot 10^3} - 0 \right| = 40 \text{ mm}$
- Load eccentricity in  $y$ ,  $|e_{u,y}| = \left| \frac{M_{Ed,x}}{V_{Ed}} - \Delta e_y \right| = \left| \frac{30 \cdot 10^6}{1241 \cdot 10^3} - 0 \right| = 24 \text{ mm}$
- Resultant eccentricity,  $e_u = \sqrt{e_{u,x}^2 + e_{u,y}^2} = \sqrt{40^2 + 24^2} = 47 \text{ mm}$

4.3.6.2.4 [4]

- Diameter of a circle with an area equivalent to  $A_{crit}$ ,  $b = \sqrt{\frac{4}{\pi} A_{crit}} = \sqrt{\frac{4}{\pi} \cdot 442191} = 750 \text{ mm}$

Eq. 56 [4]

- Load eccentricity parameter:  $k_e = \left( \frac{1}{1+e_u/b} \right) = \left( \frac{1}{1+47/750} \right) = \mathbf{0.94}$

### 5. Slab rotations (calculated with Level of Approximation 2 per 4.3.6.4.2 [4])

Distance from the column centroid to the point of contraflexure (null moments):

4.3.6.4.4 [4]

$$r_{s,x} = 0.22L_x = 0.22 \cdot 7000 = 1540 \text{ mm}$$

$$r_{s,y} = 0.22L_y = 0.22 \cdot 7000 = 1540 \text{ mm}$$

Width of the support strip for an **inner** column:  $b_s = 1.5\sqrt{r_{s,x} \cdot r_{s,y}} \leq l_{min} = \min(L_x; L_y)$

Eq. 60 [4]

$$b_s = 1.5\sqrt{1540 \cdot 1540} = \mathbf{2310 \text{ mm}} \leq \min(7000; 7000)$$

Moment in the support strip in the  $x$ -direction ( $b_{sr,x} = b_s$ ):

Eq. 61 [4]

$$m_{sd,x} = V_{Ed} \left( \frac{1}{8} + \frac{|e_{u,y}|}{2b_{sr,x}} \right) = 1241 \cdot 10^3 \left( \frac{1}{8} + \frac{24}{2 \cdot 2310} \right) = \mathbf{162 \text{ kNm}}$$

Moment in the support strip in the  $y$ -direction ( $b_{sr,y} = b_s$ ):

Eq. 61 [4]

$$m_{sd,y} = V_{Ed} \left( \frac{1}{8} + \frac{|e_{u,x}|}{2b_{sr,y}} \right) = 1241 \cdot 10^3 \left( \frac{1}{8} + \frac{40}{2 \cdot 2310} \right) = \mathbf{166 \text{ kNm}}$$

Bending resistance in support strip in the  $x$ -direction:  $m_{Rd,x} = \rho_{l,x} \cdot d_x^2 \cdot f_{yd} \left( 1 - 0.5\rho_{l,x} \cdot \frac{f_{yd}}{f_{cd}} \right)$

Eq. 18 [6]

$$m_{Rd,x} = 0.00634 \cdot 317^2 \cdot 435 \left( 1 - 0.5 \cdot 0.00634 \cdot \frac{435}{20.59} \right) = \mathbf{259 \text{ kNm}}$$

Bending resistance in support strip in the  $y$ -direction:  $m_{Rd,y} = \rho_{l,y} \cdot d_y^2 \cdot f_{yd} \left( 1 - 0.5\rho_{l,y} \cdot \frac{f_{yd}}{f_{cd}} \right)$

Eq. 18 [6]

$$m_{Rd,y} = 0.00668 \cdot 301^2 \cdot 435 \left( 1 - 0.5 \cdot 0.00668 \cdot \frac{435}{20.59} \right) = \mathbf{245 \text{ kNm}}$$

Slab rotation in the  $x$ -direction:  $\psi_x = 1.5 \cdot \frac{r_{s,x}}{d_x} \cdot \frac{f_{sd}}{E_s} \cdot \left( \frac{m_{sd,x}}{m_{Rd,x}} \right)^{3/2}$

