

Saimaa University of Applied Sciences

Lappeenranta

Double Degree Programme in Civil and Construction Engineering

Karina Kasatkina

**ADAPTATION OF PSB PUNCHING PREVENTION  
REINFORCEMENT ACCORDING TO RUSSIAN NORMATIVE  
DOCUMENTATION**

Bachelor's Thesis 2013

## ABSTRACT

Karina Kasatkina

Adaptation of PSB punching prevention system according to Russian Normative Documentation, 74 pages, 14 appendices.

Saimaa University of Applied Sciences, Lappeenranta

Double Degree Programme in Civil and Construction Engineering

Bachelor's Thesis, 2013

Instructors: Mr Petri Himmi, Mr Matvey Pirozhenko, Mr. Gatis Pocs.

The objective of the study was to prepare all necessary material to get permission to use PSB punching prevention reinforcement in Russian building projects. The work was commissioned by the Peikko Group company from Latvia, Belorussia, Russia and Finland.

During the study the main issues were description of the main characteristics, materials and production of Peikko PSB components; finding or creation of all necessary drawings; description of the designing of application of PSB Reinforcement; creation of few examples of calculation using ETA method and Peikko Designer Software. The information was gathered from literature, norms, regulations, producer's brochures, the Internet, handbooks, textbooks and from experts in that topic.

The results of the thesis are the method of calculations for PSB reinforcement that could be used in Russia; Russian Technical Approval was completed during summer 2013; annexes for Russian Technical Approval with all necessary drawings for designing, transporting, storage etc.

Keywords: Peikko PSB, Shear reinforcement, Punching prevention reinforcement, Stud rail, concrete cone

## Contents

1.	Introduction	5
2.	Common information about Russian normative documentation	7
3.	Common information about punching prevention systems	9
3.1.	Stirrups	11
3.2.	Shear heads	11
3.3.	Shear stud rails	12
3.4.	Peikko Cubo	12
4.	General information about PSB-reinforcement	14
4.1.	Definition and properties	14
4.1.1.	Standard types	15
4.2.	Materials and dimensions of the PSB double headed studs	18
4.3.	Characteristics of the Double-Headed Studs	19
4.3.1.	Geometry	19
4.3.2.	Resistance	20
4.3.3.	Mechanical strength	21
4.3.4.	Reaction to fire	21
4.3.5.	Resistance to fire	22
4.3.6.	Durability	22
4.3.7.	Fatigue strength	23
4.4.	Design requirements	23
4.5.	Positioned of PSB-studs	24
4.5.1.	Flat slabs	24
4.5.2.	Footings and ground slabs	26
5.	Design principles according to EN 1992-1-1 and ETA-13/0151	27
5.1.	Determination of the punching resistance	27
5.2.	Punching design of flat slabs and footings	31
5.2.1.	Slabs	31
5.2.2.	Footings and ground slabs	32
6.	Design principles according to Russian normative documentation	33
7.	Design examples	43

7.1.	Design example of the flat slab above the column	43
7.2.	Design example of the flat slab above the column according to Russian Norms	49
7.3.	Design example of the flat slab above the wall	53
7.4.	Design example of the flat slab above the wall according to Russian Norms	59
7.5.	Different dimensions of PSB rails for the flat slab above the column	64
7.6.	Different dimensions of PSB rails for the flat slab above the column	65
8.	Conclusion	67
	Figures	71
	Tables	73
	References	74
	Appendices	
	Appendix 1 Cast in-situ monolithic slabs: Top installation	75
	Appendix 2 Cast in-situ monolithic slabs: Bottom installation	76
	Appendix 3 Precast slabs- installation	77
	Appendix 4 PSB-F: Availability	78
	Appendix 5 Example of storage and transport of precast elements with Peikko PSB studs	79
	Appendix 6 Geometry and marking of the Peikko PSB studs	80
	Appendix 7 Assembly profiles	81
	Appendix 8 PSB standard elements	82
	Appendix 9 Arrangement of the elements	83
	Appendix 10 Report of the fatigue test	86
	Appendix 11 Examples of the Russian Technical Approval	94
	Appendix 12 Failure modes of slabs reinforced with punching reinforcement	97
	Appendix 13 Examples of the cut sections of slabs with Peikko PSB Studs after failure	98
	Appendix 14 Procedure to select PSB reinforcement using Peikko Designer	99

## 1. Introduction

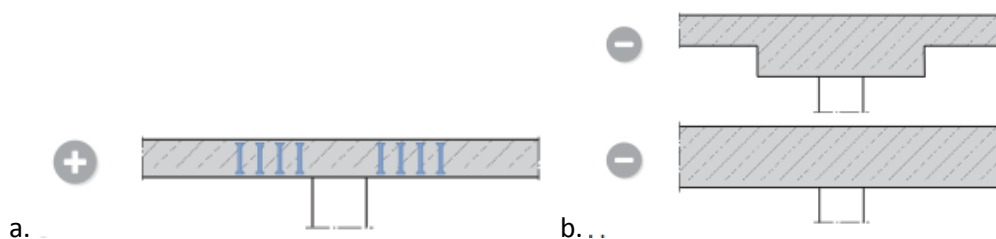
PSB Reinforcement is designed to prevent punching failure of cast-in-situ slabs from around columns. Punching Reinforcement is an efficient industrial reinforcement which replaces the traditional stirrup reinforcement. It is fast and easy to install in the reinforcement.

Double headed studs (Peikko PSB Studs, Figure 1.1 a) are one of the most efficient systems for the reinforcement of concrete flat slabs against failure by punching. The studs are the most typically used to reinforce floor slabs, foundation slabs or column footings. This reinforcement technique has become almost a standard in Central Europe over the past 20 years; it is nowadays becoming increasingly popular in other parts of Europe as well.

In Russia, such systems, as Peikko PSB Studs, have not met a wide range of usage yet. Most likely it is a height enlarge of the slab close to the column (creation of a capital) or height enlarge of the whole slab (Figure 1.1 b). Also, the absence of any technical specifications or calculations made according to Russian norms is a serious problem for usage of Peikko PSB Studs in Russia.

Figure 1.1. a. The most effective system- thin slabs, easier reinforcing

b. Uneconomical system- height enlarge of the whole slab or the part thereof



The Peikko Punching Shear Reinforcement systems enable simple installation of the floor slab reinforcement without spacers, as the system is installed on top or with spacers under the main reinforcement. The Punching Shear Reinforcement is used in reinforced concrete floor slabs that are cast directly onto columns or walls without outriggers. The system increases the punching shear capacity of the floor by as much

as 90%. The system is applicable to floor thickness starting from 180 mm. The PSB Reinforcement System facilitates reinforcement work compared to traditional reinforcement stirrup assembly.

The type, geometry and dimensions of PSB may be designed and the resistances of concrete members reinforced by PSB elements may be verified of using Peikko Designer. Peikko Designer is a design software developed by Peikko, and it is freely available from [www.peikko.com](http://www.peikko.com). Peikko Designer makes the designing process easier and faster. It also allows avoiding the mistakes because of human factor or because of inadvertency.

In case of getting approval for Peikko PSB Studs, the way described below will be used. During work for Russian Department of Peikko it was the necessity to get approval for punching prevention system. For this purpose all necessary information was collected from Latvia, Finnish, German, Belarus and Russian departments of Peikko. All data were processed and adapted to requirements set by Russian normative regulations. After preparation, the Technical Specification was sent to V.A. Kucherenko Central Research Institute of Constructions and Buildings for approval. After some correction work Technical Specification for Peikko PSB Studs was successfully approved (Appendix 11, Examples of the Russian Technical Approval). Received approval helps such companies as Compact or Barricada to freely use Peikko PSB Studs for projects in Russia. These companies are already using punching prevention system PSB Studs in their projects and they need to get technical approval to pass the expertise.

## 2. Common information about Russian normative documentation

Technical Approval is a document that defines technical requirements that must obey a particular product, material, substance or a group of them. In addition, they must contain procedures that determine realization of the requirements.

Development of technical approvals is required when manufacturer produces products which contradict GOST or there is no existing standard. Technical Approval is an obligatory document for any kind of product that regulates the process of its production and product quality standards.

### Document status

Technical approvals are technical documents developed by the decision of the developer (manufacturer) or at the request of the product's customer (consumer). Technical approvals are an integral part of a set of design or other technical documentation for the products, and if documentation is absence must contain the full set of the requirements for the product (manufacture, quality control).

Technical approvals are developing on one particular product, material, substance or a few specific products, materials, substances, etc. Technical approvals establish requirements which must not conflict with obligatory GOST requirements applied to that product.

According to the technical regulation law technical approvals and standards are obligated to the products used at hazardous production facilities.

The title of the technical approval

Example: TY 1115-017-38576343-2003

TY- technical approval

1115 - code of the product type - National Product's Classification

017 - three-digit registration number assigned by the developer

38576343 – code of the enterprise which developed the Technical Approvals – National Company's and Organization's Classification

2003 – creation year of the document

Document structure

According to the GOST 2.114-95 standard of Russia, the technical approvals should include an introduction and sections, arranged in the following order:

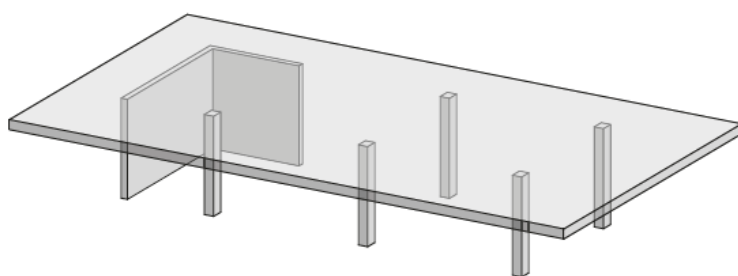
- introduction
- technical requirements;
- safety requirements;
- environmental protection requirements;
- acceptance rules;
- methods of control;
- transportation and storage;
- instructions for use;
- the manufacturer's warranty.



### 3. Common information about punching prevention systems

Reinforced concrete flat slabs are nowadays one of the most popular structural systems in residential, administrative, industrial and many other types of buildings. The system usually consists of slabs locally supported by columns or walls without down stand beams. Such configuration allows optimizing the space on the floor area and to perform saving with regards to the total height of the building.

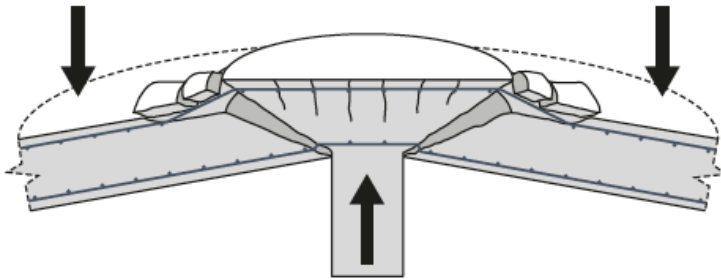
Figure 3.1. Flat slab supported on columns and walls



Between supports, the slab is usually designed as a two-way slab to resist bending moments in two orthogonal directions. In support area, the bending moments are combined with transverse loads – reactions from supports. Such a combined loading resulting in a state of stress may lead to failure of the slab by punching. The verification of the punching resistance of the slab is often decisive for the definition of the thickness of the concrete slab.

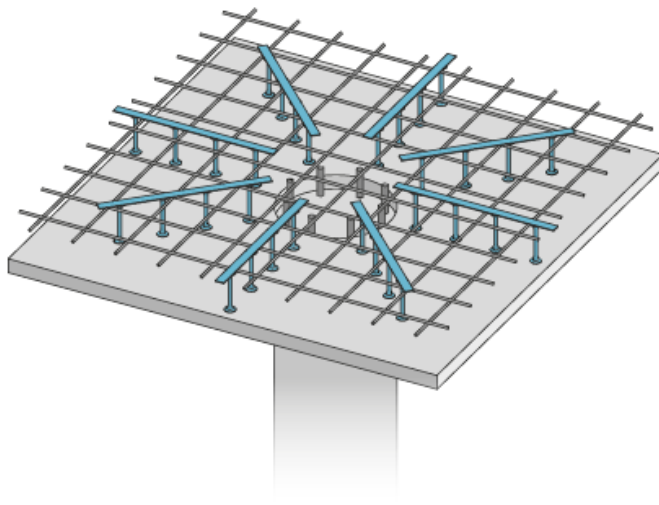
Punching usually occurs so that a concrete cone is separated from the slab, bending reinforcement is pulled away from concrete and the slab falls down due to gravity forces (Figure 3.2). Experience shows that failure by punching is particularly dangerous since it is a brittle phenomenon that happens suddenly without any previous signs of warning (extensive deformations, cracks....). Moreover, the failure of one column may impact on adjacent columns and lead to an in-chain failure of the whole reinforced concrete floor. (According to “Evaluation of the Efficiency of Shear Studs for Punching Shear Resistance of Slab-Column Connections”)

Figure 3.2. Failure of a slab by punching



A slab without vertical reinforcement has only a very limited resistance against punching failure. This resistance may be increased by placing reinforcement elements in the concrete slab in such a manner that they prevent the concrete cone to develop (Figure 3.3) (according to Peikko PSB Brochure).

Figure 3.3. Flat slab reinforced with PSB



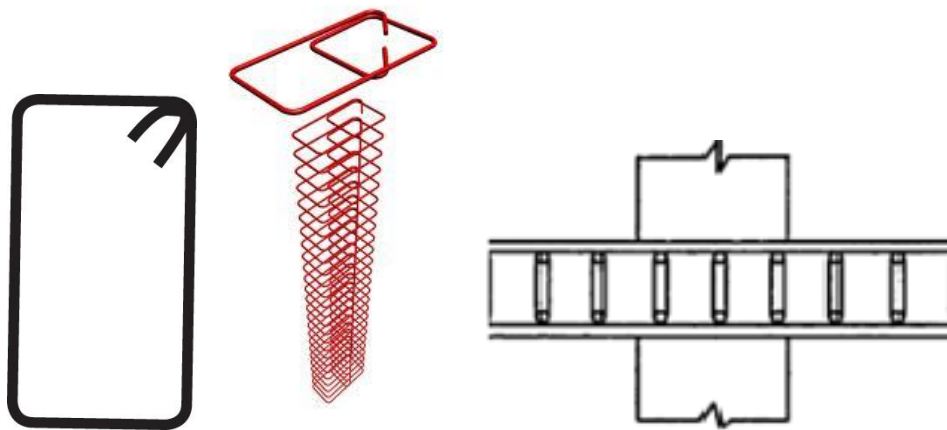
There are different types of reinforcement for the purpose of prevention punching phenomenon. The main types and descriptions of these systems are listed below according to “Enhancing the punching shear resistance of flat plates using shear heads, shear stud rails and shear stirrups: a comparative study”

### 3.1. Stirrups

Shear stirrups are conventional beam reinforcement placed between the main reinforcement and assembled in configurations, such as a cross or L-shape in order to deal with the punching shear forces at internal, edge and corner junctions respectively.

The installation of conventional shear force stirrups is very complicated and time-consuming, as the stirrups must be sealed after the installation.

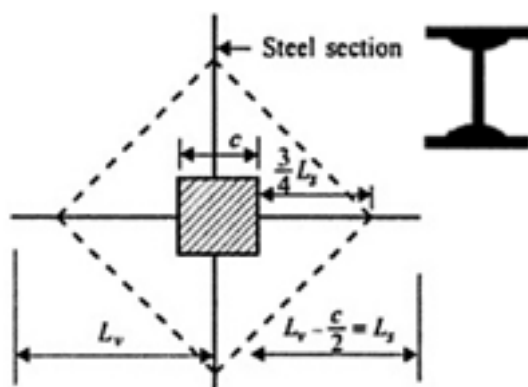
Figure 3.4. Shear stirrups



### 3.2. Shear heads

Shear heads are steel sections welded together into a grid and placed around the column. Shear heads are generally used for large structures where high levels of punching shear are present around the columns and for this reason they are relatively expensive and very heavy

Figure 3.5. Shear heads

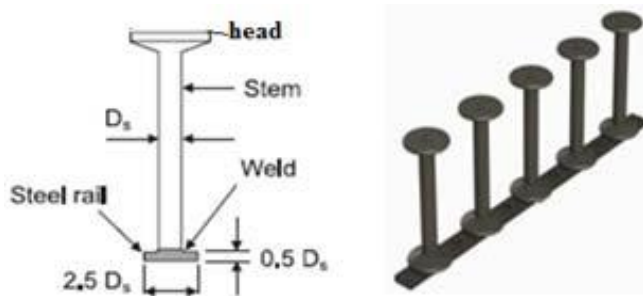


### 3.3. Shear stud rails

Stud rail is probably the most widely used type of reinforcement against punching shear. The system consists of studs that are welded onto a metal strip; the studs are fabricated from plain or deformed reinforcement bars, with an enlarged head welded to one or both ends.

Stud rails can be located around a column head or base to reinforce a flat slab against punching shear. The shear load from the slab is transferred through the studs and into the column

Figure 3.6. Shear stud rails



### 3.4. Peikko Cubo

CUBO Column Caps are applicable for high punching loads. By increasing the critical circumference the shear stresses are reduced. Often used in combination with the PSB Punching Reinforcement it enables to resist against major punching loads.

CUBO Column Caps are available in four different standard design types depending on the arising punching loads and the location of the column. They are calculated according to the static requirements.

Standard design variants:

Figure 3.7.1. CUBO-N  
Normal type for internal columns

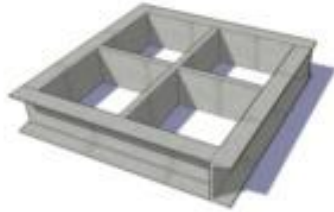


Figure 3.7.3. CUBO-D  
Double-type for high punching resistance and internal columns

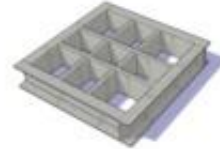


Figure 3.7.2. CUBO-H  
H-type for higher punching resistance and internal columns

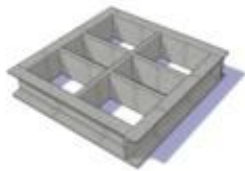
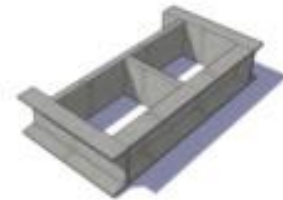


Figure 3.7.4. CUBO-E  
Edge-type for edge columns



## 4. General information about reinforcement

Basic information about designing, application, main characteristics, dimensions and components of Peikko PSB punching prevention reinforcement are presented in this chapter.

### 4.1. Definition and properties

The PSB punching reinforcement is shear studs rail reinforcement. It is the most popular type of reinforcement against punching. PSB consists of few PSB double-headed studs and the bars are assembled in order to ensure the right distance between the studs.

The studs are installed as shear reinforcement in reinforced concrete flat slabs on columns, ground slabs or in footings in order to increase the punching shear resistance of the slabs. They may also be used for the increase of the load-bearing capacity of the slabs subjected to high concentrated loads.

Double headed studs can also be used for semi-prefabricated slabs also in combination with lattice girders when the respective ETAs or national guidelines are observed. Double-headed studs installed as shear reinforcement are also effective as interface reinforcement.

The provisions made in this European technical approval are based on an assumed working life of the Double Headed Studs of 50 to 100 years, provided that the conditions laid down in chapter 4.5 for the installation, use and maintenance are met. The indications given on the working life cannot be interpreted as a guarantee given by the producer, but are to be regarded only as a means for choosing the right products in relation to the expected economically reasonable working life of the works.

#### 4.1.1. Standard types

- PSB studs

The main elements that are using in all other types.

PSB- punching prevention reinforcement consist of few studs and assembled bars or strips

Figure 4.1. Peikko PSB Studs

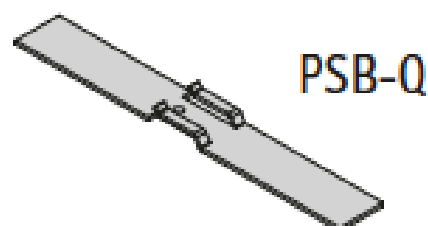


- PSB- Q

For floor systems in cast-in-situ concrete, top-installation of the PSB elements is recommended.

For Top installation: The PSB elements are hung to the main reinforcement of the slab. The whole bending reinforcement is installed to the mould prior to PSB. The proper mounting position of the PSB elements is ensured by using the PSB-Q cross connector (Appendix 1 Cast in-situ monolithic slabs: Top installation)

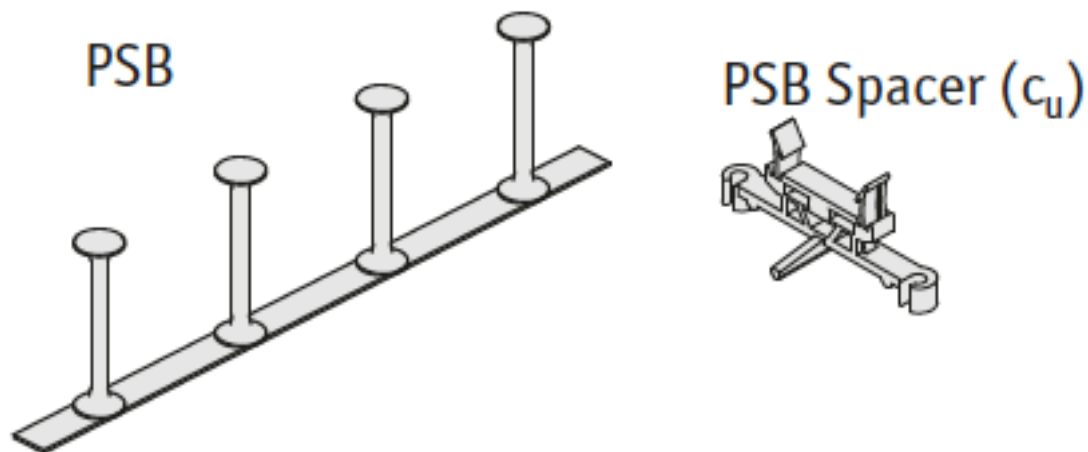
Figure 4.2. PSB-Q element



- PSB- Spacers

Bottom installation: As alternative to the installation from the top, PSB elements are placed to the mould of the slab from bottom prior to the installation of the bending reinforcement. In order to achieve sufficient concrete cover of the headed studs, PSB plastic spacers are mounted to the assembly profile of the PSB elements. The spacers available for concrete covering from 15-45 mm prior to installing the slab reinforcement. The spacers have to be ordered separately from the PSB elements. (Appendix 2 Cast in-situ monolithic slabs: Bottom installation)

Figure 4.3. PSB-Spacer



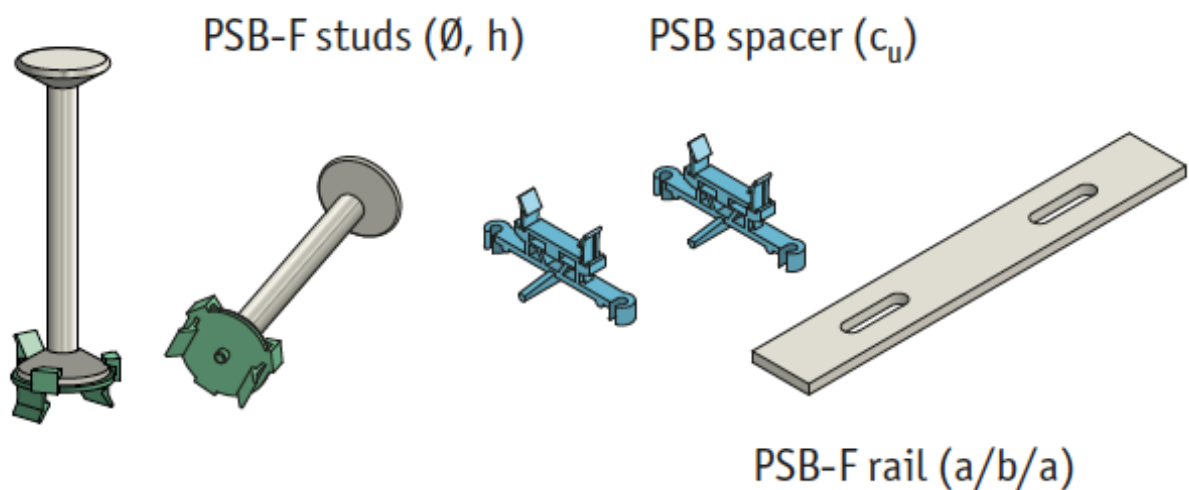
- PSB-F (Precast variant)

A special type of PSB elements (PSB-F) is available for the use within filigree slabs. The assembly profile of the PSB-F elements is installed to the formwork from bottom on plastic spacers prior to the reinforcement of the filigree slab. The reinforcement of the filigree slab (bending reinforcement and lattice girders) may thereafter be installed manually or by automatized process without being limited by the presence of studs. The studs are installed on the assembly profile only once the reinforcement process of the filigree slab is finished. They are simply clicked on the assembly profiles; the slotted holes on the assembly profiles offer mounting tolerances to ensure the proper installation of the studs.



The multi-component type PSB-F is for the use in precast factories. The partial structure enables the easy and fast installation of the punching reinforcement in the preferred phase of the automated production process without disturbing it. PSB-F rails are mounted by means of Peikko PSB spacers (available for concrete coverings from 15-45 mm) in required height on the shuttering table in defined positions marked by the plotter. Lower bending reinforcement and the lattice girders can be positioned freely by reinforcement robot. The reinforcement work is easy, as the studs are not yet in place. When reinforcement process is complete the required PSB-F studs are easily clicked on the rails in predefined positions. The slotted holes on the rails offer assembly tolerance to ensure the proper installation of the studs. (Appendix 3 Precast slabs- installation; Appendix 4 PSB-F: Availability; Appendix 5 Example of storage and transport of precast elements with Peikko PSB studs)

Figure 4.4. Elements for PSB-F



## 4.2. Materials and dimensions of the PSB double headed studs

The PSB double-headed studs with ribbed shafts are made of weldable ribbed reinforcement bars with nominal characteristic yield strength of 500 MPa. Studs are made of steel A500C according to GOST 52544-2008, S500 according to STB 1341-2009 or B500B according to EN 10080, DIN 488

They have a head at both ends with a diameter of three times the shaft diameter.

The diameters of the shafts are 10, 12, 14, 16, 20 and 25 mm.

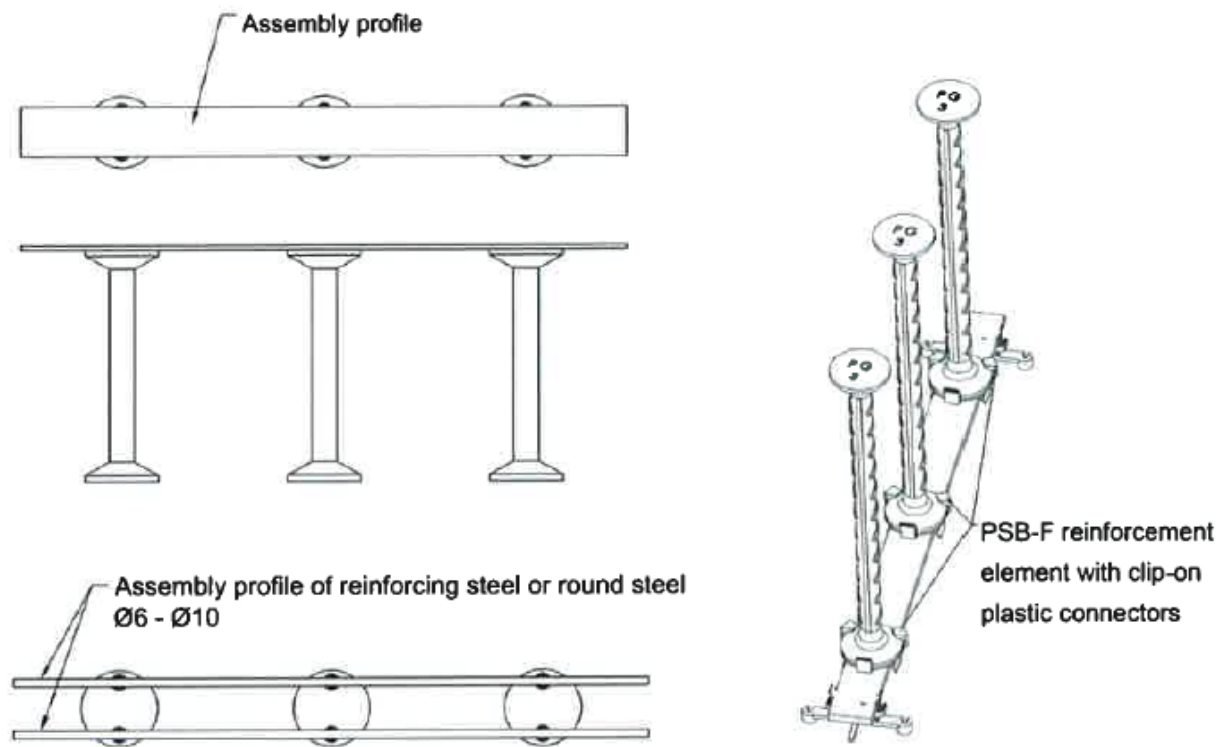
The bars used to secure the stud's position during casting are made of weldable reinforcing steel or structural steel (smooth steel bars)  $d_s=6$  mm to  $d_s=10$  mm and the rails are made of structural steel with a thickness of  $t=4$  mm.

The studs are assembled to form reinforcement elements comprising of at least two studs (Figure 4.5). The studs are tack welded or clamped at one end to a non-structural steel rail or reinforcing bars  $d_s =6$  mm for securing the position of the double headed studs when pouring the concrete. All studs of one of those reinforcement elements shall have the same diameter.

The material for the structural steel (bars or rails) shall be No. 1.0037, 1.0038 or 1.0045 acc. To EN 10025-2 or non-corrosive steel No.1.4401, 1.4404, 1.4439, 1.4571 according to EN 10088-5 or 25Г2С according to GOST 5781-82 or A500C according to GOST 52544-2006 or B500B according to EN 10080, DIN 488 or S235JR according to EN 10025-2:2004 or St3 according to GOST 14637-89.

The reinforcement element with double headed studs may be installed in an upright (rail at the bottom of the slab) or hanging position, but always perpendicular to the faces of the reinforced slab or footing

Figure 4.5. PSB double-headed studs with assembly profiles welded to the heads or PSB-F reinforcement element with clip-on plastic connectors



### 4.3. Characteristics of the Double-Headed Studs

#### 4.3.1. Geometry

The essential geometrical properties of the product are given in Appendix 6 Geometry and marking of the Peikko PSB studs. In Table 2 the stud's dimensions are given (diameter of the shaft  $d_A$ , diameter of the stud head  $d_k$ , height of the stud  $h_A$ ). Dimensions of the steel rail for the non-structural rails or reinforcement bars are given in Appendix 7 Assembly profiles.

Table 1. Geometry information

Diameter of the stud	Diameter of the head	Head thickness	Section of the stud
$d_A$	$d_K$	$h_K$	A
[mm]	[mm]	[mm]	[mm <sup>2</sup> ]
10	30	5	79
12	36	6	113
14	42	7	154
16	48	7	201
20	60	9	314
25	75	12	491

#### 4.3.2. Resistance

The characteristic values of resistances of individual PSB studs in accordance with ETA-13/0151 are summarized in Table 2.

Table 2. Characteristic values of tensile resistances of PSB studs

Diameter	mm	10	12	14	16	20	25
Resistance	kN	39,3	56,5	77,0	100,5	157,1	245,4

The resistance of a concrete member reinforced by PSB has to be verified case-by-case for each project. Peikko Designer may be used to design PSB and verify the resistances of concrete members reinforced by PSB according to the requirements of ETA-13/0151.

### 4.3.3. Mechanical strength

The PSB double-headed studs are made of steel bars or reinforcement steel with mechanical properties according to EN 1992-1-1, Annex C and the technical documentation of the ETA.

The following conditions concerning the yield strength and tensile strength of the double-headed studs are considered proven:

- $f_{yk} \geq 500 \text{ MPa}$
- ratio  $(f_t/f_y)_k \geq 1.05$
- $\epsilon_{uk} \geq 2.5 \%$

Table 3. Geometry and mechanical strength

Diameter of the stud $d_A$ [mm]	Diameter of the head $d_k$ [mm]	Head thickness $h_k$ [mm]	Section of the stud $A$ [mm <sup>2</sup> ]	Characteristic value of yield strength $f_{yk}$ [MPa]	Characteristic value of tensile strength of the stud $F_k = A \cdot f_{yk}$ [kN]
10	30	5	79	500	39,3
12	36	6	113		56,5
14	42	7	154		77,0
16	48	7	201		100,5
20	60	9	314		157,1
25	75	12	491		245,4

### 4.3.4. Reaction to fire

The double-headed studs are considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire, in accordance with the provisions of EC Decision 96/603/EC (as amended) without the need for testing on the basis of its listing in that decision

#### 4.3.5. Resistance to fire

Fire resistance performance cannot be claimed for individual products (non-installed), but for the installed double-headed studs cast-in slabs or footings

#### 4.3.6. Durability

Supporting evidence that corrosion will not occur is not required if the steel parts are protected against corrosion, as set out below:

No separate verifications are necessary for durability against environmental influences if:

- the double headed studs are protected by a minimum concrete cover according to the requirements given at the place of use,
- or the bars or steel rails (assembling profile) for securing the position of the studs are made of steel which has been hot-dip galvanized (coating  $\geq 50 \mu\text{m}$ ) and will be installed in concrete member under dry internal conditions and the stud heads have at least the minimum concrete cover according to the national provisions of the Member States,
- or the bars or steel rails (assembling profile) are made of suitable stainless steel (1.4401/1.4404/1.4571) where they will be installed in slabs under dry internal conditions, in humid internal conditions, external environment, also in industrial environment or in marine environment proximity, if no particular aggressive conditions exist, and the stud heads have at least the minimum concrete cover according to the regulations and provisions at the place of use.

If corrosion protection (material or coating) other than those mentioned above is specified, it will be necessary to provide evidence in support of its effectiveness in the defined service conditions; with due regard to the aggressiveness of the conditions concerned.

#### 4.3.7. Fatigue strength

The fatigue strength of the double-headed studs for non-predominantly static loading shall deal with the fatigue of the reinforcement steel only.

The double headed studs can be used for a stress range of  $\sigma_{Rs,k} = 70 \text{ N/mm}^2$  and  $N \leq 2 \cdot 10^6$  load cycles in analogy to EN 1992-1-1, clause 6.8.6 (1) and (2). The results of investigations are in Appendix 10 Report of the fatigue test.

#### 4.4. Design requirements

The fitness of the double headed studs for the intended use is given under the following condition:

The concrete strength class according to EN 206-1:2000 of the slabs or footings shall be at least C20/25 and shall not exceed C50/60

The slabs may have a minimum height of  $h = 180 \text{ mm}$ .

It is assumed that

- The lower reinforcement of the slab is laid over the column according to the indication in EN 1992-1-1.
- The upper reinforcement of the slab is placed continuously over the loaded area.
- The load-bearing capacity of the column below the shear reinforcement as well as the local compressive stress at the joint between slab and column are each verified individually and by taking into account of national provisions and guidelines.
- The load-bearing capacity of the concrete slab outside the punching shear reinforced area is verified separately and in accordance with the relevant national provisions.
- All studs in the punching area around a column or concentrated load shall be of the same diameter.

- The bending resistance of the entire slab is verified in accordance with the relevant national provisions.
- In case of cast in-situ slabs, the punching shear reinforced area is poured monolithically with the slab. In case of semi-prefabricated slabs, when the final concrete is cast on-site, one head of the double-headed studs shall be cast in the prefabricated slab.
- The flexural reinforcement over the column has to be anchored outside the outer control perimeter  $u_{out}$ .

The favourable effect of normal compressive stresses on the maximum punching shear resistance shall not be included for slabs with double-headed studs as punching shear reinforcement. If inclined pre-stressed tendons cross the punching zone, a negative influence shall be considered and a positive influence may be considered.

#### 4.5. Positioned of PSB-studs

The position, the type, the size and the length of the double-headed studs shall be indicated on the design drawings. (Appendix 9 Arrangement of the elements)

The double-headed studs shall be positioned in the following way:

##### 4.5.1. Flat slabs

On each stud on a radius, the stud nearest to the column face shall be placed at a radial distance between  $0.35 d$  and  $0.5 d$ , the second stud within  $1.125d$  from the column face. The area within  $1.125 d$  from the column face is designated area C. The tangential distance of the studs shall not exceed  $1.7 d$  within  $1.00 d$  from the column face. The maximum distance between studs shall not exceed  $0.75d$  in radial direction.

Outside the area C, the maximum tangential distance is  $3.5 d$ . The number of punching reinforcement elements in the area D may be increased in comparison to area C to fulfil



this requirement. If the number of elements is increased, additional elements shall be placed radially to the column between the existing elements.

In the area D the radial distance between the studs shall not exceed  $0.75d$ . In thick slabs, if three or more headed studs are arranged per rail in area C, the radial distance of the double headed studs in area D shall be reduced according to the following equation:

$$s_{w,D} = \frac{3 \cdot d \cdot m_D}{2 \cdot n_C \cdot m_C} \leq 0,75 \cdot d$$

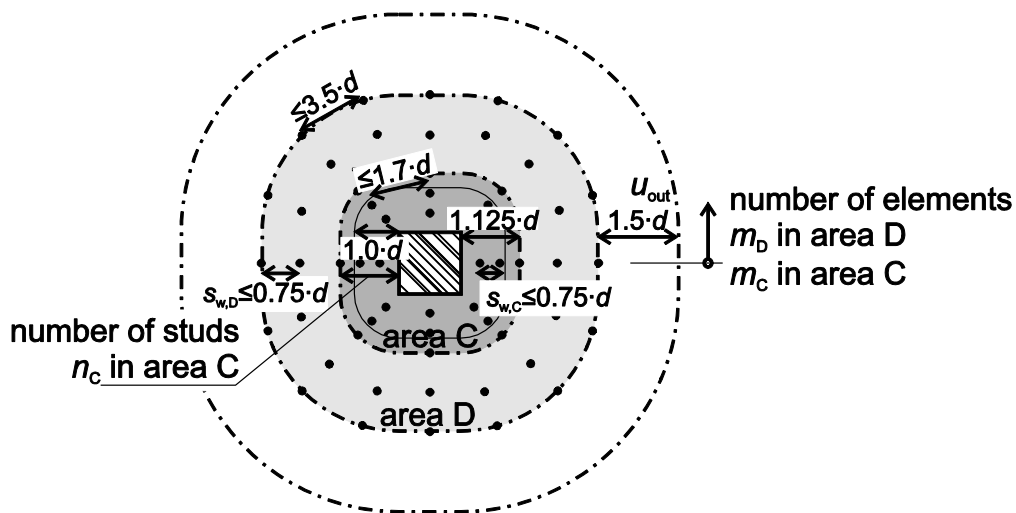
$m_C$ : number of elements (rows) in area C

$m_D$ : number of elements (rows) in area D

$n_C$ : number of studs of each element (row) in area C

For double headed studs placed next to free slab edges and recesses, a transverse reinforcement shall be provided to control the transverse tensile forces

Figure 4.6. Maximum allowed spacing of studs in area C and D of flat slabs

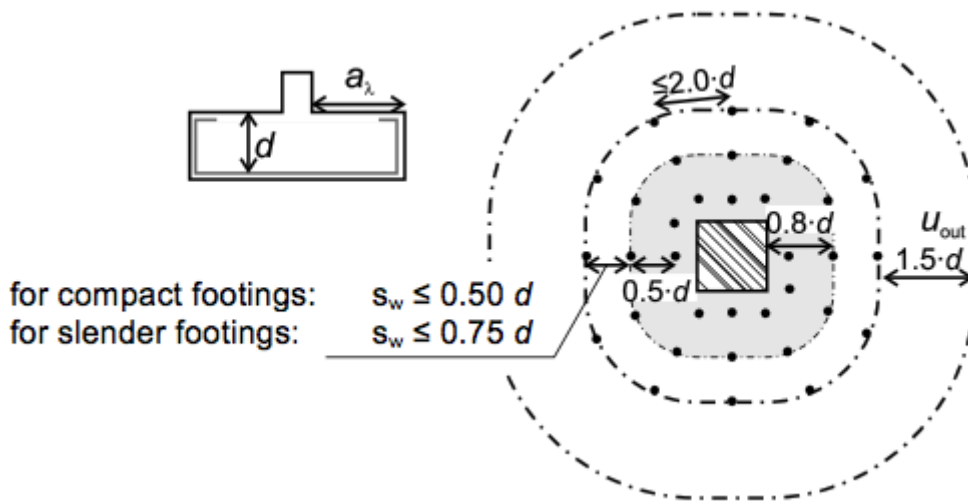


#### 4.5.2. Footings and ground slabs

For footings, the first row of studs shall be placed at a distance of  $0.3 d$  and the second row in a range up to  $0.8d$  from the column face.

If outside  $0.8d$  further rows of double headed studs are required, the radial distance in compact footings with a small shear span-depth ratio of  $a_{\lambda}/d \leq 2.0$  is limited to  $0.5 d$ . For slender footings ( $a_{\lambda}/d > 2.0$ ) the radial distance outside of  $0.8 d$  can be increased to  $0.75d$ . The double-headed studs are evenly distributed along the circular sections and the maximum tangential distance may not exceed  $2.0 d$

Figure 4.7. Maximum allowed spacing of studs in slender and compact footings



## 5. Design principles according to EN 1992-1-1 and ETA-13/0151

### 5.1. Determination of punching shear resistance

The verification of the punching shear resistance at ultimate limit state is performed as follows:

The ultimate limit state of punching shear shall be assessed in control perimeters. The slab shall be designed to resist a minimum of bending moments according to national guidelines. Outside the control perimeter the verification of the ultimate limit state design for shear and bending shall be carried out according to national guidelines.

To determine the punching shear resistance, an inner critical perimeter  $u_1$  perpendicular to the flat slab surface at a distance  $2.0 d$  ( $d$  = effective depth of the slab) around the column and an outer control perimeter  $u_{out}$  at a distance of  $1.5 d$  from the outermost row of the punching shear reinforcement are considered. For footings, the distance to the critical perimeter has to be calculated with an iterative method.

The critical perimeter may be determined as stated above for columns with a perimeter  $u_0$  less than  $12 d$  and a ratio of the longer column side to the shorter column side not greater than 2.0. If these conditions are not fulfilled, the shear forces are concentrated along the corners of the column and the critical perimeter has to be reduced.

For irregular shaped columns the perimeter  $u_0$  is the shortest length around the loaded area. The critical perimeters  $u_1$  shall be determined according to EN 1992-1-1, 6.4.2.

In a first step, the design value of the shear stress  $v_{Ed}$  along the critical control perimeter  $u_1$  is calculated:

$$v_{Ed} = \frac{\beta \cdot V_{Ed}}{u_1 \cdot d}$$

$v_{Ed}$  shear stress calculated along the critical perimeter

$\beta$  coefficient taking into account the effects of load eccentricity.

$V_{Ed}$  design value of the applied shear force

$u_1$  perimeter of the critical section with a distance of 2.0  $d$  from the column face

For structures where the lateral stability does not depend on frame action between the slabs and the columns, and where the adjacent spans do not differ in length by more than 25 %, approximate values for  $\beta$  may be used:

interior columns	$\beta = 1.10$
edge columns	$\beta = 1.40$
corner columns	$\beta = 1.50$
corner of wall	$\beta = 1.20$
end of wall	$\beta = 1.35$

Alternatively, the more detailed calculation according to EN 1992-1-1 (6.39) can be used to determine the factor  $\beta$ , but the method with the reduced basic control perimeter is not recommended.

In flat slabs, where the total shear force is greater than the resistance of the slab without punching reinforcement according to equation punching shear reinforcement is necessary:

$$V_{Rd,c} = C_{Rd,c} \cdot k \cdot \left( 100 \cdot \rho_l \cdot f_{ck} \right)^{1/3} + k_1 \cdot \sigma_{cp} \geq \sigma_{min} + k_1 \cdot \sigma_{cp}$$

$C_{Rd,c}$  empirical factor, the recommended value is  $C_{Rd,c} = 0.18/\gamma_C$

$\gamma_C$  partial safety factor for concrete ( $\gamma_C = 1.5$ )

$k$  coefficient for taking into account size effects,  $d$  in [mm]

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$$

$\rho_l$  mean reinforcement ratio of the y- and z-directions

$$\rho_l = \sqrt{\rho_{lz} \cdot \rho_{ly}} \leq 2.0 \cdot 0.5 \cdot f_{cd} / f_{yd}$$

$f_{cd}$  design value of cylinder concrete strength

$f_{yd}$  design value of yield stress of the reinforcing steel

$k_1$  empirical factor, the recommended value is  $k_1 = 0.1$

$\sigma_{cp}$  normal concrete stresses in the critical section

$V_{min}$   $(0.0525/\gamma_C) \cdot k^{3/2} \cdot f_{ck}^{1/2}$  for  $d \leq 600$  mm

$(0.0375/\gamma_C) \cdot k^{3/2} \cdot f_{ck}^{1/2}$  for  $d > 800$  mm, intermediate depths are linearly interpolated

In case of small ratios of the column perimeter to the effective depth ( $u_0/d$ ), the punching shear resistance has to be reduced.