Eq. 59 [4]

$$\psi_x = 1.5 \cdot \frac{1540}{317} \cdot \frac{435}{205000} \cdot \left( \frac{162}{259} \right)^{3/2} = \mathbf{0.00875 \text{ rads}} \rightarrow \text{governing rotation}$$

Slab rotation in the  $y$ -direction:  $\psi_y = 1.5 \cdot \frac{r_{s,y}}{d_y} \cdot \frac{f_{sd}}{E_s} \cdot \left( \frac{m_{sd,y}}{m_{Rd,y}} \right)^{3/2}$

Eq. 59 [4] 
$$\psi_y = 1.5 \cdot \frac{1540}{301} \cdot \frac{435}{205000} \cdot \left( \frac{166}{245} \right)^{3/2} = 0.00795 \text{ rads}$$

## 6. Verification without punching shear reinforcement

Eq. 37 [4] Aggregate interlock effect,  $k_g = \frac{48}{16+D_{max}} = \frac{48}{16+32} = 1.0$

Eq. 58 [4] Rotation parameter,  $k_r = \min\left(\frac{1}{0.45+0.18 \cdot k_g \cdot \psi \cdot d_{ef}}; 2\right) = \min\left(\frac{1}{0.45+0.18 \cdot 1.0 \cdot 0.00875 \cdot 309}; 2\right) = 1.068$

Eq. 1 Design resistance without punching shear reinforcement,  $V_{Rd,c} = k_d(k_r \tau_{cd} d_{ef} u_{red})$

$$V_{Rd,c} = 1.0 \cdot (1.068 \cdot 1.075 \cdot 309 \cdot 2417) = 857 \text{ kN}$$

**Since  $V_{Rd,c} \leq V_{Ed}$ , strengthening is required!**

Eq. 5 Maximum punching shear resistance ( $k_d = 1.0$ ):  $V_{Rd,max} = k_d \cdot \min(2 \cdot k_r; 3,5) \cdot \tau_{cd} \cdot d_{ef} \cdot u_{red}$

$$V_{Rd,max} = 1.0 \cdot \min(2 \cdot 1.068; 3,5) \cdot 1.075 \cdot 309 \cdot 2417 = 1715 \text{ kN}$$

**Since  $V_{Ed} \leq V_{Rd,max}$ , strengthening is possible!**

## 7. Verification with the HIT-Punching Shear strengthening system

Rearranging Eq. 65 [4], design punching shear resistance must satisfy:

$$\min(V_{Rd,c} + V_{Rd,s,pi}; V_{Rd,max}) \geq V_{Ed}$$

The **M16 8.8 HAS(-U)** with  $A_{sw} = 157 \text{ mm}^2$  is sufficient to proceed with the verification, with  $d_{ef} = 309 \text{ mm}$ ,  $k_d = 1.0$ , and  $k_{pi} = 0.82$  adopted to verify  $V_{Rd,s,pi}$ .

Eq. 2 & Eq. 66 [4] Resistance provided by HIT-Punching Shear strengthening,  $V_{Rd,s,pi} = k_{pi} \cdot (\sum A_{sw} \cdot k_e \cdot \sigma_{swd}) \geq 0.5V_{Ed}$

Effective design strength of the strengthening elements ( $f_{ywd} = 390 \text{ N/mm}^2$ ),

Eq. 4 
$$\sigma_{swd} = \frac{E_{sw} \cdot \Delta\psi}{6} \cdot \left( 1 + \frac{f_{bd}}{f_{ywd}} \cdot \frac{d_{ef}}{\phi_{sw}} \right) \leq f_{ywd}$$

$\Delta\psi = \psi(V_{Ed}) - \psi(V_{inst})$ : effective slab rotation activated by the HIT-Punching Shear strengthening system after strengthening, calculated as the difference between the slab rotation at the Ultimate Limit State (ULS),  $\psi(V_{ULS})$ , and at the quasi-permanent loading state during installation,  $\psi(V_{inst})$ . Since  $V_{inst} = 500 \text{ kN}$ , the corresponding moments in the support strip are:

Eq. 61 [4] • Moment in the support strip in the  $x$ -direction ( $b_{sr,x} = b_s$ ):

$$\Delta m_{sd,x} = V_{inst} \left( \frac{1}{8} + \frac{|e_{u,y}|}{2b_{sr,x}} \right) = 500 \cdot 10^3 \left( \frac{1}{8} + \frac{24}{2 \cdot 2310} \right) = 65 \text{ kNm}$$

Eq. 61 [4] • Moment in the support strip in the  $y$ -direction ( $b_{sr,y} = b_s$ ):

$$\Delta m_{sd,y} = V_{inst} \left( \frac{1}{8} + \frac{|e_{u,x}|}{2b_{sr,y}} \right) = 500 \cdot 10^3 \left( \frac{1}{8} + \frac{40}{2 \cdot 2310} \right) = 67 \text{ kNm}$$

- Slab rotation in the  $x$ -direction:  $\Delta\psi_x = 1.5 \cdot \frac{r_{s,x}}{d_x} \cdot \frac{f_{sd}}{E_s} \cdot \left[ \left( \frac{m_{sd,x}}{m_{Rd,x}} \right)^{3/2} - \left( \frac{\Delta m_{sd,x}}{m_{Rd,x}} \right)^{3/2} \right]$

Eq. 59 [4]

$$\Delta\psi_x = 1.5 \cdot \frac{1540}{317} \cdot \frac{435}{205000} \cdot \left[ \left( \frac{162}{259} \right)^{3/2} - \left( \frac{65}{259} \right)^{3/2} \right] = 0.00651 \text{ rads} \rightarrow \text{governing rotation}$$

- Slab rotation in the  $y$ -direction:  $\Delta\psi_y = 1.5 \cdot \frac{r_{s,y}}{d_y} \cdot \frac{f_{sd}}{E_s} \cdot \left[ \left( \frac{m_{sd,y}}{m_{Rd,y}} \right)^{3/2} - \left( \frac{\Delta m_{sd,y}}{m_{Rd,y}} \right)^{3/2} \right]$

Eq. 59 [4]

$$\Delta\psi_y = 1.5 \cdot \frac{1540}{301} \cdot \frac{435}{205000} \cdot \left[ \left( \frac{166}{245} \right)^{3/2} - \left( \frac{67}{245} \right)^{3/2} \right] = 0.00592 \text{ rads}$$

Eq. 4 Thus, the stress activated in the strengthening elements:

$$\sigma_{swd} = \min \left[ \frac{200000 \cdot 0.00651}{6} \cdot \left( 1 + \frac{3.275}{390} \cdot \frac{309}{16} \right); 390 \right] = 252 \text{ N/mm}^2$$

Eq. 3 Minimum reinforcement required:  $\Sigma A_{sw} = \frac{\max(0.5V_{Ed}; V_{Ed} - V_{Rd,c})}{k_{pi} \cdot k_e \cdot \sigma_{swd}}$

$$\Sigma A_{sw} = \frac{\max(0.5 \cdot 1241; 1241 - 857) \cdot 10^3}{0.82 \cdot 0.94 \cdot 252} = 3194 \text{ mm}^2$$

Spacing of post-installed punching shear strengthening elements:

Parameter	Check for minimum and maximum	
$s_0 = 150 \text{ mm}$	$0.35d_{ef} \leq s_0 \leq 0.5d_{ef}$	Fulfilled
$s_r = 150 \text{ mm}$	$s_{min,M16} = 96 \text{ mm}$ & $s_r \leq 0.75d_{ef}$ (from $181 \leq d_{ef} \leq 340$ )	Fulfilled
$s_t$ for first two perimeters	$s_{min} \leq s_t \leq 1.5d_{ef}$ where $s_{min,M16} = 96 \text{ mm}$	Fulfilled
$s_t$ beyond the second perimeter	$s_{min} \leq s_t \leq 2.0d_{ef}$ where $s_{min,M16} = 96 \text{ mm}$	Fulfilled

Since  $0.35d_{ef} \leq s_0 + s_r \leq 1.0d_{ef}$ , strengthening elements in the **first and second** reinforcing perimeters,  $\Sigma A_{sw}$ , may contribute to the steel resistance,  $V_{Rd,s,pi}$ .

## 8. Strengthening reinforcement layout and Installation Data

Eq. 6 Outer perimeter where strengthening is not required,  $V_{Ed} \leq V_{Rd,c,out} = k_r \tau_{cd} d_{ef,out} u_{out}$ , where  $d_{ef,out} = d_{ef} - c_{res}$ . The residual cover,  $c_{res} = 40 \text{ mm}$ , is taken from Table 3 of aBG Z.15-5.387 & the Hilti Technical Note for the size M16.

$$u_{out} = \frac{V_{Ed}}{k_r \tau_{cd} (d_{ef} - c_{res})} = \frac{1241 \cdot 10^3}{1.068 \cdot 1.075 \cdot (309 - 40)} = 4018 \text{ mm}$$

- Radius of  $u_{out}$  from the **centre** of the support,  $r_{out} = \frac{u_{out}}{2\pi} = 640 \text{ mm}$
- Eccentricity of the outer perimeter,  $k_{e,out} = \left( \frac{1}{1+e_u/2r_{out}} \right) = \left( \frac{1}{1+47/2 \cdot 640} \right) = 0.96$
- Modified outer perimeter,  $u_{out,mod} = \frac{u_{out}}{k_{e,out}} = 4185 \text{ mm}$
- Radius of  $u_{out,mod}$  from the **face** of the support,  $r_{out,mod} = \frac{u_{out,mod} - u_0}{2\pi} = \frac{4185 - 1600}{2\pi} = 411 \text{ mm}$



With  $s_0 = 150 \text{ mm}$  and  $s_r = 150 \text{ mm}$ , a maximum of **two** reinforcing perimeters can fit within  $u_{out,mod}$ ; additionally, punching reinforcement may only stop at a distance greater than  $(411 - 0.5d_{ef}) = 257 \text{ mm}$  from the column face.

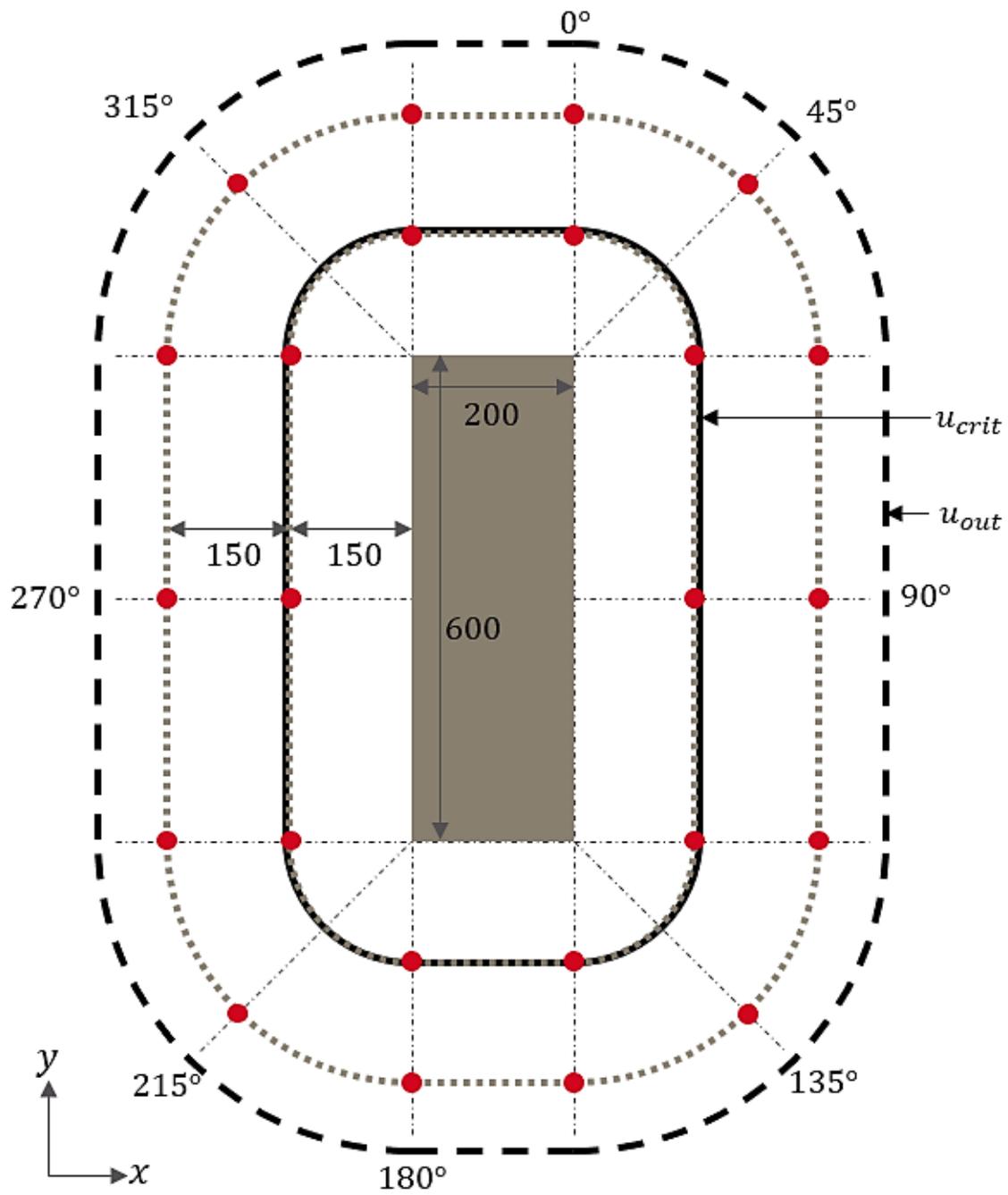
Perimeter	Distance from column face (mm)	Perimeter length (mm)	Required steel area (mm <sup>2</sup> ) $\Sigma A_{sw}$	Transverse Spacing (mm)	Elements provided per perimeter	Provided steel area (mm <sup>2</sup> )
1	150	2543	3194	$300 \leq s_{t,max}$	10	1570
2	300	3485		$300 \leq s_{t,max}$	14	2198