If punching shear reinforcement is necessary, an adequate amount of punching reinforcement elements has to be placed in the slab. The length of the control perimeter  $u_{out}$  at which shear reinforcement is not required shall be calculated using the following expression:

$$u_{out} = \frac{\beta_{red} \cdot V_{Ed}}{V_{Rd,c} \cdot d}$$

$\beta_{red}$  reduced factor for taking into account the effects of eccentricity in perimeter  $u_{out}$

$V_{Rd,c}$  design punching shear resistance without punching reinforcement according to expression,

$C_{Rd,c}$  can be taken from the national guidelines for members not requiring design shear reinforcement (EN 1992-1-1, 6.2.2(1)), the recommended value is  $0.15/\gamma_c$

For the calculation of the shear resistance along the outer perimeter ( $u_{out}$ ) of edge and corner columns, a reduced factor  $\beta_{red}$  in combination with  $C_{Rd,c} = 0.15/\gamma_c$  can be used:

$$\beta_{red} = k_{\beta} \cdot l \geq 1.10$$

edge columns

$$k_{\beta} = \frac{1}{1.2 + \frac{\beta}{20} \cdot \frac{l_s}{d}}$$

corner columns

$$k_{\beta} = \frac{1}{1.2 + \frac{\beta}{15} \cdot \frac{l_s}{d}}$$

corner of wall

$$k_{\beta} = 1.0$$

end of wall

$$k_{\beta} = 1.0$$

$l_s$ : distance between the face of the column and the outermost stud

The punching shear resistance  $v_{Rd,c}$  for footings is defined according to the following equation:

$$v_{Rd,c} = \frac{C_{Rk,c}}{\gamma_c} \cdot k \cdot \left( 100 \cdot \rho_1 \cdot f_{ck} \right)^{1/3} \cdot \frac{2 \cdot d}{a}$$

$C_{Rk,c}$  0.15 for footings with  $a/d \leq 2.0$

0.18 for slender footings and ground slabs

$a$  the distance from the column face of the column to the control perimeter considered

## 5.2. Punching design of flat slabs and for footings

### 5.2.1. Slabs

It has to be distinguished between area C (adjacent to the column) and the area D (further than  $1.125 \cdot d$  from the column face). The double headed studs in the area C shall be dimensioned according to the following equation:

$$\beta \cdot V_{Ed} \leq V_{Rd,sy} = m_C \cdot n_C \cdot \frac{d_A^2 \cdot \pi \cdot f_{yk}}{4 \cdot \gamma_s \cdot \eta}$$

$m_C$  number of elements (rows) in the area C

$n_C$  number of studs of each element (row) in the area C

$d_A$  shaft diameter of the double-headed stud

$f_{yk}$  characteristic value of yield strength of the stud

$\gamma_s$  partial safety factor for steel ( $\gamma_s = 1.15$ )

$\eta$  factor to take into account the effective depth, interim values have to be interpolated:

$$\eta = \begin{cases} = 1.0 & \text{for } d \leq 200 \text{ mm} \\ = 1.6 & \text{for } d \geq 800 \text{ mm} \end{cases}$$

In the area D, the dimensioning of the studs is governed by the rules for positioning of the studs as given in clause 4.3.

The maximum punching shear resistance in the critical perimeter  $u_1$  is defined as a multiple value of the resistance of the slab without shear reinforcement:

$$V_{Rd,max} = 1.96 \cdot V_{Rd,c} \quad (\text{flat slabs})$$

$V_{Rd,c}$  is the calculated design value of the punching shear resistance, taking into account the relevant partial safety factors for material properties.

The favourable effect of normal compressive stresses on the maximum punching shear resistance  $V_{Rd,max}$  of the slab may not be included. If inclined pre-stressed tendons

influence the punching shear resistance negatively, the effect shall be included with the maximum value of the negative influence when dimensioning the studs. If inclined pre-stressed tendons increase the punching shear resistance, they have to be effective in both area C and area D.

### 5.2.2. Footings and ground slabs

In footings, the amount of double-headed studs shall be dimensioned according to the following equation:

$$V_{Ed,red} \leq V_{Rd,s} = f_{yd} \times A_{sw,0.8d}$$

Where  $V_{Ed,red} = V_{Ed} - V_{Ed} \cdot \frac{A_{crit}}{A}$

$f_{yd}$  design value of the yield strength of the double-headed studs

$A_{sw,0.8d}$  cross section of punching reinforcement in a distance between  $0.3 \cdot d$  and  $0.8 \cdot d$  from the column face

$A_{crit}$  area within the critical perimeter  $u$  in the iteratively determined distance  $a$  from the column face

$A$  area of the footing for ground slabs (area within the line of contraflexure for the bending moment in radial direction)

If outside of  $0.8 d$  further rows of studs are necessary, the required cross section may be determined as a shear reinforcement for 33 % of the design shear force taking into account the reduction by the soil pressure within the outermost row of double headed studs.

The maximum punching shear resistance along the critical perimeter  $u_{crit}$  is defined as a multiple value of the resistance of the footing without shear reinforcement:

$$V_{Rd,max} = 1.5 \cdot V_{Rd,c} \quad (\text{Footings and ground slabs})$$

$V_{Rd,c}$  is the calculated punching shear resistance, taking into account the relevant partial safety factors for material properties.



## 6. Design principles according to Russian normative documentation

Calculation of the slab without shear reinforcement occurs from “Method of Calculation of the beamless flat slabs”:

$$F \leq F_{b,ult}$$

$F$  – local load from the external forces acting on the slab

$F_{b,ult}$  – ultimate local load taken by the cross-section slabs concrete

Local load  $F$  calculated from:

1. In case of connection a flat slab with the column

$$F = N_2 - N_1 - F_q - F_{q1}$$

$N_1$  and  $N_2$  - longitudinal forces acting inside the columns above and below the slab in the cross-sections near the slabs edges

$F_q$  – normal local load from the relieve action of the load within an effective punching area contour

$F_{q1}$  – normal local load from the relieve action of the slabs dead load between the bottom and top columns within an effective punching area contour

$$F_q = q A_q$$

$q$ - load acting on the slab within the area  $A_q$

$A_q$  – punching area located at  $\frac{1}{2} h_0$  distance from the column face

$$A_q = h_0 * (a_1 + b_1 + h_0)$$

$a_1$  and  $b_1$ - cross-section dimensions of the column

$$F_{q1} = q_1 * A_{q1}$$

$q_1$ - load from the slabs dead load

$A_{q1}$ - slabs area located at  $\frac{1}{2} h_0$  distance from the column face

$$A_{q1}=(a_1+h_0)(b_1+h_0)$$

2. In case of connection of a flat slab with the column located above the slab

$$F=N_1+F_{q1}$$

$N_1$  – longitudinal force acting inside the column in the cross-sections near the slabs edge

$F_{q1}$  – normal local load from the filling up action of the slabs dead load under the column within an effective punching area contour

3. In case of connection of the column with the foundation slab

$$F=N_1-F_q+F_{q1}$$

$N_1$  - longitudinal force acting inside the column cross-section near the column face

$F_q$  – normal local load from the relieve action of the soil pressure within the area at  $h_0$  distance from the column face

$F_{q1}$  – normal local load from the filling up action of the slabs dead load under the column within an effective punching area contour

$F_{b,ult}$  ultimate load follows from

$$F_{b,ult}=R_{bt} \cdot U_b \cdot h_0$$

$U_b$  – effective area contour perimeter at  $\frac{1}{2} h_0$  distance from the column face

$$U_b=2(a+b)$$

a, b- slabs cross-section sides dimensions

$$a=a_1+h_0$$

$$b=b_1+h_0$$

$a_1$  and  $b_1$ - cross-section dimensions of the column

Effective cross-section slabs height

$$h_0 = 1/2 (h_{0x} + h_{0y})$$

$h_{0x}$  and  $h_{0y}$  effective height of the longitudinal slabs reinforcement for perpendicular axes X and Y

Design models in the Figure 6.1. Calculation of the slab with shear reinforcement occurs from:

$$F \leq F_{b,ult} + F_{sw,ult}$$

$F_{sw,ult}$  – ultimate load taken by the shear reinforcement of the slab

$$F_{sw,ult} = 0,8 q_{sw} U_s$$

$q_{sw}$  – shear reinforcement load per unit of the slabs length, arranged regularly around the perimeter  $U_s$  within the area at  $1/2 h_0$  distance from the both sides of the effective contour

---

$R_{sw}$  – design strength of the shear reinforcement bars

but

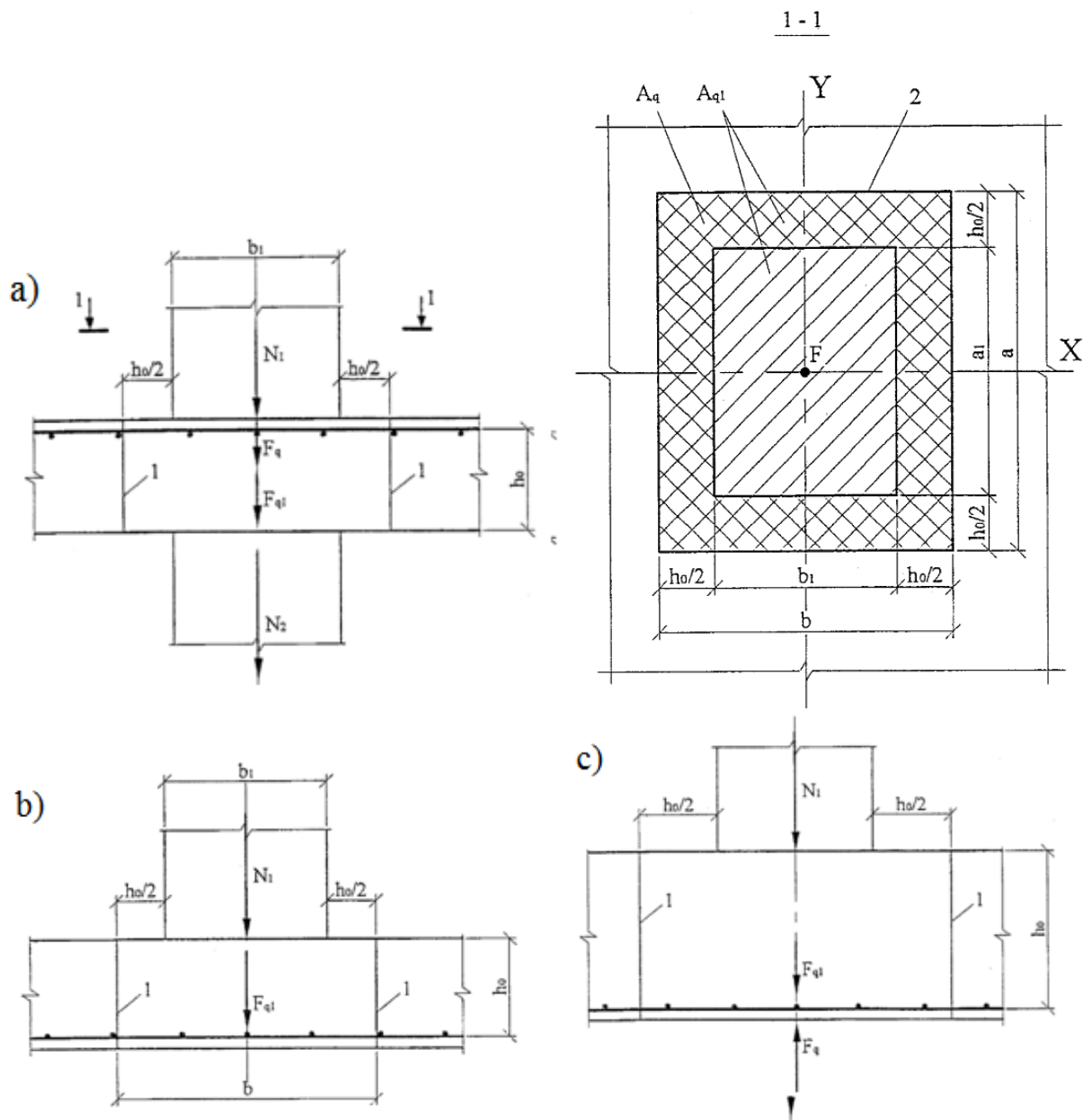
$A_{sw}$  – total area of the shear reinforcement at  $1/2 h_0$  distance from the effective slabs cross section

$s_w$  – step of the shear reinforcement bars

$U_s$  – perimeter of the effective slabs cross section placed at  $1/2 h_0$  distance from the column face ( $U_b$ )

Figure 6.1. Design scheme for reinforced concrete slab without shear reinforcement against punching

- a) The slab between the columns
  - b) The slab under the column
  - c) Connection of the column with the foundation slab
- 1- effective cross-section      2- effective cross- section contour



Total value of the loads  $F_{b,ult}+F_{sw,ult}$  accepted at maximum  $2F_{b,ult}$ . Shear reinforcement is taken into account in case when  $F_{sw,ult} \geq 0,5F_{b,ult}$ . Shear reinforcement is taken into account in case when slabs thickness not less than 180 mm.

Outside the area with shear reinforcement, punching design is made as for concrete section. In this case effective cross-section contour of the slab placed at  $\frac{1}{2} h_0$  distance from the last line of the shear reinforcement.

The maximum distance between the shear reinforcement bars is  $\frac{1}{3} h_0$  (in perpendicular to the effective contour sides direction). The first (from the column face) line of the shear reinforcement bars have to be in that limits:

- not closer than  $\frac{1}{3} h_0$
- not further than  $\frac{2}{3} h_0$

The minimum distance from the column face to the farthest bar is  $1,5h_0$ .

When shear-reinforcing bars are uniformly distributed inside the punching area the maximum distance between the bars is  $\frac{1}{4} h_0$  (in parallel to the effective contour sides direction).

The design scheme is shown in Figure 6.2.



Shear reinforcement might be tied or welded.

Tied reinforcement might be in the form of stirrups or singular studs. The minimum anchorage length is  $10 d_{sw}$  ( $d_{sw}$  – diameter of the shear reinforcement stud). Tied reinforcement is shown in Figure 6.3.

Welded reinforcement might be in the form of cage of reinforcement or steel studs connected by steel rail or bars. Anchorage realized by welded steel rail (minimum width is  $d_{sw}/2$ , minimum dimensions are  $3 d_{sw}$ ). Welded reinforcement is shown in Figure 6.4.

Also in a punching area shear reinforcement might be concentrated or radially placed from the center of the column. Concentrated shear reinforcement is shown in Figure 6.5.

Figure 6.3. Tied shear reinforcement

- a) Stirrups                      b) Singular studs

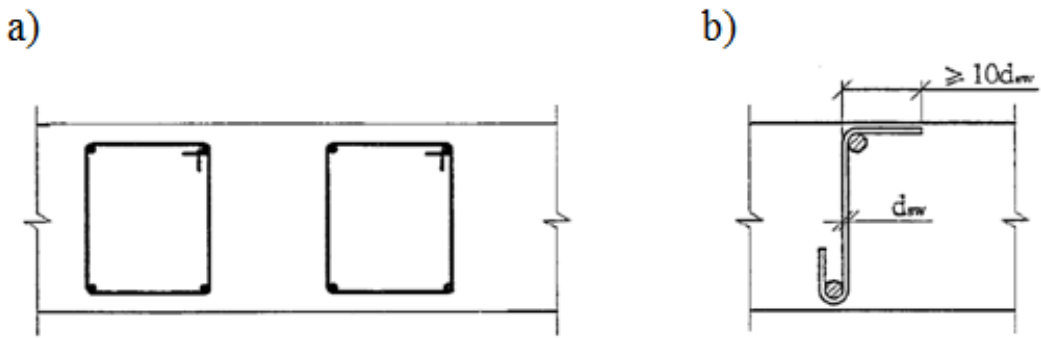


Figure 6.4. Welded shear reinforcement

a) Cage of reinforcement

b) Singular studs

c) Group of studs

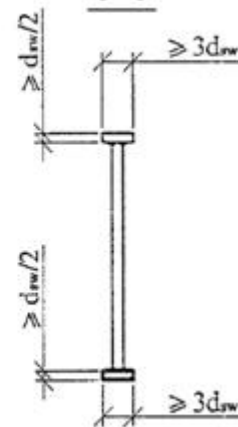
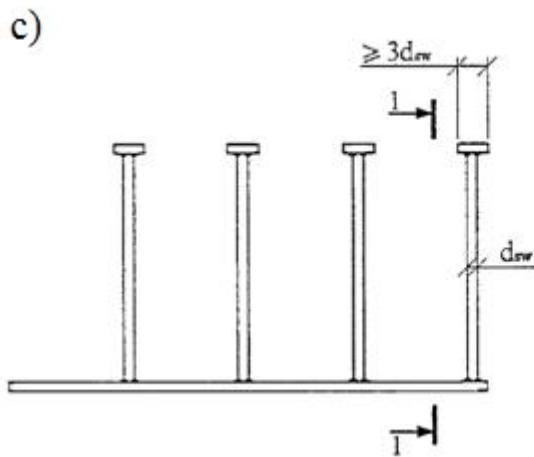
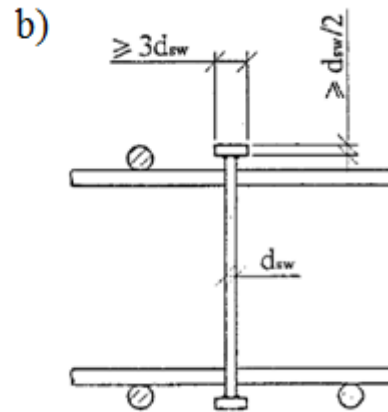
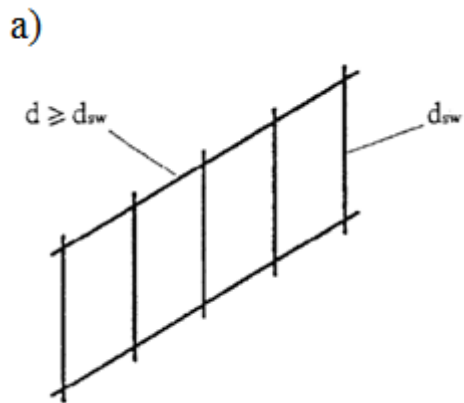
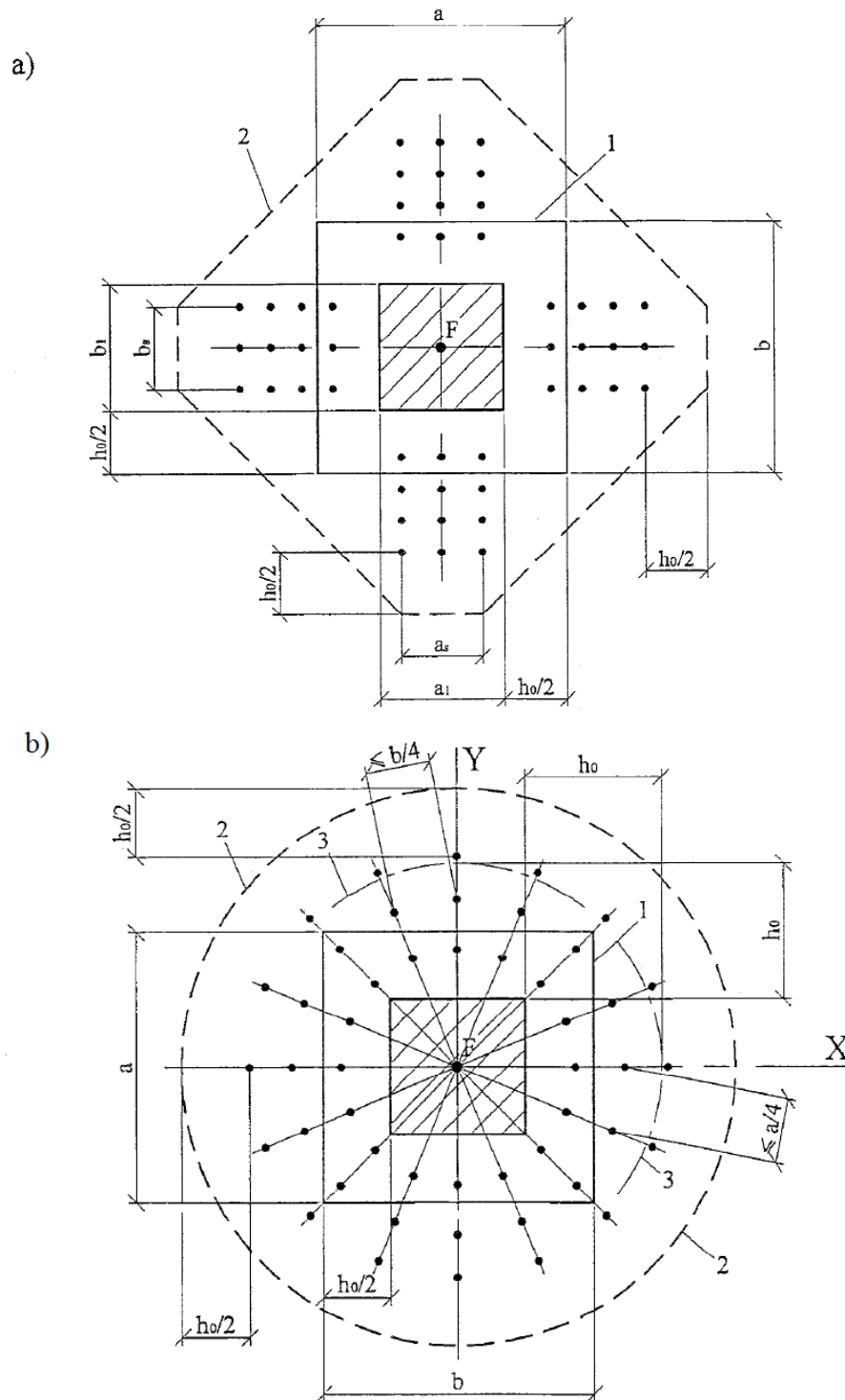


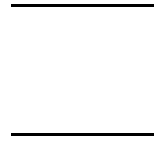


Figure 6.5. Design scheme for concentrated and radial directed reinforcement inside the slab

- 1- effective cross-section contour
- 2- effective cross- section contour without shear reinforcement
- 3- area within which maximum tangential distance is  $a/4$  ( $b/4$ )



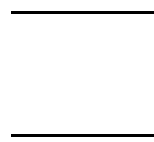
Concentrated shear reinforcement is calculated by the general rules hereinbefore. Effective shear reinforcement contour is accepted like many singular direct lines (parallel to the sides of the cross section of the column  $a_s$  and  $b_s$ ). Distributed loads  $q_{sw,a}$  and  $q_{sw,b}$  follows from Klovanich's and Shehovcov's "Punching of the concrete slabs":



, –shear reinforcement area within area at  $\frac{1}{2} h_0$  distance from the effective area contour with  $a_s$  and  $b_s$  sides.

In that case ultimate load is designed according this equation:

In case of radial direction of the shear reinforcement, cross-section at  $\frac{1}{2} h_0$  distance from the column face with sides dimensions  $a$  and  $b$  is considered. ). Distributed loads  $q_{sw,a}$  and  $q_{sw,b}$  follows from:



, –shear reinforcement area within area at  $\frac{1}{2} h_0$  distance from the effective area contour with  $a$  and  $b$  sides.

In that case ultimate load is designed according this equation:

In case of radially placed shear reinforcement, radial distance is taken into account like step of the shear reinforcement (if evenly distributed load). Inside the contour placed at  $h_0$  distance from the column face, the maximum tangential distance is  $a/4$  ( $b/4$ ).

## 7. Design examples

Design examples of the flat slab above the column and above the wall are presented in this chapter. Calculations are made according to the European Norms (ETA-13/0151) and according to Russian norms (SP 52-101-2004).

Because of creation Technical Approval for PSB it is possible to use special software developed by Peikko programmers for easier calculations. It is recommended to select the appropriate reinforcement with PSB using Peikko Designer individually for each separate case. Peikko Designer is design software freely available from [www.peikko.com](http://www.peikko.com).

The Russian Technical Approval allows to use Peikko Designer without any problems during the Authority Expertise.

### 7.1. Design example of the flat slab above the column according to ETA-13/0151

#### Input

Column dimension	a=	300 mm
	b=	300 mm
Concrete grade	C25/30	
Height of slab	h=	250 mm
Concrete cover bottom	c <sub>u</sub> =	25 mm
Concrete cover top	c <sub>o</sub> =	30 mm
	Φ <sub>x</sub> =	12 mm
Diameter of bending reinforcement	Φ <sub>y</sub> =	12 mm
Applied load	V <sub>Ed</sub> =	730 kN
Position of column		Internal column

Figure 7.1. Input data

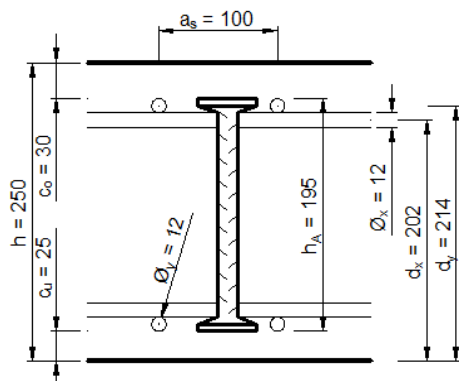
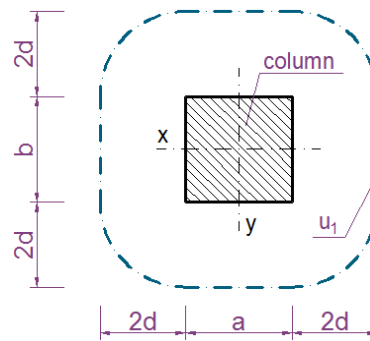


Figure 7.2. Design scheme



### Effective depth and bending reinforcement ratio

➤ Effective depth

$$d_y = h - c_o - \Phi_y / 2 = 214mm$$

$$d_x = h - c_o - \Phi_y - \Phi_x / 2 = 202mm$$

$$d = \frac{d_x + d_y}{2} = 208mm$$

➤ Bending reinforcement ratio

$$\rho_x = \frac{A_{s,x}}{a_{s,x} \cdot d_x} \cdot 100 = 0,56\%$$

$$\rho_y = \frac{A_{s,y}}{a_{s,y} \cdot d_y} \cdot 100 = 0,528\%$$

$$\rho_l = \sqrt{\rho_x \cdot \rho_y} = 0,544\%$$

### Basic control perimeter ( $u_1$ ) and perimeter of column ( $u_0$ ) (EN 1992-1-1 6.4.2)

$$u_1 = 2\pi \cdot 2 \cdot d + 2 \cdot a + 2 \cdot b = 3813,8 \text{ mm}$$

$$u_0 = 2 \cdot (a + b) = 1200 \text{ mm}$$

### Load increase factor $\beta$ (ETA-13/0151)

- Recommended value for internal column  $\beta = 1,10$

### Punching shear resistance of slab without punching reinforcement

$$v_{Rd,c} = \left\{ \begin{array}{l} C_{Rd,c} \cdot k_d \cdot \rho_l \cdot f_{ck}^{1/3} \\ \frac{0,0525}{\gamma_c} \cdot k_d^{3/2} \cdot 2 \cdot f_{ck}^{1/2} \end{array} \right\} = 0,603 \text{ N/mm}^2$$

$$k_d = \min \left\{ \begin{array}{l} 2,0 \\ 1 + \sqrt{\frac{200}{d}} \end{array} \right\} = 1,98$$

$$C_{Rd,c} = \frac{0,18}{\gamma_c} = 0,12$$

### Maximum resistance of slab with punching reinforcement

$$v_{Rd,max} = k_{max} \cdot v_{Rd,c} = 1,182 \text{ N/mm}^2$$

### Design value of the shear stress

$$v_{Ed} = \frac{\beta \cdot V_{Ed}}{u_1 \cdot d} = 1,012 \text{ N/mm}^2$$

## Load bearing capacity of the slab

$$v_{Rd,c} < v_{Ed} < v_{Rd,max}$$

0,603 < 1,012 < 1,182 PSB reinforcement can be used

## Dimension of stud

- Height of studs

$$h_A = h_d - c_u - c_o = 195mm$$

- Spacing between elements

$$s_1 = 150mm$$

$$s_0 = 75mm$$

- Check spacing

$$s_1 = 150 \Rightarrow \frac{s_1}{d} = 0,72 < 0,75$$

$$s_0 = 75 \Rightarrow \frac{s_0}{d} = 0,37 \begin{cases} < 0,5 \\ > 0,35 \end{cases}$$

## Number of studs and length of reinforcement elements

- Required length of outer perimeter

$$u_{out,req} = \frac{\beta_{red} \cdot V_{Ed}}{v_{Rd,c,out} \cdot d} = 7230mm$$

- Punching shear resistance of slab on outer perimeter

$$v_{Rd,c,out} = \max \left\{ \begin{array}{l} \frac{0,15}{\gamma_c} \cdot k_d \cdot \rho_l \cdot f_{ck}^{2/3} \\ \frac{0,0525}{\gamma_c} \cdot k_d^{3/2} \cdot f_{ck}^{1/2} \end{array} \right\} = 0,534 \text{ N/mm}^2$$

Required length of

reinforcement element

$$l_{s,req} = \frac{u_{out,req} - 2 \cdot (a + b)}{\pi \cdot 2} - 1,5d = 648mm$$

➤ Min. number of PSB in one element

$$n_{req} = \frac{l_{s,req} - s_0}{s_1} + 1 = 4,82 \Rightarrow n_{prov} = 5$$

➤ Provided length of one element

$$l_{s,prov} = s_0 + (n_{prov} - 1) \cdot s_1 =$$

675mm

➤ Provided control perimeter

$$u_{out,prov} = 2\pi \cdot (r_{s,prov} + 1,5d) + 2 \cdot a + 2 \cdot b =$$

7398mm

➤ Check outer control perimeter length

$$u_{out,req} \leq u_{out,prov} \quad l_{s,req} \leq l_{s,prov}$$

$$7230 < 7398 \quad 648 < 675$$

Figure 7.3. Control perimeters

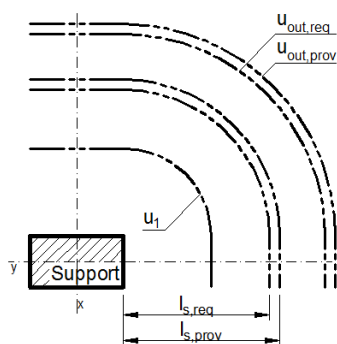
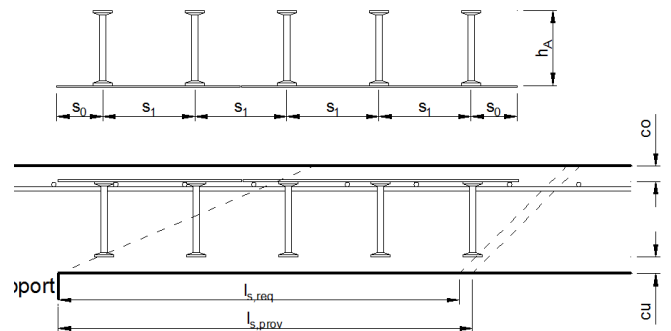


Figure 7.4. Reinforcement's arrangement



### Resistance of the slab in outer perimeter

$$v_{Ed,out} = \frac{\beta_{red} \cdot V_{Ed}}{u_{out,prov} \cdot d} = 0,521 N/mm^2$$

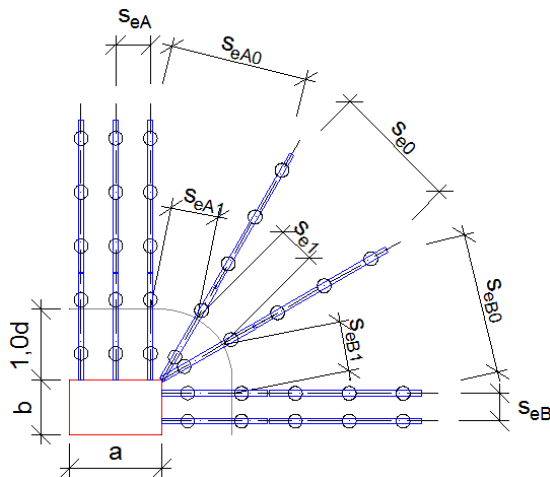
$$V_{Rd,c,out} \geq V_{Ed,out} \quad 0,534 > 0,521$$

## Number of reinforcement elements

### 1. Strength condition – $m_{c,req}$

$$m_{c,req} \geq \frac{\beta \cdot V_{Ed} \cdot \eta}{n_c \cdot A_{si} \cdot f_{yd}}$$

### 2. Spacing condition - $m_{spac}$



$$\max \begin{Bmatrix} s_{eA0} \\ s_{e0} \\ s_{eB0} \end{Bmatrix} \leq 3,5 \cdot d \quad \max \begin{Bmatrix} s_{eA} \\ s_{eA1} \\ s_{e1} \\ s_{eB1} \\ s_{eB} \end{Bmatrix} \leq 1,7 \cdot d$$

Table 4. Selection of the PSB Studs, example 1

Diameter of studs	10	12	14	16	20	25
$m_{c,req}$	12	9	7	5	3	2
$m_{c,spac}$	12	12	8	8	8	8
$m_{c,prov} = \max \begin{Bmatrix} m_{c,req} \\ m_{c,spac} \end{Bmatrix}$	12	12	8	8	8	8

### Total resistance of PSB (ETA-13/0151)

$$V_{Rd,sy} = m_c \cdot n_c \cdot \frac{d_A^2 \cdot \pi \cdot f_{yk}}{4 \cdot \gamma_s \cdot \eta} = 1060,3kN$$

$$\beta \cdot V_{Ed} \leq V_{Rd,sy}$$

$$803 < 1060,3$$

$$8xPSB-14/195-5/750 \quad (75/4 \cdot 150/75)$$

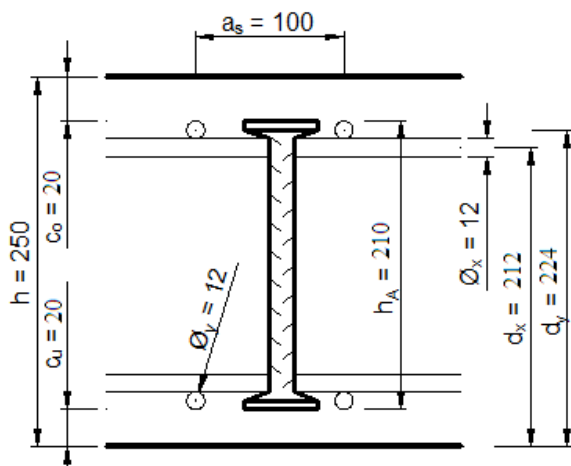


7.2. Design example of the flat slab above the column according to Application to SP 52-101-2003 “Reinforced concrete constructions without pre-stress or post-tension”

**Input**

Column dimension	a=	300 mm
	b=	300 mm
Concrete grade		B30
Height of slab	h=	250 mm
Concrete cover bottom	$c_u$ =	20mm
Concrete cover top	$c_o$ =	20 mm
	$\Phi_x$ =	12 mm
Diameter of bending reinforcement	$\Phi_y$ =	12 mm
Applied load	F =	730 kN
Position of column		Internal column

Figure 7.5. Input data



## Effective depth and bending reinforcement ratio

➤ Effective depth

$$h_{xy} = h - c_o - \Phi_y / 2 = 224mm$$

$$h_x = h - c_o - \Phi_y - \Phi_x / 2 = 212mm$$

$$h_0 = \frac{h_x + h_y}{2} = 218mm$$

➤ Bending reinforcement ratio

$$\rho_x = \frac{A_{s,x}}{a_{s,x} \cdot h_x} \cdot 100 = 0,53\%$$

$$\rho_y = \frac{A_{s,y}}{a_{s,y} \cdot h_y} \cdot 100 = 0,507\%$$

$$\rho_l = \sqrt{\rho_x \cdot \rho_y} = 0,518\%$$

## Basic control perimeter (u) and perimeter of column (u<sub>o</sub>) (EN 1992-1-1 6.4.2)

$$u = 4h_0 + 2 \cdot a + 2 \cdot b = 2072mm$$

$$u_0 = 2 \cdot (a + b) = 1200mm$$

According to SP 20.13330.2011 "Loads and efforts" recommended value of load increase factor  $\beta = 1,3$

Punching shear resistance of slab without punching reinforcement

$$F_{b,ult} = R_{bt} \cdot U \cdot h_0 \quad 519 \text{ kN}$$

### Necessary shear strength

$$F_{sw,ult} \geq \beta F - F_{b,ult} \quad 430 \text{ kN}$$

### Dimension of stud

- Height of studs

$$h_A = h_d - c_u - c_o = \quad 210 \text{ mm}$$

- Spacing between elements

$$s_1 = \quad 140 \text{ mm}$$

$$s_0 = \quad 70 \text{ mm}$$

- Check spacing

$$s_1 = 140 \Rightarrow h_0/3 < s_1 < 2h_0/3$$

$$72 \text{ mm} < 140 \text{ mm} < 145 \text{ mm}$$

$$s_0 = 70 \Rightarrow s_0 < h_0/3$$

$$70 \text{ mm} < 72 \text{ mm}$$

## Number of studs and length of reinforcement elements

- Required cross section of the shear reinforcement

$$F_{sw} = 0,8R_{sw}A_{sw}$$

$$R_{sw} = 0,8R_s < 300MPa$$

$$R_{sw} = 0,8 \cdot 500 = 400 \rightarrow R_{sw} = 300MPa$$

$$A_{sw} = F_{sw}/0,8R_{sw}$$

1792mm<sup>2</sup>

- Minimum distance from the column face to the farthest bar

$$1,5h_0$$

327mm

- Required cross section for 1 PSB element

$$A_{1sw} = A_{sw}/8$$

224mm<sup>2</sup>

- Accept PSB elements with diameter 12 mm, 4 studs per element

- 8xPSB – 12 / 210 – 4 / 560 (70/140/140/140/70)

- Check strength

$$\beta F < F_{b,ult} + F_{sw}$$

$$1,3 \cdot 730 < 519 + 300 \cdot 0,8 \cdot 8 \cdot 306$$

$$949kN < 519 + 587,5kN$$

648mm

### 7.3. Design example of the flat slab above the wall according to ETA-13/0151

#### Input

Wall dimension	a=	300 mm
Concrete grade	C25/30	
Height of slab	h=	320 mm
Concrete cover bottom	c <sub>u</sub> =	25 mm
Concrete cover top	c <sub>o</sub> =	30 mm
Diameter of bending reinforcement	Φ <sub>x</sub> =	16 mm
	Φ <sub>y</sub> =	16 mm
Applied load	V <sub>Ed</sub> =	600 kN
Position of column	End of wall	

Figure 7.5. Input data

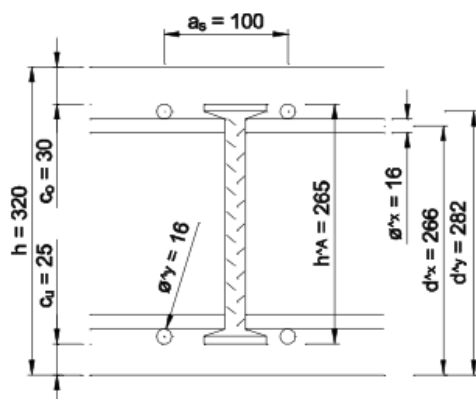
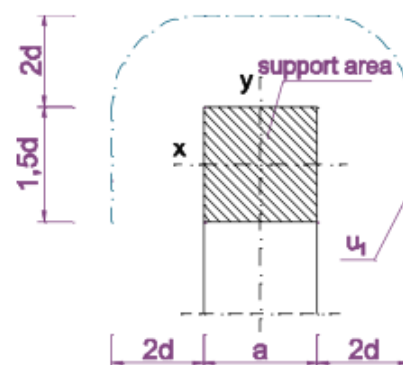


Figure 7.6. Design scheme



#### Effective depth and bending reinforcement ratio

- Effective depth

$$d_y = h - c_o - \Phi_y / 2 =$$

282mm

$$d_x = h - c_o - \Phi_y - \Phi_x / 2 = 266\text{mm}$$

$$d = \frac{d_x + d_y}{2} = 274\text{mm}$$

➤ Bending reinforcement ratio

$$\rho_x = \frac{A_{s,x}}{a_{s,x} \cdot d_x} \cdot 100 = 0,71\%$$

$$\rho_y = \frac{A_{s,y}}{a_{s,y} \cdot d_y} \cdot 100 = 0,76\%$$

$$\rho_l = \sqrt{\rho_x \cdot \rho_y} = 0,734\%$$

**Basic control perimeter ( $u_1$ ) and perimeter of column ( $u_0$ ) (EN 1992-1-1 6.4.2)**

$$u_1 = \pi \cdot 2 \cdot d + a + 2 \cdot 1,5 \cdot d = 2843\text{mm}$$

$$u_0 = a + 2 \cdot 1,5 \cdot d = 1122\text{mm}$$

**Load increase factor  $\beta$  (ETA-13/0151)**

➤ Recommended value for end wall  $\beta = 1,35$

Punching shear resistance of slab without punching reinforcement

$$v_{Rd,c} = \left\{ \begin{array}{l} \left[ \frac{f_{Rd,c} \cdot k_d \cdot \rho_l \cdot f_{ck}^{2/3}}{\gamma_c} \right] \\ \frac{0,0525}{\gamma_c} \cdot k_d^{3/2} \cdot 2 \cdot f_{ck}^{1/2} \end{array} \right. = 0,587 \text{ N/mm}^2$$

$$k_d = \min \left\{ \begin{array}{l} 2,0 \\ 1 + \sqrt{\frac{200}{d}} \end{array} \right\} = 1,854$$

$$C_{Rd,c} = \frac{0,18}{\gamma_c} =$$

0,12

### Maximum resistance of slab with punching reinforcement

$$v_{Rd,max} = k_{max} \cdot v_{Rd,c} = 1.15 \text{ N/mm}^2$$

### Design value of the shear stress

$$v_{Ed} = \frac{\beta \cdot V_{Ed}}{u_1 \cdot d} = 1,04 \text{ N/mm}^2$$

Load bearing capacity of the slab

$$v_{Rd,c} < v_{Ed} < v_{Rd,max} \quad 0,587 < 1,04 < 1,182 \quad \text{PSB reinforcement can be used}$$

### Dimension of stud

- Height of studs

$$h_A = h_d - c_u - c_o = 265 \text{ mm}$$

- Spacing between elements

$$s_1 = 200 \text{ mm}$$

$$s_0 = 100 \text{ mm}$$

- Check spacing

$$s_1 = 200 \Rightarrow \frac{s_1}{d} = 0,73 < 0,75$$

$$s_0 = 100 \Rightarrow \frac{s_0}{d} = 0,37 \begin{cases} < 0,5 \\ > 0,35 \end{cases}$$

## Number of studs and length of reinforcement elements

- Required length of outer perimeter

$$u_{out,req} = \frac{\beta_{red} \cdot V_{Ed}}{v_{Rd,c,out} \cdot d} = 6045mm$$

- Punching shear resistance of slab on outer perimeter

$$v_{Rd,c,out} = \max \left\{ \begin{array}{l} \frac{0,15}{\gamma_c} \cdot k_d \cdot \rho_l \cdot f_{ck}^{2/3} \\ \frac{0,0525}{\gamma_c} \cdot k_d^{3/2} \cdot f_{ck}^{1/2} \end{array} \right\} = \text{Required length of} \\ 0,489N/mm^2$$

reinforcement element

$$l_{s,req} = \frac{u_{out,req} - 2 \cdot (a + b)}{\pi \cdot 2} - 1,5d = 1157mm$$

- Min. number of PSB in one element

$$n_{req} = \frac{l_{s,req} - s_0}{s_1} + 1 = 6,29 \Rightarrow n_{prov} = 7$$

- Provided length of one element

$$l_{s,prov} = s_0 + (n_{prov} - 1) \cdot s_1 =$$

1300mm

- Provided control perimeter

$$u_{out,prov} = 2\pi \cdot (l_{s,prov} + 1,5d) + 2 \cdot a + 2 \cdot b =$$

6494mm

- Check outer control perimeter length

$$u_{out,req} \leq u_{out,prov} \quad l_{s,req} \leq l_{s,prov} \\ 6045 < 6494 \quad 1157 < 1300$$