**Note:** When the position of any strengthening element coincides with existing flexural reinforcement, the affected element can be adjusted by a minimum distance of  $2d_0$  and a maximum of  $0,2d_{ef}$ . However, the minimum and maximum spacing rules for radial,  $s_0$  and  $s_r$ , as well as tangential distances,  $s_t$ , from Section 7 of this Annex must always be observed.

#### Installation according to the National Approval [1] and Manufacturer's Instructions for Use:

- Strengthening solution: HIT-RE 500 V4 + HAS-U 8.8 M16 + Filling Set
- Maximum installation torque,  $T_{inst}$ : 80 Nm
- Hole diameter in the slab,  $d_0$ : 18 mm
- Hole depth in the slab,  $l_{sw}$ : 310 mm
- Proposed drilling method: Hammer-drilled (HD) with Drilling Aid
- Concrete condition: Dry Concrete

As an example, the recommended reinforcement layout is provided below:



**Note 1:** All dimensions in millimetres.



## REFERENCES

- [1] Deutsches Institut für Bautechnik, "Z-15.5-387 - Hilti Durchstanzverstärkungssystem (HIT-Punching Shear Strengthening) mit Hilti HIT-RE 500 V4," DIBt, Berlin, 2025.
- [2] DIN, "Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings; German version EN 1992-1-1:2004 + AC:2010," DIN, Berlin, 2011.
- [3] DIN EN 1992-1-1/NA: National Annex – Nationally determined parameters – Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings, Berlin: DIN, 2013.
- [4] SIA, "SIA 262: Concrete Structures," Swiss Society of Engineers and Architects, Zürich, 2017.
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- [6] A. Muttoni, M. F. Ruiz, E. Bentz, S. Foster and V. Sigrist, "Background to fib Model Code 2010 Shear provisions - Part II: Punching Shear," *Structural Concrete*, vol. 14, no. 3, pp. 204-214, 2013.
- [7] SIA, "SIA 260: Basis of structural design," Swiss Society of Engineers and Architects, Zurich, 2017.