Figure 7.7. Control perimeters

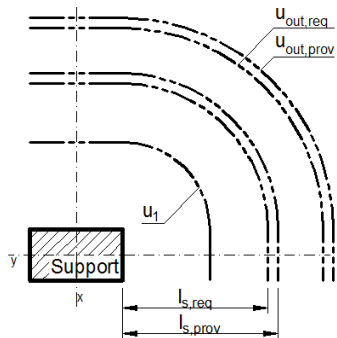
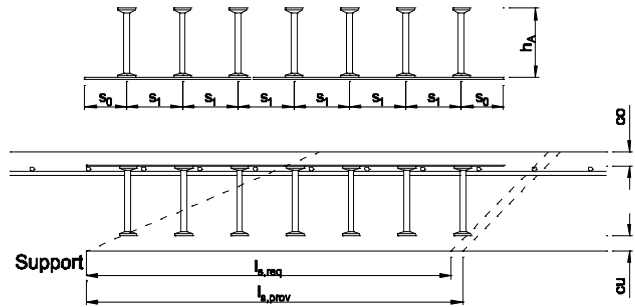


Figure 7.8. Reinforcement's arrangement



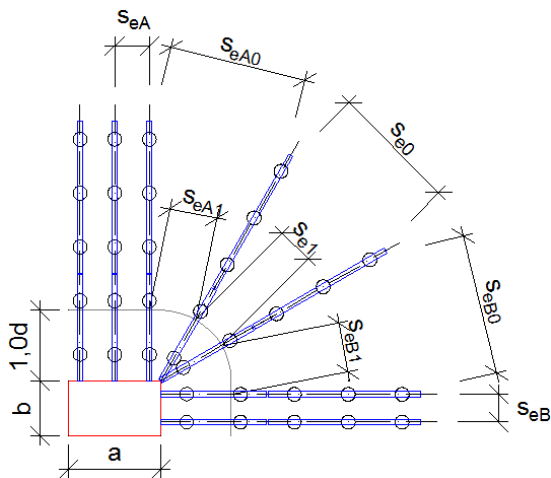
### Resistance of the slab in outer perimeter

$$v_{Ed,out} = \frac{\beta_{red} \cdot V_{Ed}}{u_{out,prov} \cdot d} = 0,455 MPa$$

$$v_{Rd,c,out} \geq v_{Ed,out} \quad 0,489 = 0,455$$

### Number of reinforcement elements (ETA-13/0151)

#### 1. Strength condition – $m_{c,req}$



$$m_{c,req} \geq \frac{\beta \cdot V_{Ed} \cdot \eta}{n_c A_{si} f_{yd}}$$

#### 2. Spacing condition - $m_{spac}$

$$\max \left\{ \begin{matrix} s_{eA0} \\ s_{e0} \\ s_{eB0} \end{matrix} \right\} \leq 3,5 \cdot d \quad \max \left\{ \begin{matrix} s_{eA} \\ s_{eA1} \\ s_{e1} \\ s_{eB1} \\ s_{eB} \end{matrix} \right\} \leq 1,7 \cdot d$$

Table 5. Selection of the PSB Studs, example 2

Diameter of studs	10	12	14	16	20	25
$m_{c,req}$	14	10	7	6	4	3
$m_{c,spac}$	7	7	7	7	7	7
$m_{c,prov} = \max \begin{cases} m_{c,req} \\ m_{c,spac} \end{cases}$	14	10	7	7	7	7

**Total resistance of PSB (ETA-13/0151)**

$$V_{Rd,sy} = m_c \cdot n_c \cdot \frac{d_A^2 \cdot \pi \cdot f_{yk}}{4 \cdot \gamma_s \cdot \eta} = 836,2kN$$

$$\beta \cdot V_{Ed} \leq V_{Rd,sy}$$

$$810 < 836,2$$

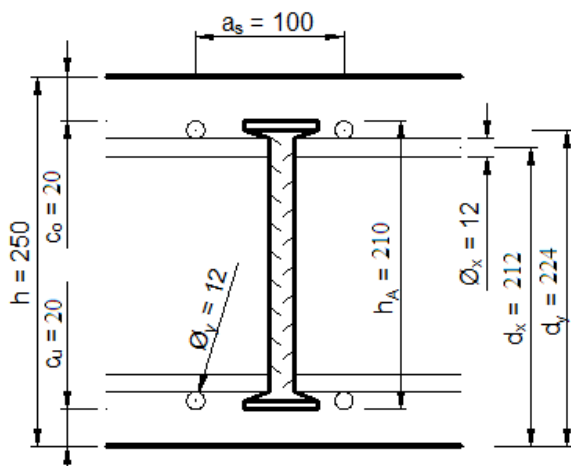
7xPSB-14/265-7/1400 (100/6\*200/100)

7.4. Design example of the flat slab above the wall according to Application to SP 52-101-2003 “Reinforced concrete constructions without pre-stress or post-tension”

**Input**

Column dimension	a=	300 mm
Concrete grade	B30	
Height of slab	h=	320mm
Concrete cover bottom	$c_u$ =	20mm
Concrete cover top	$c_o$ =	20 mm
	$\Phi_x$ =	16 mm
Diameter of bending reinforcement	$\Phi_y$ =	16 mm
Applied load	$V_{Ed}$ =	600 kN
Position of column	End of wall	

Figure 7.9. Input data



## Effective depth and bending reinforcement ratio

➤ Effective depth

$$h_{xy} = h - c_o - \Phi_y / 2 = 292mm$$

$$h_x = h - c_o - \Phi_y - \Phi_x / 2 = 276mm$$

$$h_0 = \frac{h_x + h_y}{2} = 284mm$$

➤ Bending reinforcement ratio

$$\rho_x = \frac{A_{s,x}}{a_{s,x} \cdot h_x} \cdot 100 = 0,686\%$$

$$\rho_y = \frac{A_{s,y}}{a_{s,y} \cdot h_y} \cdot 100 = 0,73\%$$

$$\rho_l = \sqrt{\rho_x \cdot \rho_y} = 0,708\%$$

## Basic control perimeter (u) and perimeter of column (u<sub>o</sub>) (EN 1992-1-1 6.4.2)

$$u = 2h_0 + 2 \cdot a + 2 \cdot 1,5 \cdot h_0 = 2020mm$$

$$u_0 = a + 2 \cdot 1,5h_0 = 1152mm$$

According to SP "Loads and efforts" recommended value of load increase factor  $\beta = 1,45$

Punching shear resistance of slab without punching reinforcement

$$F_{b,ult} = R_{bt} \cdot U \cdot h_0$$

619kN

### Necessary shear strength

$$F_{sw,ult} \geq \beta F - F_{b,ult}$$

251kN

### Dimension of stud

- Height of studs

$$h_A = h_d - c_u - c_o =$$

280mm

- Spacing between elements

$$s_1 =$$

140mm

$$s_0 =$$

70mm

- Check spacing

$$s_1 = 140 \Rightarrow h_0/3 < s_1 < 2h_0/3$$

$$95mm < 180mm < 190mm$$

$$s_0 = 90 \Rightarrow s_0 < h_0/3$$

$$90mm < 95mm$$

## Number of studs and length of reinforcement elements

- Required cross section of the shear reinforcement

$$F_{sw} = 0,8 \cdot 0,6 R_{sw} A_{sw}$$

$$R_{sw} = 0,8 R_s < 300 \text{MPa}$$

$$R_{sw} = 0,8 \cdot 500 = 400 \rightarrow R_{sw} = 300 \text{Mpa}$$

$$A_{sw} = F_{sw} / 0,8 \cdot 0,6 R_{sw}$$

$$1848 \text{mm}^2$$

- Minimum distance from the column face to the farthest bar

$$1,5h_0$$

$$426 \text{mm}$$

- Required cross section for 1 PSB element

$$A_{1,sw} = A_{sw} / 7$$

$$250 \text{mm}^2$$

- Accept PSB elements with diameter 12 mm, 7 studs per element

- 7xPSB – 12 / 280 – 7 / 540 (90/6\*180/90)

- Check strength

$$\beta F < F_{b,ult} + F_{sw}$$

$$1,45 \cdot 600 < 619 + 300 \cdot 0,8 \cdot 0,6 \cdot 7 \cdot 535$$

$$930 \text{kN} < 619 + 539,5 \text{kN}$$

## 7.5. Different dimensions of PSB rails for the flat slab above the column

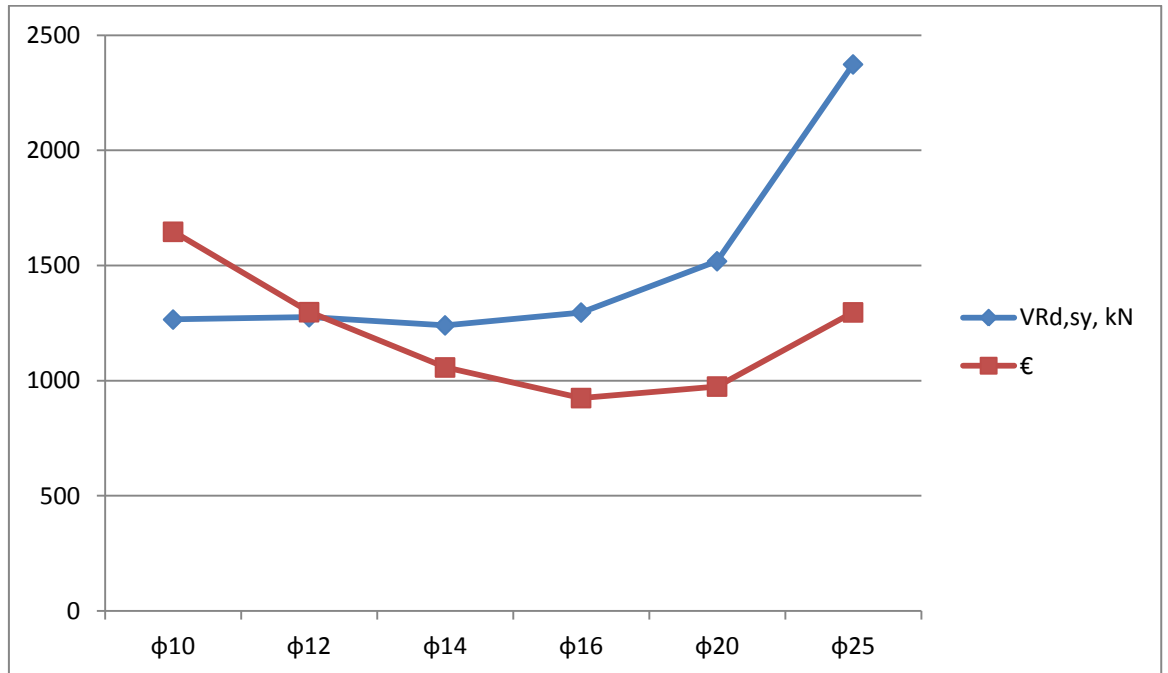
### Input

Column dimension	a=	300 mm
	b=	300 mm
Concrete grade	C25/30	
Height of slab	h=	320 mm
Concrete cover bottom	$c_u$ =	25 mm
Concrete cover top	$c_o$ =	30 mm
Reinforcement ratio	$\rho_x$ =	0,9 %
	$\rho_y$ =	0,9 %
Applied load	$V_{Ed}$ =	1050 kN
Position of column	Internal column	

Table 6. Variants of PSB-dimensions for example 5

PSB	$V_{Rd,sy}$ , kN	Amount of studs
20xPSB – 10 / 265 – 3 / 600 (100/200/200/100)	1265,9	60
14xPSB – 12 / 265 – 3 / 600 (100/200/200/100)	1276,0	42
10xPSB – 14 / 265 – 3 / 600 (100/200/200/100)	1240,6	30
8xPSB – 16 / 265 – 3 / 600 (100/200/200/100)	1296,3	24
6xPSB – 20 / 265 – 3 / 600 (100/200/200/100)	1519,1	18
6xPSB – 25 / 265 – 3 / 600 (100/200/200/100)	2373,6	18

Figure 7.10. Load capacity and price dependence on diameter of PSB for example 5



## 7.6. Different dimensions of PSB rails for the flat slab above the column

### Input

Column dimension	a=	300 mm
	b=	300 mm
Concrete grade		C25/30
Height of slab	h=	320 mm
Concrete cover bottom	$c_u$ =	25 mm
Concrete cover top	$c_o$ =	30 mm
Reinforcement ratio	$\rho_x$ =	0,7 %



$\rho_y = 0,7 \%$

Applied load

$V_{Ed} = 1050 \text{ kN}$

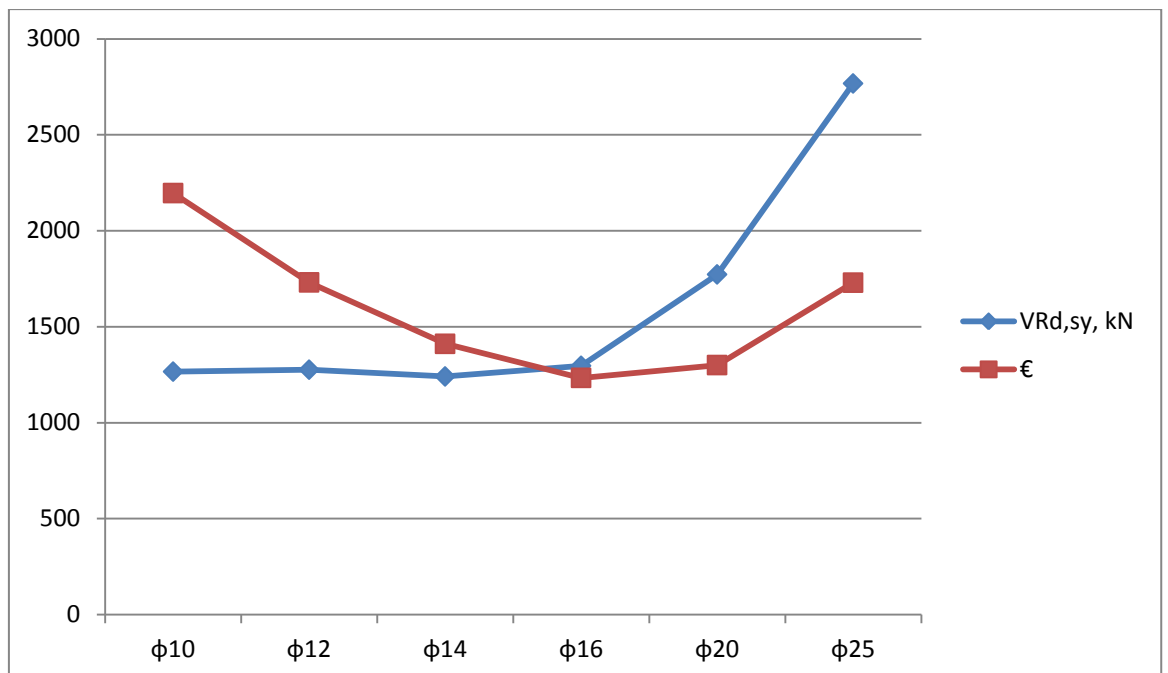
Position of column

Internal column

Table 7. Variants of PSB-dimensions for example 6

PSB	$V_{Rd,sy}$ , kN	Amount of studs
20xPSB – 10 / 265 – 4 / 800 (100/200/200/200/100)	1265,9	80
14xPSB – 12 / 265 – 4 / 800 (100/200/200/200/100)	1276,0	56
10xPSB – 14 / 265 – 4 / 800 (100/200/200/200/100)	1240,6	40
8xPSB – 16 / 265 – 4 / 800 (100/200/200/200/100)	1296,3	32
7xPSB – 20 / 265 – 4 / 800 (100/200/200/200/100)	1772,3	28
7xPSB – 25 / 265 – 4 / 800 (100/200/200/200/100)	2767,2	28

Figure 7.11. Load capacity and price dependence on diameter of PSB for example 6



## 8. Conclusion

Recent market conditions show that the modern infrastructure development is aimed to utilize the available resources to their optimum levels, may the resources be in terms of economy or in terms of space. When the space criterion comes into picture, the utility of the maximum space is the main concern of present day architects and designers. If plate thickness is decreased the available floor height is increased. Hence, flat plate gives an economical alternative in utilizing the internal space to maximum extent. Flat plates are necessary because of architectural demand for better illumination, lesser fire resistance of sharp corners present in the form of beams, simple and fast formwork, optimum use of space and this leads to the new concept in field of structural engineering as reinforced concrete flat plates. Flat plate is provided in malls and other structures where large beam free spaces are required. Shear walls are compulsory for flat plate construction when earthquake resistance is considered. If effect of lateral load analysis and some design features are to be studied; punching shear is a matter of concern for any structural designer.

Stud rails are an effective means of reinforcing flat concrete slabs against punching shear at column locations. They offer considerably reduced fixing times when compared to loose shear links and are designed using free calculation software available from stud rail manufacturers. Double-headed steel studs are supplied welded to flat steel rails, at the designed centres. The rails ensure stud alignment and the accurate vertical positioning of the studs within the slab.

The installation of conventional shear force stirrups is very complicated and time-consuming, as the stirrups must be sealed after the installation. Furthermore, it is often impossible to maintain the required concrete covering when using stirrups.

The PEIKKO PSB punching reinforcement is a powerful and economical solution of the punching reinforcement issue in punctiform supported flat slabs with concentrated load induction.

Punching describes the usually unexpected, local collapse of the reinforced concrete slab due to punching of a punctiform padding of the slab

The Peikko PSB punching reinforcement as a vertical tensile force component enables the construction of a spatial truss in the connection area of the column. Due to the almost perfect form fit of the bolt heads with the surrounding concrete, shear cracks are minimized and punching load is increased by 90% versus a non-reinforced slab. The increase versus stirrup reinforced slabs amounts to 26%.

During the analyzing part of work two different situations were calculated according to Russian and European Norms. In case of placed PSB-reinforcement into flat slab near internal column European norms recommend to place eight PSB-elements with five studs 14 mm diameter each meanwhile Russian norms recommend eight PSB-elements with four studs 12 mm diameter each.

In case of placed PSB-reinforcement into flat slab near end of wall European norms recommend to place seven PSB-elements with seven studs 14 mm diameter each meanwhile Russian norms recommend seven PSB-elements with seven studs 12 mm diameter each.

European norms are more reliable than Russian norms. Stud's diameters in Russian's norms calculations a little bit smaller than in European's norms, but height of the studs is bigger according Russian normative documents. The differences of the heights are because of odds between concrete cover layers. According to Russian norms concrete cover layers are 20 mm from both sides. According European norms concrete cover layers 25 mm and 30 mm.

All differences and results are summarized in Table 8 and 9

Table 8 Summarized data in case of placed near internal column

	Russian Norms	European norms
Applied load	730 kN	730 kN
Concrete grade	B30	C25/30
Concrete covers	20 mm and 20 mm	25 mm and 30 mm
Load increase factor	1,3	1,1
Effective depth	212 mm	202 mm
Space between studs	140/70 mm	150/75 mm
Diameter of the studs	12 mm	14 mm
Height of the studs	210	195
Amount of the studs per one element	4	5
Amount of the PSB-elements per one place of connection	8	8
PSB- elements	8xPSB-12/210-4/560 (70/3*140/70)	8xPSB-14/195-5/750 (75/4*150/75)

Table 9 Summarized data in case of placed near the wall

	Russian Norms	European norms
Applied load	600 kN	600 kN
Concrete grade	B30	C25/30
Concrete covers	20 mm and 20 mm	25 mm and 30 mm
Load increase factor	1,45	1,35
Effective depth	284	274 mm
Space between studs	180/90	200/100 mm
Diameter of the studs	12	14
Height of the studs	280	265
Amount of the studs per one element	7	7
Amount of the PSB-elements per one place of connection	7	7
PSB-elements	7xPSB-12/280-7/1260 (90/6*180/90)	7xPSB-14/265-7/1400 (100/6*200/100)

According to calculations the more bending reinforcement is arranged, the less amount of PSB punching reinforcement is needed. Therefore, punching prevention reinforcement will cost less if amount of arranged bending reinforcement is greater. In Figure 7.10 and 7.11. are observed dependences of load capacity and price on diameter of PSB Studs, punching resistance in kN, amount of money with coefficient for better illustration, In examples 5 and 6 the results of the calculations are the same: the best value for money in case of using PSB studs diameter 16 mm. It is the cheapest variant with middle punching resistance, Almost the same results for PSB studs diameter 20 mm but in case of 16 mm diameter studs are more uniformly distributed.

During the work in Peikko Russian Technical Approval was developed. Nowadays, the expertise is done and that document needs last corrections. Due to the developed approval customers can utilize PSB punching prevention reinforcement in Russia (without any problems with documentation or with inspection) and also calculate the slabs according to the method from Chapter 5. Moreover Russian designers could use special software (Peikko Designer) that makes easier to design punching forces and select the PSB reinforcement, and also allows to avoid human factor.

Information about main types, dimension, way of production and materials is included in the specification part of approval. Test results were utilized to go by the extra inspection.

The main goals of this thesis work are fully achieved and the main result is a presence of a full base of material necessary for the preparation of Russian Technical Approval.

## Figures

Figure 1.1. a. The most effective system- thin slabs, easier reinforcing b. Uneconomical system- height enlarge of the whole slab or the part thereof, p.5

Figure 3.1. Flat slab supported on columns and walls, p.9

Figure 3.2. Failure of a slab by punching, p.9

Figure 3.3. Flat slab reinforced with PSB, p.10

Figure 3.4. Shear stirrups, p.10

Figure 3.5. Shear heads, p.11

Figure 3.6. Shear stud rails, p.11

Figure 3.7.1. CUBO-N, p.12

Figure 3.7.2. CUBO-H, p.12

Figure 3.7.3. CUBO-D, p.12

Figure 3.7.4. CUBO-E, p.12

Figure 4.1. Peikko PSB Studs, p.14

Figure 4.2. PSB-Q element, p.14

Figure 4.3. PSB-Spacer, p.15

Figure 4.4. Elements for PSB-F, p.16

Figure 4.5. PSB double-headed studs with assembly profiles welded to the heads or PSB-F reinforcement element with clip-on plastic connectors, p.17

Figure 4.6. Maximum allowed spacing of studs in area C and D of flat slabs, p.23

Figure 4.7. Maximum allowed spacing of studs in slender and compact footings, p.23

Figure 6.1. Design scheme for reinforced concrete slab without shear reinforcement against punching, p.32

Figure 6.2. Design scheme for reinforced concrete slab with evenly distributed shear reinforcement, p.34

Figure 6.3. Tied shear reinforcement, p.35

Figure 6.4. Welded shear reinforcement, p.36

Figure 6.5. Design scheme for concentrated and radial directed reinforcement inside the slab, p.37

Figure 7.1. Input data, p.39

Figure 7.2. Design scheme, p.39

Figure 7.3. Control perimeters, p.42

Figure 7.4. Reinforcement's arrangement, p.42

Figure 7.5. Input data, p.44

Figure 7.6. Design scheme, p.44

Figure 7.7. Control perimeters, p.47

Figure 7.8. Reinforcement's arrangement, p.63

Figure 7.10. Load capacity and price dependence on diameter of PSB for example 5, p.65

Figure 7.11. Load capacity and price dependence on diameter of PSB for example 6, p.66



## Tables

Table 1. Geometry information, p.18

Table 2. Characteristic values of tensile resistances of PSB studs, p.22

Table 3. Geometry and mechanical strength, p.23

Table 4. Selection of the PSB Studs, example 1, p.53

Table 5. Selection of the PSB Studs, example 2, p.58

Table 6. Variants of PSB-dimensions for example 5, p.64

Table 7. Variants of PSB-dimensions for example 6, p.65

Table 8 Summarized data in case of placed near internal column, p.68

Table 9 Summarized data in case of placed near the wall, p.69

## References

Klovanich S., Shehovcov V., Punching of the concrete slabs, 2011, Odessa

SP 20.13330.2011 "Loads and efforts"

SP 52-101-2003 "Reinforced concrete constructions without pre-stress or post-tension"

Zalesov A., Chistyakov E., Method of Calculation of the beamless flat slabs, 2002, Moscow

Dr N. Subramanian, Evaluation and enhancing the punching shear resistance of flat slabs using HSC, The Indian Concrete Journal, April 2005 pp 31-37.

P.C.Varghese, Advanced Reinforced Concrete Design, Chapter 12 pp 211-239

Peikko PSB Brochure 2013

PSB Technical Manual 2013

ETA-13/0151

Muttoni A., Punching shear strength of reinforced concrete slabs without transverse reinforcement, ACI Structural Journal, V. 105, No. 4, 2008, pp. 440-450

EN 1992-1-1, Eurocode 2: Design of Concrete Structures—Part 1-1: General Rules and Rules for Buildings

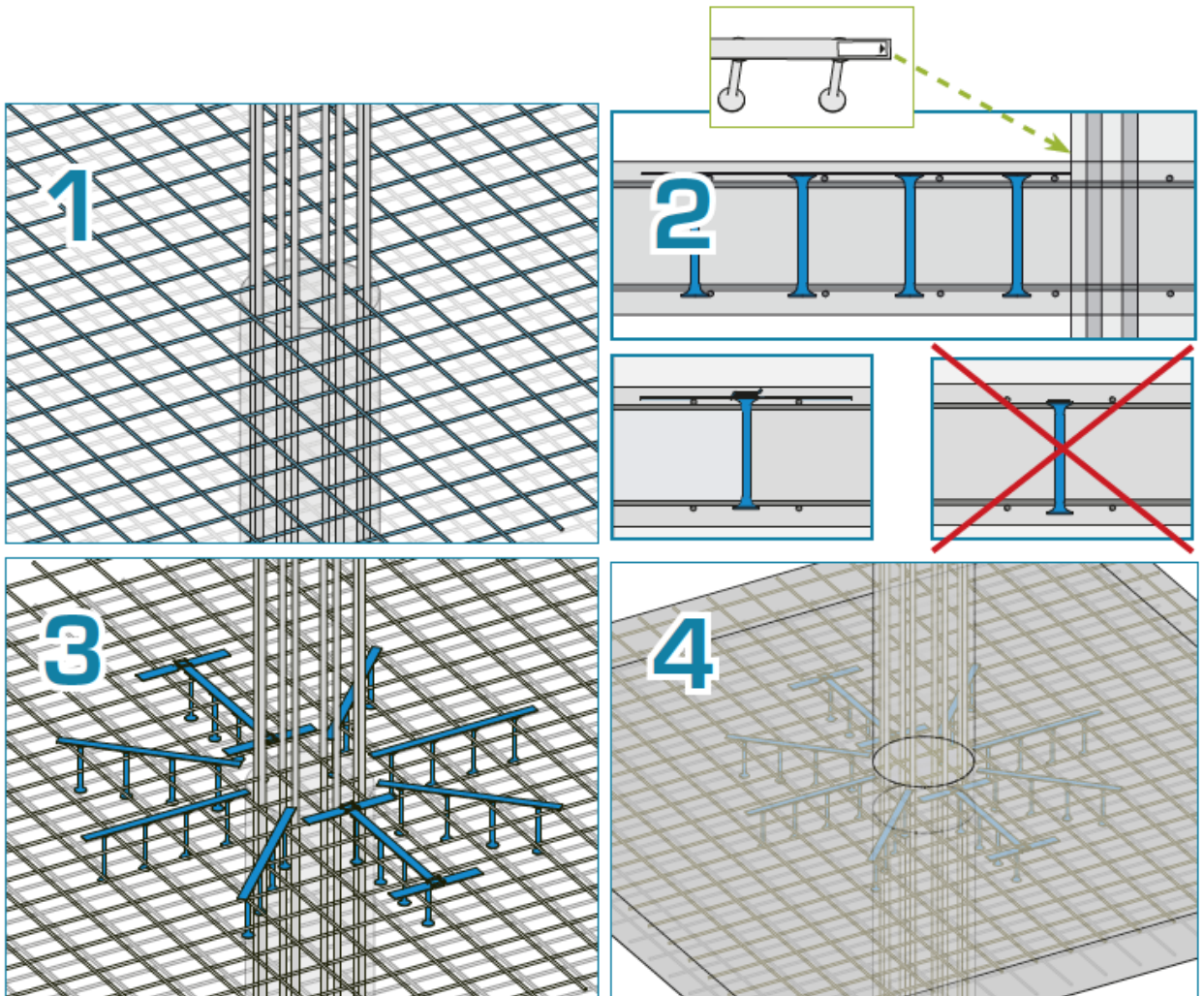
Vikunj K.Tilva, B. A. Vyas, Enhancing the punching shear resistance of flat plates using shear heads, shear stud rails and shear stirrups: a comparative study, International Journal of Earth Sciences and Engineering ISSN 0974-5904, Volume 04, No 06 SPL, October 2011, pp. 596-599

Shear studs in slab-column connections with rectangular column, 27th Conference on our world in concrete & structures, 2002, Singapore

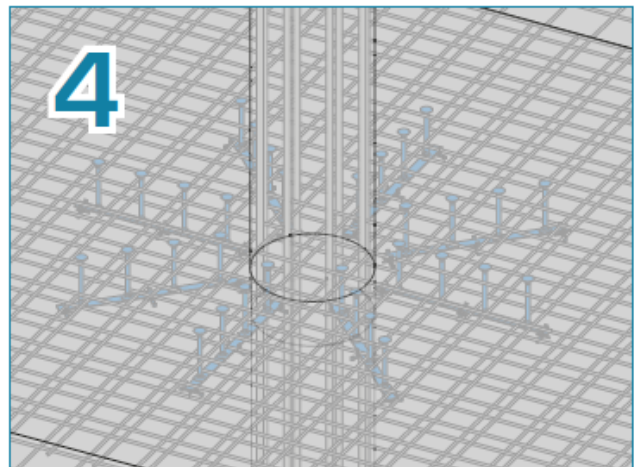
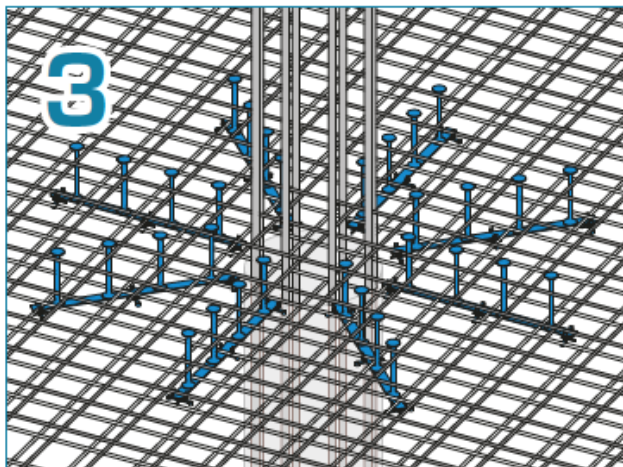
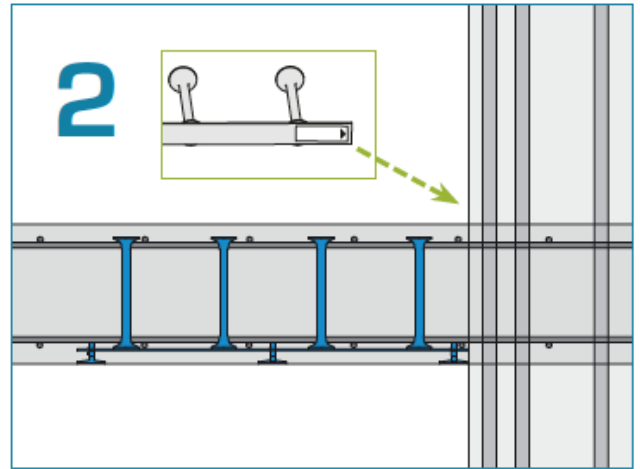
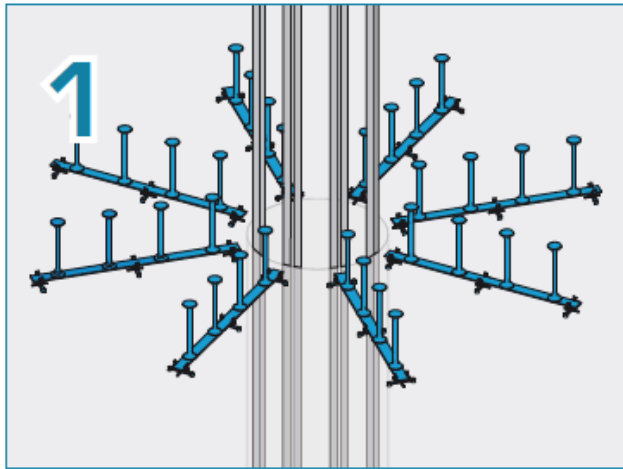
Evaluation of the Efficiency of Shear Studs for Punching Shear Resistance of Slab-Column Connections, University of Michigan, 11/26/2010

Aurelio Muttoni, performance of slabs reinforced by peikko psb studs, Concrete Connections 1/2013

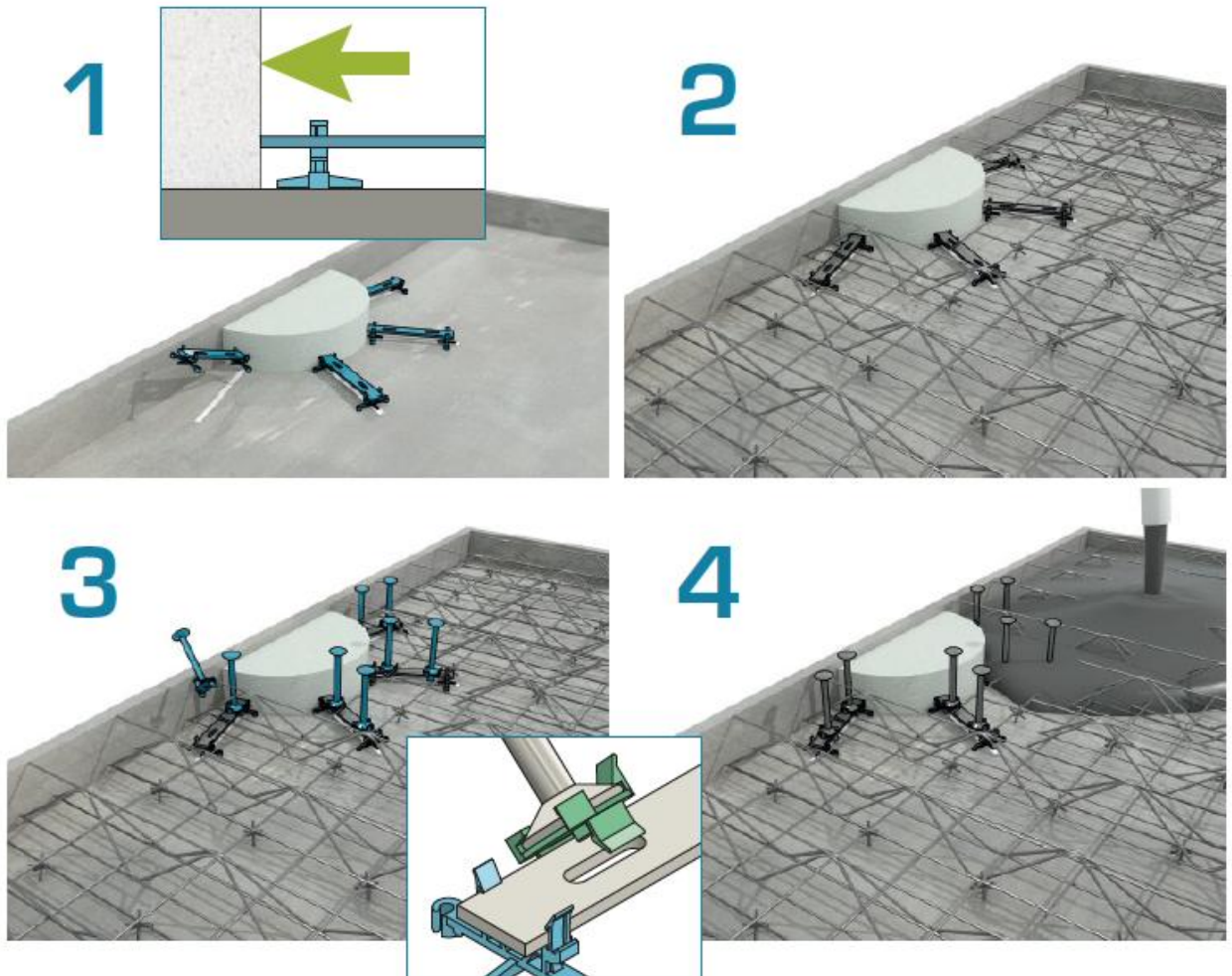
Cast in-situ monolithic slabs: Top installation



Cast in-situ monolithic slabs: Bottom installation



### Precast slabs- installation

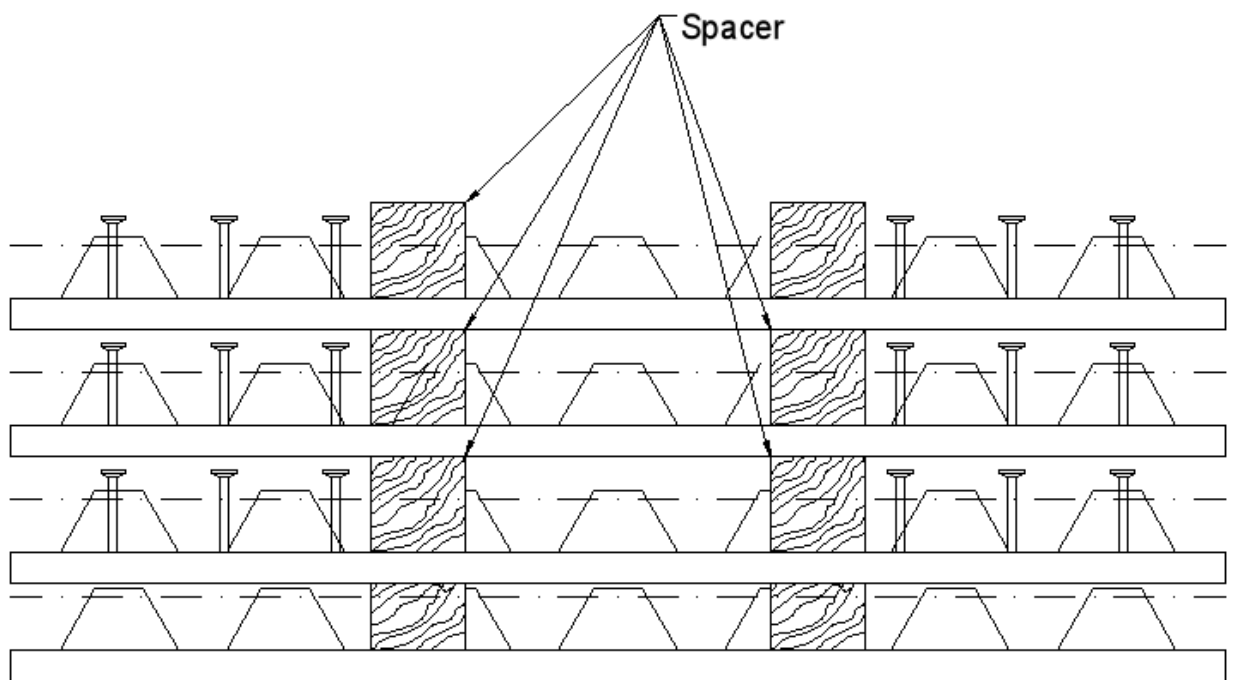


## PSB-F: Availability

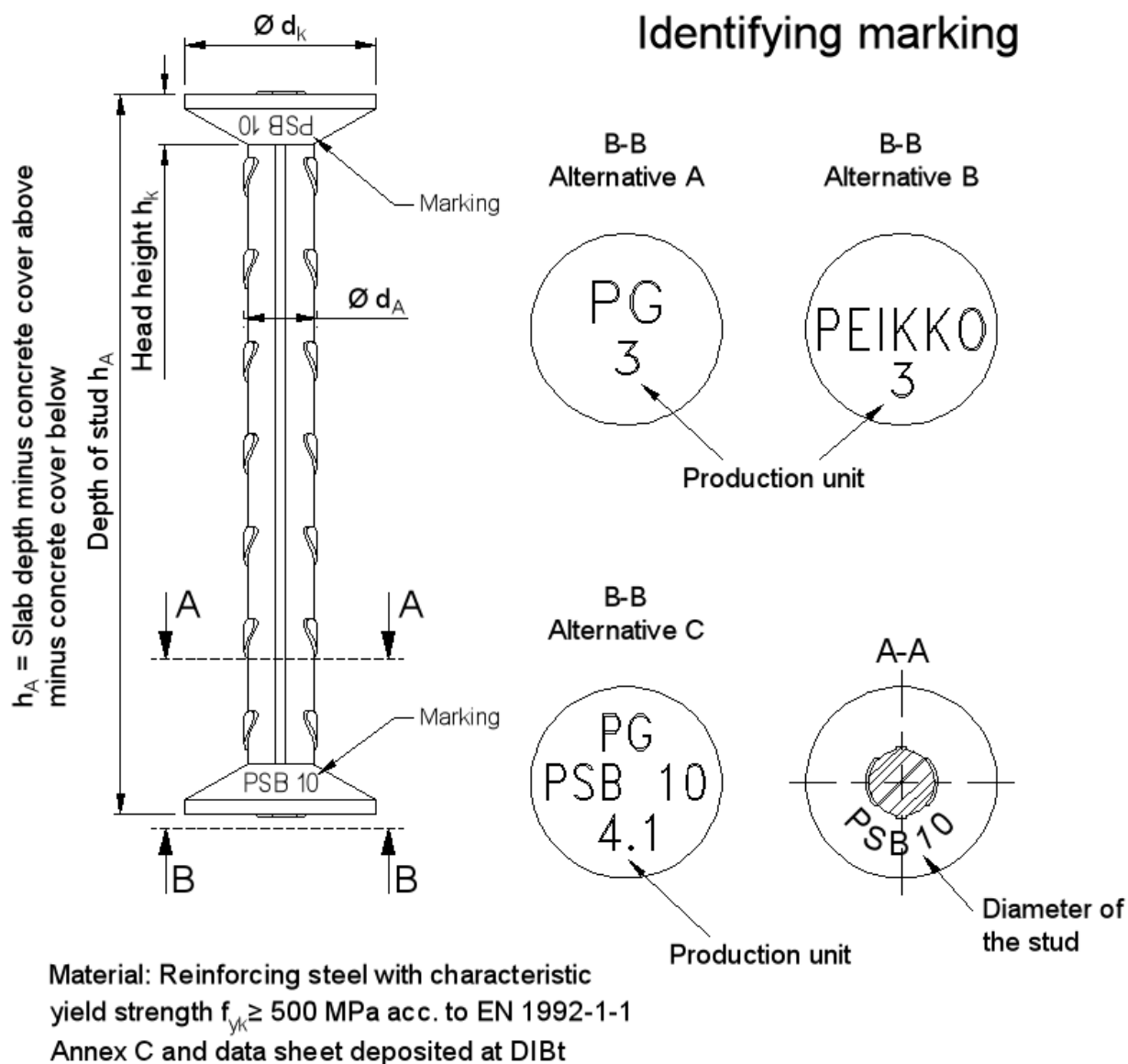
PSB-F studs, with connector, already pre-assembled						
ø /HA	ø 10	ø 12	ø 14	ø 16	ø 20	
125	PSB-F 10/125	PSB-F 12/125	PSB-F 14/125			
135	PSB-F 10/135	PSB-F 12/135	PSB-F 14/135	PSB-F 16/135		
145	PSB-F 10/145	PSB-F 12/145	PSB-F 14/145	PSB-F 16/145		
155	PSB-F 10/155	PSB-F 12/155	PSB-F 14/155	PSB-F 16/155		
165	PSB-F 10/165	PSB-F 12/165	PSB-F 14/165	PSB-F 16/165		
175	PSB-F 10/175	PSB-F 12/175	PSB-F 14/175	PSB-F 16/175		
185	PSB-F 10/185	PSB-F 12/185	PSB-F 14/185	PSB-F 16/185	PSB-F 20/185	
195	PSB-F 10/195	PSB-F 12/195	PSB-F 14/195	PSB-F 16/195	PSB-F 20/195	
205	PSB-F 10/205	PSB-F 12/205	PSB-F 14/205	PSB-F 16/205	PSB-F 20/205	
215	PSB-F 10/215	PSB-F 12/215	PSB-F 14/215	PSB-F 16/215	PSB-F 20/215	
225	PSB-F 10/225	PSB-F 12/225	PSB-F 14/225	PSB-F 16/225	PSB-F 20/225	
235	PSB-F 10/235	PSB-F 12/235	PSB-F 14/235	PSB-F 16/235	PSB-F 20/235	
245	PSB-F 10/245	PSB-F 12/245	PSB-F 14/245	PSB-F 16/245	PSB-F 20/245	
255	PSB-F 10/255	PSB-F 12/255	PSB-F 14/255	PSB-F 16/255	PSB-F 20/255	
265	PSB-F 10/265	PSB-F 12/265	PSB-F 14/265	PSB-F 16/265	PSB-F 20/265	
275	PSB-F 10/275	PSB-F 12/275	PSB-F 14/275	PSB-F 16/275	PSB-F 20/275	
285	PSB-F 10/285	PSB-F 12/285	PSB-F 14/285	PSB-F 16/285	PSB-F 20/285	
295	PSB-F 10/295	PSB-F 12/295	PSB-F 14/295	PSB-F 16/295	PSB-F 20/295	
305	PSB-F 10/305	PSB-F 12/305	PSB-F 14/305	PSB-F 16/305	PSB-F 20/305	
stock size			possible but not on stock			

PSB-F rails: 2-stud (A/B/A) or 3-stud (A/B/B/A)					PSB spacers	
B	L 2-stud-rail	[10 pcs/unit]	L 3-stud-rail	[10 pcs/unit]	cu	[100 pcs/unit]
100	200	PSB-F 200/2	300	PSB-F 300/3	15mm	PSB spacer 15
110	220	PSB-F 220/2	330	PSB-F 330/3	20mm	PSB spacer 20
120	240	PSB-F 240/2	360	PSB-F 360/3	25mm	PSB spacer 25
130	260	PSB-F 260/2	390	PSB-F 390/3	30mm	PSB spacer 30
140	280	PSB-F 280/2	420	PSB-F 420/3	35mm	PSB spacer 35
150	300	PSB-F 300/2	450	PSB-F 450/3	40mm	PSB spacer 40
160	320	PSB-F 320/2	480	PSB-F 480/3	45mm	PSB spacer 45
170	340	PSB-F 340/2	510	PSB-F 510/3		
180	360	PSB-F 360/2	540	PSB-F 540/3		
190	380	PSB-F 380/2	570	PSB-F 570/3		
200	400	PSB-F 400/2	600	PSB-F 600/3		
210	420	PSB-F 420/2	630	PSB-F 630/3		
220	440	PSB-F 440/2	660	PSB-F 660/3		

Example of storage and transport of precast elements with Peikko PSB studs

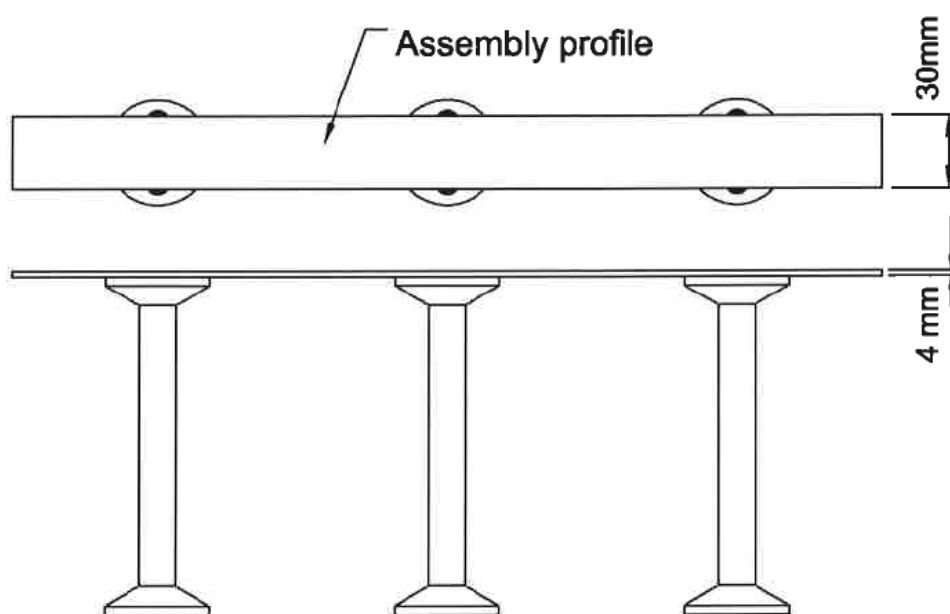


Geometry and marking of the Peikko PSB studs

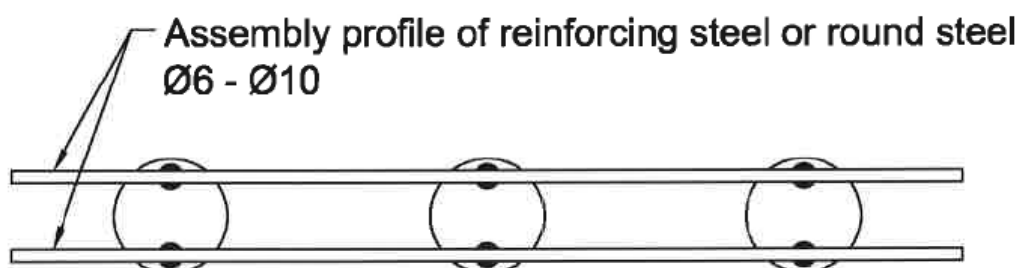




## Assembly profiles



Material: S235JR = 1.0038 (EN 10025-2:2004)

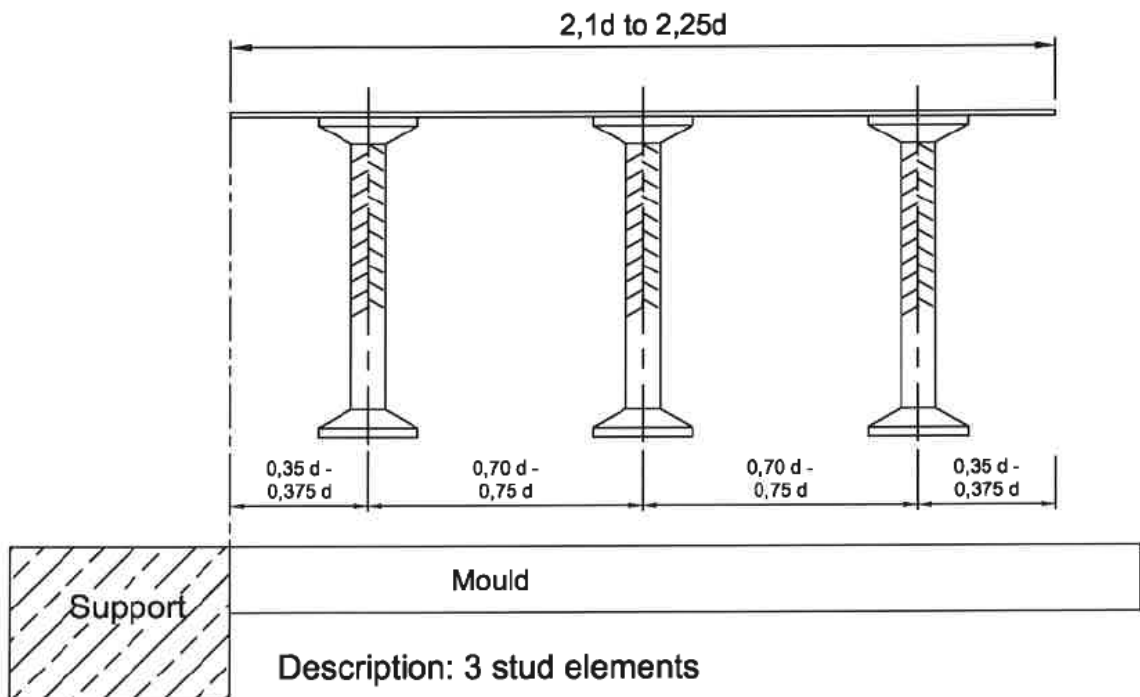
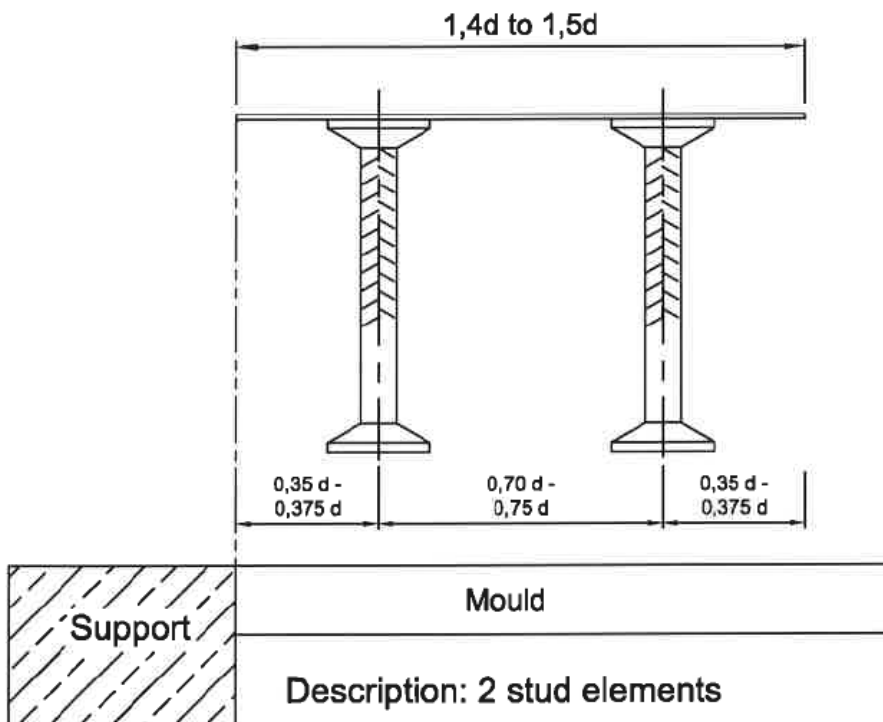


Material:

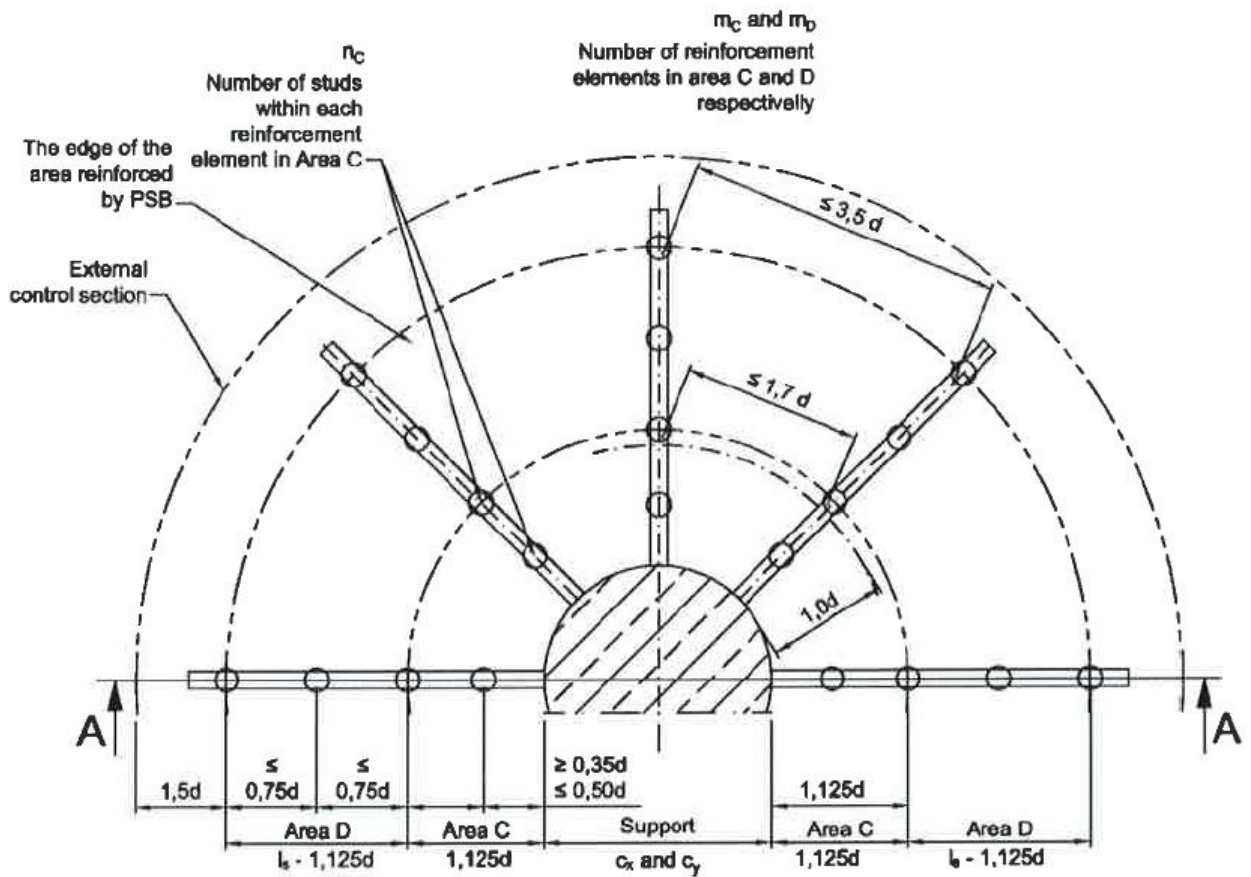
Reinf. steel: Reinforcing steel with characteristic yield strength  $f_{yk} \geq 500 \text{ MPa}$  acc. to EN 1992-1-1 Annex C and data sheet deposited at DIBt

Round steel: S235 JR (EN 10025-2:2004)  
A4 = 1.4571/1.4401/1.4404 (EN 10088-5:2009)

PSB standard elements



Arrangement of the elements

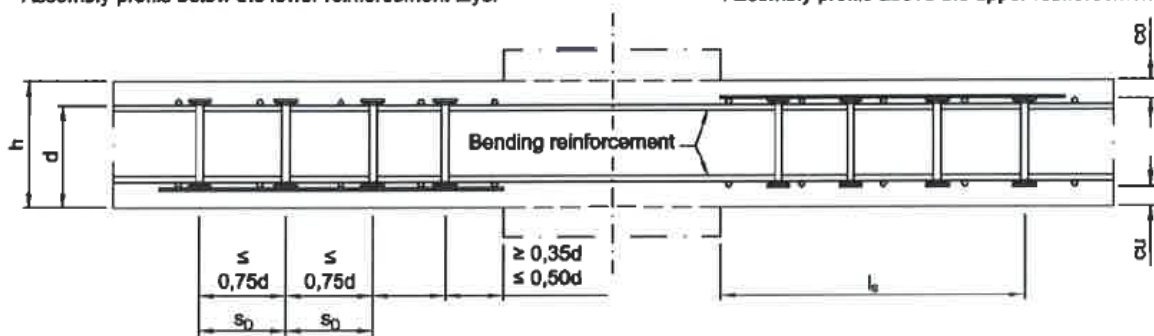


Cross section A-A  
"Bottom installation"

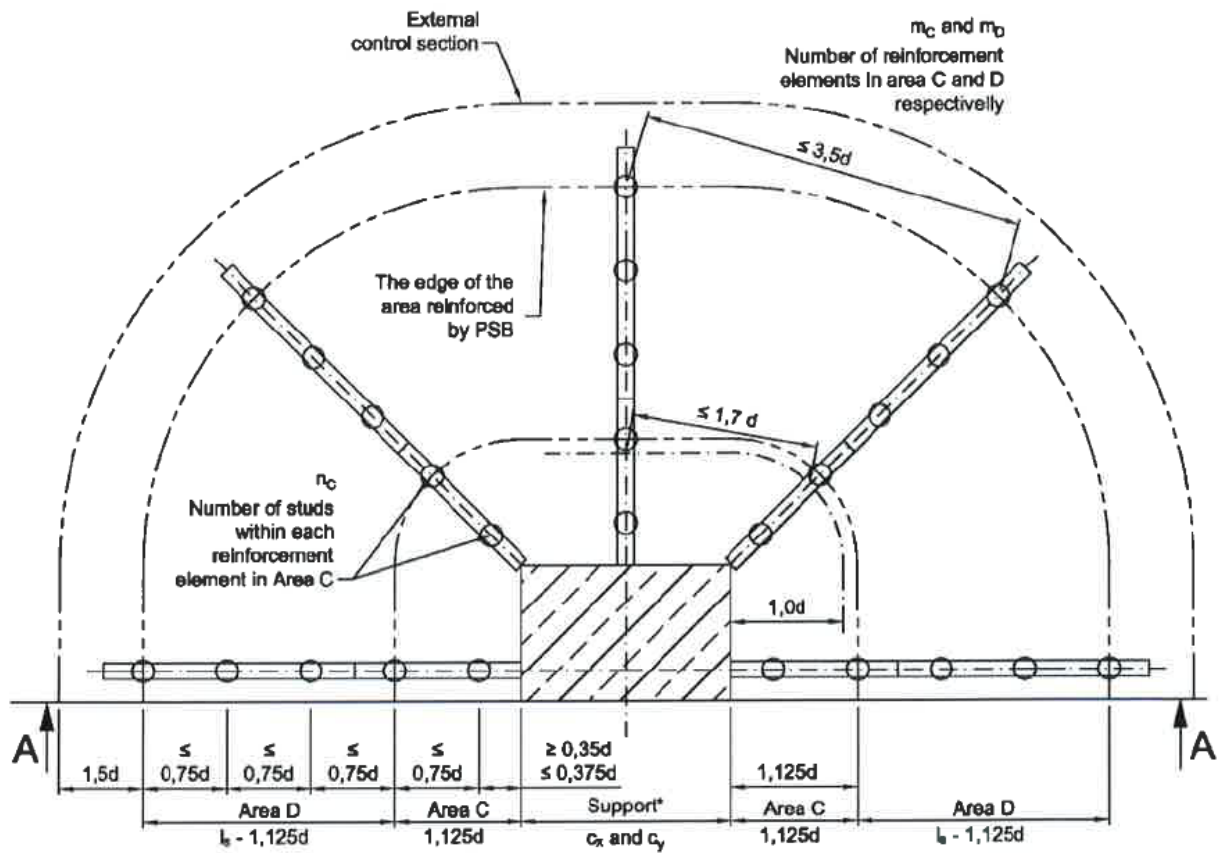
Assembly profile below the lower reinforcement layer

Cross section A-A  
"Top installation"

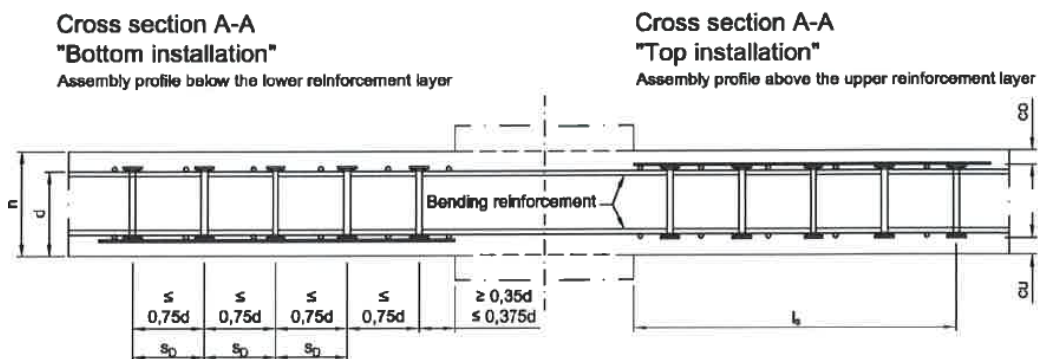
Assembly profile above the upper reinforcement layer



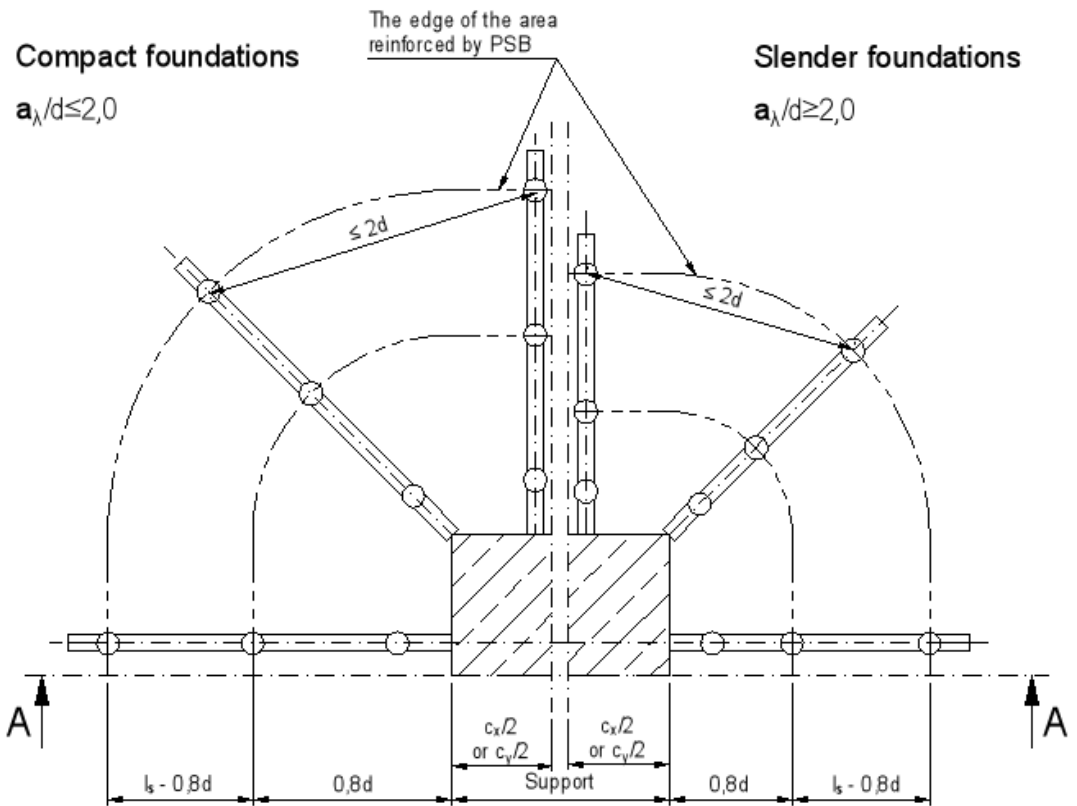
Concrete cover  $c_o$  and  $c_u$  according to EN 1992-1-1:2004, Section 4



\* Combination of 2 and 3 standard elements analogous with round columns

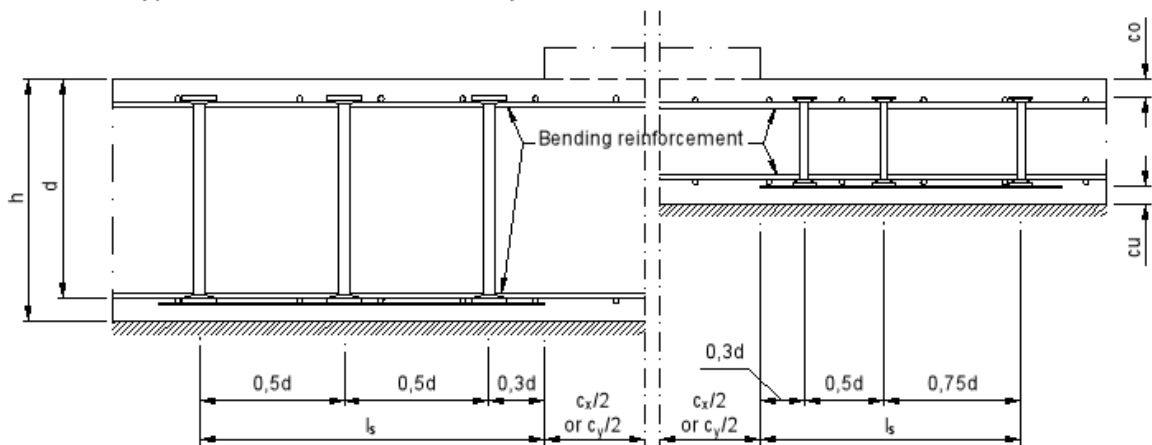


Concrete cover  $c_s$  and  $c_w$  according to EN 1992-1-1:2004, Section 4



**Cross section A-A**  
**"Bottom installation"**

Assembly profile below the lower reinforcement layer



Concrete cover  $c_0$  and  $c_u$  according to EN 1992-1-1:2004, Section 4

## Report of the fatigue test



Technische Universität München

## Report

No. RN-2012152  
 Dated 09.11.2012  
 Lab.-No. 12-2397

Subject/Project: PSB Reinforcement

Test: Fatigue tests on one-head-studs  
 according to CUAP 03.01/05

Client: Peikko Group Oy  
 PL 5301  
 70701 KUOPIO  
 Finland

Assigned: at 14.06.2012

Sampling: by Client

Testing Period: June to October 2012

The report consists of: 6 pages  
 2 enclosures

Fakultät für Bauingenieur-  
und Vermessungswesen

**Materialprüfungsamt  
 für das Bauwesen  
 Abteilung Massivbau**

Theresienstraße 90  
 Gebäude N6  
 80333 München  
 Germany

Tel +49.89.289.23000  
 Fax +49.89.289.23046

mpa@tum.de  
 www.mb.bv.tum.de  
 Your message  
 --

Workgroup  
 Concrete structures

Contact  
 PD Dr.-Ing. habil. Roland Niedermeier

Phone  
 +49.89.289.23031

E-Mail  
 roland.niedermeier@tum.de

Account Holder  
 Staatsbank Bayern  
 für TU München

Bank Account  
 Bayerische Landesbank  
 München  
 Bank Code: 24 866  
 BLZ 700 500 00

VAT Nr: DE811193231  
 Tax-Nr: 143/241/80037  
 SWIFT-Code: bylademm  
 IBAN:  
 DE1070050000000024866

This report is to be issued unabridged. Abridged or extracted versions of this publication require the prior authorisation of the MPA BAU Abteilung Massivbau.

## Content

1	Introduction .....	3
2	Test specimens .....	3
3	Testing .....	4
4	Results .....	6
	Annex .....	1

### Tables:

Table 1: Test plan .....	3
Table 2: Test parameters according to section 2.5.5 of CUAP 03.01/05, Version February 2012 .....	4
Table 3: Test parameters according to section 2.5.5 of CUAP 03.01/05, Version February 2012 .....	5

### Figures:

Figure 1: Condition of the specimens on delivery .....	3
Figure 2: Test setup and bedding of the stud head .....	4
Annex	
Figure 3: Packing slip of delivery date 11.06.2012 .....	1
Figure 4: Packing slip of delivery date 26.09.2012 .....	2

## 1 Introduction

On 14.06.2012 Peikko Group OY, Finland (Peikko). assigned the Materialprüfungsamt für das Bauwesen (MPA BAU) der Technischen Universität München to perform 15 fatigue tests on PEIKKO PSB one-head-studs according to section 2.5.5 of CUAP 03.01/05, Version February 2012.

The test is shown in Table 1.

**Table 1: Test plan**

Number of tests	Diameter of rebar [mm]
6	10
6	16
3	25

## 2 Test specimens

For testing 10 specimens for each diameter to be tested were supplied by Peikko. The packing slips are shown in the annex. Figure 1 shows the condition of the specimens on delivery. The specimens used for the tests were selected randomly of the entire delivery by MPA BAU. Specimens of diameter 10 mm and 25 mm were taken from delivery dated 11.06.2012, specimens of diameter 16 mm were taken from delivery dated 26.09.2012.



**Figure 1: Condition of the specimens on delivery**



### 3 Testing

The tests were performed according to section 2.5.5 of CUAP 03.01/05, Version February 2012 in different different calibrated testing machines. The test parameters are summarized in Table 2. The studs were embedded into a bearing device according to figure 2 of CUAP 03.01/05, Version February 2012. To reduce localized stresses and eccentric loading of the specimens the heads of the studs were bedded into a layer of quartz sand filled epoxy resin. Depending on the type of testing machine a spherical calotte was used additionally. The test setup and the bedding are shown in

Figure 2. The frequency of cyclic loading was about 7 Hz.

Table 2: Test parameters according to section 2.5.5 of CUAP 03.01/05, Version February 2012

Stress at upper load $\sigma_o$	Stress range $\Delta\sigma$	Number of load cycles N
$0.7 \cdot R_{e,Nom,bar}$	90 N/mm <sup>2</sup>	$2 \cdot 10^6$

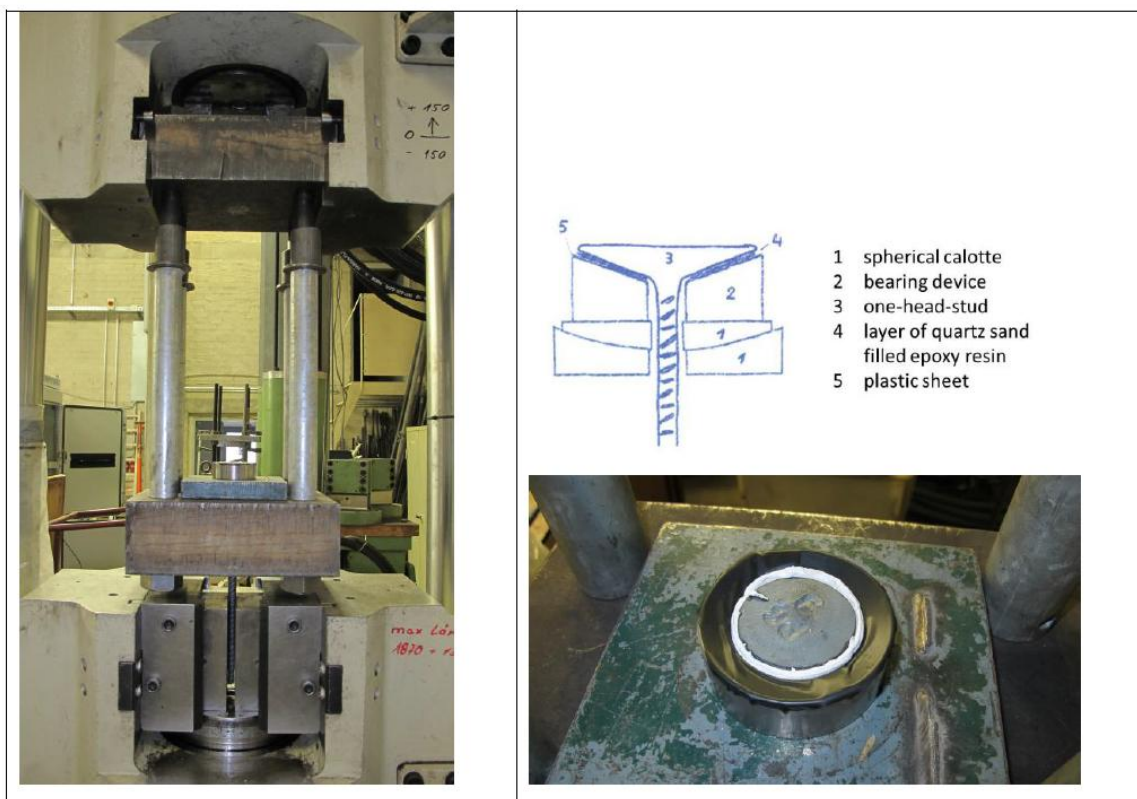


Figure 2: Test setup and bedding of the stud head

The tests listed in the following table were performed.

**Table 3: Test parameters according to section 2.5.5 of CUAP 03.01/05, Version February 2012**

Test No.	Diameter of rebar [mm]	Upper Load [kN]	Lower Load [kN]	Stress Range N/mm <sup>2</sup>	Number of Loadcycles
1	25	171.8	127.6	90	2·10 <sup>6</sup>
2	25	171.8	127.6	90	2·10 <sup>6</sup>
3	25	171.8	127.6	90	2·10 <sup>6</sup>
4	16	70.3	52.3	90	2·10 <sup>6</sup>
5	16	70.3	52.3	90	2·10 <sup>6</sup>
6	16	70.3	52.3	90	2·10 <sup>6</sup>
7	16	70.3	52.3	90	2·10 <sup>6</sup>
8	16	70.3	52.3	90	2·10 <sup>6</sup>
9	16	70.3	52.3	90	2·10 <sup>6</sup>
10	10	27.5	20.4	90	2·10 <sup>6</sup>
11	10	27.5	20.4	90	2·10 <sup>6</sup>
12	10	27.5	20.4	90	2·10 <sup>6</sup>
13	10	27.5	20.4	90	2·10 <sup>6</sup>
14	10	27.5	20.4	90	2·10 <sup>6</sup>
15	10	27.5	20.4	90	2·10 <sup>6</sup>

## 4 Results

All specimens reached  $2 \cdot 10^6$  load cycles without failure. No extraordinary deformation could be observed after cyclic loading.

PD Dr.-Ing. habil.  
Roland Niedermeier

Andreas Greubel

**Deltabeam Slovakia GmbH.**

SK-92591

Kráľová nad Váhom 660  
Kráľová nad Váhom  
Slovakia

ID.Nr.: 36718611

VAT-Nr.: SK2022302854

Company reg: OR Trnava-1945/T

Telephone: +421 31 773 2510

Telefax: +421 31 773 2520

Mobile:

Web: [www.peikko.com](http://www.peikko.com)

Delivery note:

**GE-2012-02-samples PSB**

Shipping date

11.6.2012

Delivery time:

13.6.2012

Consignee:



description:

**Samples to MPA**

Delivery address:

MPA TU München  
Theresienstr. 90/N6 (Ecke Arcisstr.)  
80333 München  
GERMANY**contact person: Andreas Greubel**

Laborleiter

tel.: 0049 8928923068

Pos	Text	Quantity		Weight	
		Pcs.	kg/Pcs	kg	
1	<b>PSB one-head-stud 10/300</b> heat nr.: 51646	10	0,21	2,1	
2	<b>PSB one-head-stud 16/400</b> heat nr.: HO501789	10	0,72	7,2	
3	<b>PSB one-head-stud 25/500</b> heat nr.: HO500733	10	2,27	22,7	
4					
5					
6					
7					
8					
9					
10					
11					
12					
gross amount		30 pcs		32 kg	

Technische Universität München  
 Materialprüfungsamt für das Bauwesen  
 Abteilung Massivbau

Annex of report Nr. RN-2012152 dated 09.11.2012, enclosure 2 of 2

Peikko Slovakia s.r.o.			
SK-92591	Kráľová nad Váhom 660 Kráľová nad Váhom Slovakia	ID.Nr.: 36718611 VAT-Nr.: SK2022302854 Company reg: OR Trnava-1945/T	Telephone: +421 31 773 2510 Telefax: +421 31 773 2520 Mobile: +421 911 250 698 Web: <a href="http://www.peikko.com">www.peikko.com</a>

Delivery note: **GE-2012-03-samples PSB**  
 Shipping date: 26.9.2012  
 Delivery time: 1.10.2012  
 Consignee:





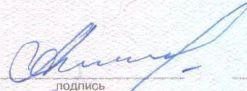

description: **Samples to MPA**

Delivery address: MPA TU München  
 Theresienstr. 90/N6 (Ecke Arcisstr.)  
 80333 München  
 GERMANY

contact person: **Andreas Greubel**  
 Laborleiter  
 tel.: 0049 8928923068

Pos	Text	Quantity		Weight
		Pcs.	kg/Pcs	kg
1	<b>PSB one-head-stud 16/400</b> heat nr.: 54024	10	0,72	7,2
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
gross amount		10 pcs		7 kg

## Example of GOST-R certificate

СИСТЕМА СЕРТИФИКАЦИИ ГОСТ Р ФЕДЕРАЛЬНОЕ АГЕНТСТВО ПО ТЕХНИЧЕСКОМУ РЕГУЛИРОВАНИЮ И МЕТРОЛОГИИ	
	<b>СЕРТИФИКАТ СООТВЕТСТВИЯ</b>
№ РОСС RU.МЛ17.Н00155	Срок действия с 23.06.2010 по 22.06.2013
	№ <b>0140994</b>
<b>ОРГАН ПО СЕРТИФИКАЦИИ</b> РОСС RU.0001.11МЛ17	
ПРОДУКЦИИ ООО "ЭТАЛОН-ТЕСТ" 117042, Россия, г. Москва, ул. Изюмская, д. 46, тел. (495) 645-80-61	
<b>ПРОДУКЦИЯ</b> Строительные металлические арматурные элементы для плит перекрытий, балконов и лоджий Reikko-NIRO ТКМ/ТКА 2-9 ТУ 5290-001-94677387-2010 серийный выпуск.	код ОК 005 (ОКП): 52 8590
<b>СООТВЕТСТВУЕТ ТРЕБОВАНИЯМ НОРМАТИВНЫХ ДОКУМЕНТОВ</b> ТУ 5290-001-94677387-2010	
	код ТН ВЭД России:
<b>ИЗГОТОВИТЕЛЬ</b> ООО «Пейкко». ИНН: 7841340350 197348, Санкт-Петербург, Коломяжский пр., 10, Литера Ф. Телефон (812) 329-07-04 факс (812) 329-07-04	
<b>СЕРТИФИКАТ ВЫДАН</b> ООО «Пейкко». ИНН: 7841340350 197348, Санкт-Петербург, Коломяжский пр., 10, Литера Ф, Россия Телефон (812) 329-07-04, факс (812) 329-07-04	
<b>НА ОСНОВАНИИ</b> протокола сертификационных испытаний № 047/06 от 22.06.2010 г. Испытательный центр ЗАО "ЦС "Композит-Тест", рег. РОСС RU.0001.21АЮ48, адрес 141070, Россия, Московская область, г. Королев, ул. Пионерская, 4.	
<b>ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ</b> Схема сертификации – 3.	
	Руководитель органа  подпись
Эксперт	 подпись
	Е. О. Азарова инициалы, фамилия В. С. Митрохин инициалы, фамилия
Сертификат не применяется при обязательной сертификации	
<small>Бланк изготовлен ЗАО "ОПЦИОН" (лицензия № 05-05-09/ОСЗ ФНС РФ уровень В) тел. (495) 648 6068, 608 7617, г. Москва, 2009 г.</small>	

## Example of the title page of Russian Technical Approval

ООО «Пейкко»

ОКП 52 8590 Группа Ж33

СОГЛАСОВАНО: УТВЕРЖДАЮ


 Генеральный директор  
 ООО «ЭГАДОН»  
 Салиев К. Р.  
 «20» июня 2010 г.


 Генеральный директор  
 ООО «Пейкко»  
 М.Е. Пироженко  
 «20» июня 2010 г.

Строительные металлические элементы с бетонным опорным элементом для  
 плит, перекрытий балконов и лоджий  
 Peikko-NIRO ТКМ/ТКА 2-9

Технические условия

ТУ 5290-001-94677387-2010

Дата введения в действие «20» июня 2010 г.

ФЕДЕРАЛЬНОЕ АГЕНТСТВО ПО  
 ТЕХНИЧЕСКОМУ РЕГУЛИРОВАНИЮ  
 И МЕТРОЛОГИИ  
 Орехово-Зуевский филиал  
 ФГУ «Меделеевский ЦСМ»

ЗАРЕГИСТРИРОВАН *КЛП*  
 № 001937 от 28.06.2010 г.

г. Санкт-Петербург  
2010

Title page for Peikko PSB reinforcement

**Общество с ограниченной ответственностью  
«Пейкко»**

ОКП 52 8590

Группа Ж 34

**СОГЛАСОВАНО:**

Зам. директора ЦНИИСК  
им. В.А.Кучеренко  
И. И. Ведяков  
« 19 » января 2013 г.

**УТВЕРЖДАЮ:**

Генеральный директор  
ООО «Пейкко»  
М. Е. Пироженов  
« 19 » января 2013 г.

**ТЕХНИЧЕСКИЕ УСЛОВИЯ**

**«Поперечная арматура PSB PEIKKO»**  
для дополнительного вертикального армирования  
железобетонных элементов на продавливание

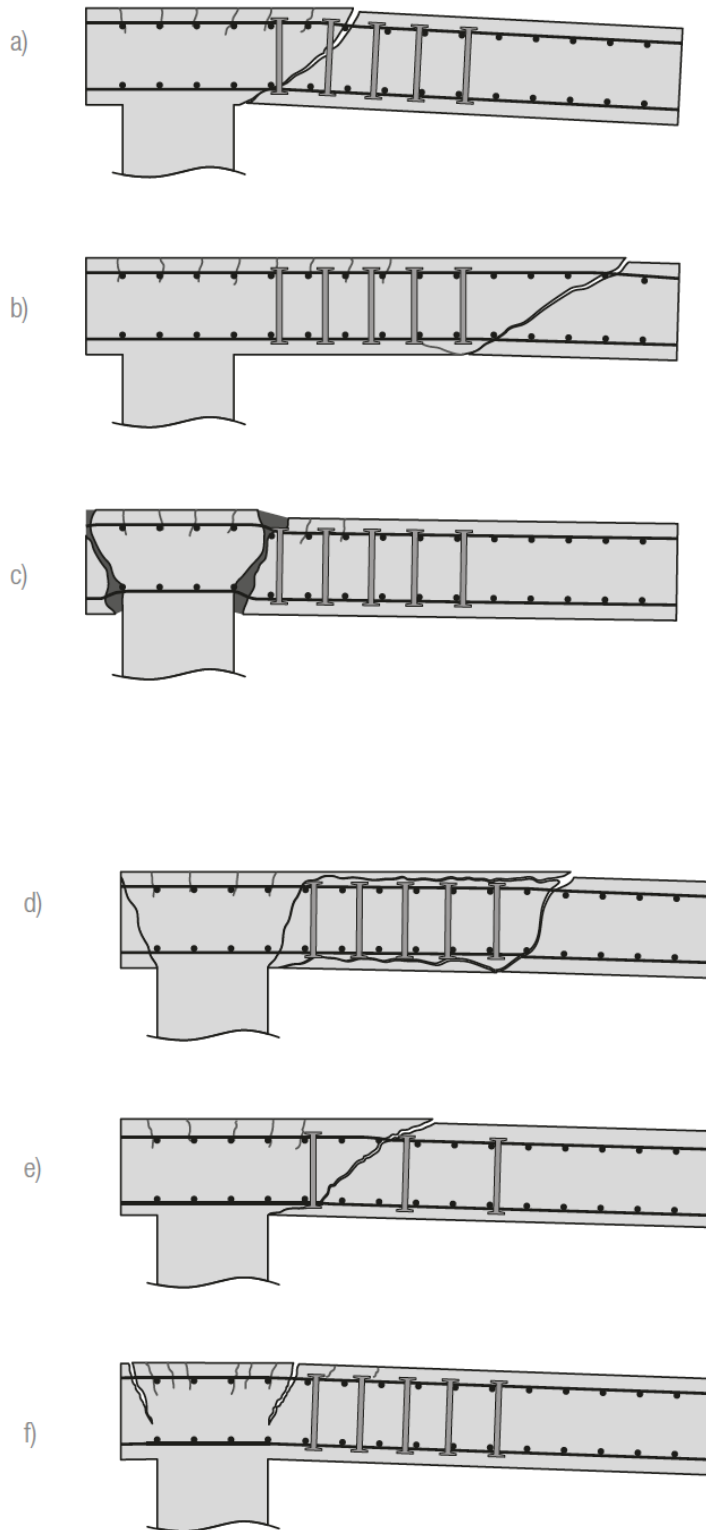
Дата введения в действие  
19 января 2013 г.

Разработаны  
ЦНИИСК им. В.А.Кучеренко  
филиал ФГУП «НИЦ «Строительство»  
« 19 » января 2013 г.

Москва  
2013 г.



Failure modes of slabs reinforced with punching reinforcement



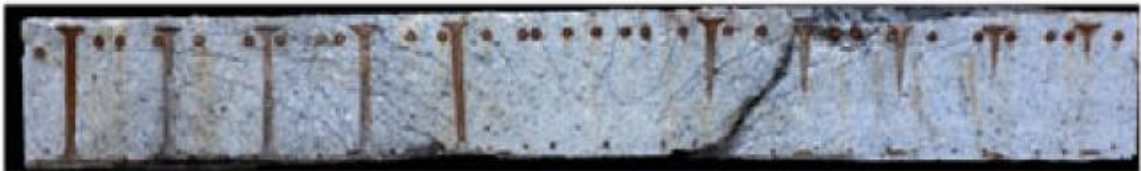
Examples of the cut sections of slabs with Peikko PSB Studs after failure



a) Slab PP1



b) Slab PP2



c) Slab PP3



d) Slab PP4



e) Slab PP5



f) Slab PP6

Procedure to select PSB reinforcement using Peikko Designer

