PEIKKO

WHITE PAPER

SHEAR RESISTANCE OF PRECAST WALL CONNECTION WITH SUMO® WALL SHOE

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INTRODUCTION

Proper execution of joints is essential for safe and efficient functioning of precast wall elements. Peikko bolted connection provides a safe and reliable solution for wall connections while offering numerous practical benefits, such as quick assembly and practical installation tolerances at a building site.

Precast walls are typically connected using SUMO® Wall Shoes in combination with anchor bolts HPM®, PPM® or COPRA® (Figure 1, Figure 2). SUMO® Wall Shoes are cast into precast wall elements at a precast factory. Anchor bolts are cast either to foundation or to another precast concrete element. At the building site, precast walls are assembled on the supporting structure with anchor bolts. Vertical position of the wall element is secured by steel shim plates placed to the wall joint. SUMO® Wall Shoe with slotted hole in the base plate allows easy horizontal adjustment of the precast element to the required position. Nuts are then tightened on anchor bolts. Joint created between the two wall elements is grouted with the low expansion grout (Figure 2).

SUMO® Wall Shoes are designed to transfer tensile forces between precast elements. Compressive forces are transferred by direct bearing of the precast wall on the hardened grout. On the other hand, it is not obvious if slotted hole in the base plate of SUMO® Wall Shoe allows the transfer of shear loads between the anchor bolt and the wall connection. Also, no explicit reference for the design shear resistance of bolted precast wall-to-wall connections is available. The test program presented in this paper has been conducted to demonstrate the shear capacity of precast walls connected with SUMO® Wall Shoes.

EXPERIMENTAL PROGRAM

A total of 12 specimens with two sizes of SUMO® Wall Shoes have been tested. Wall shoes SUMO® 16 were used in precast wall elements with thickness of 90 mm and SUMO® 30 were cast to wall elements with thickness of 120 mm. For the purpose of the tests, the anchor bars of SUMO® 30 and HPM® 30 were modified by anchor plates to fit to the concrete specimen. The shape, dimensions and arrangement of the test specimens are shown in Figure 3. Length of the wall-to-wall interface was 1.0 m in all tests. The wall-to-wall interface was either left unmodified (Figure 4) or intentionally roughened using the Peikko GRIP recess plate (Figure 5). A summary of the main parameters of the test specimens is provided in Table 1.

FIGURE 1. COMPONENTS FOR WALL CONNECTION

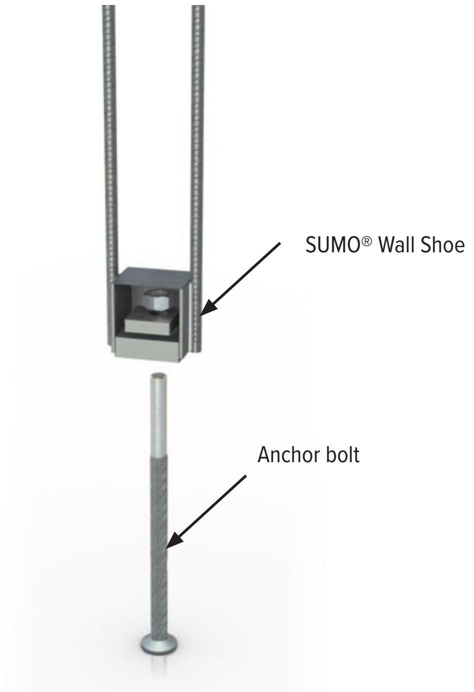


FIGURE 2. SUMO® WALL SHOE INSTALLED IN PRECAST WALLS

FIGURE 3. GEOMETRY OF TEST SPECIMENS

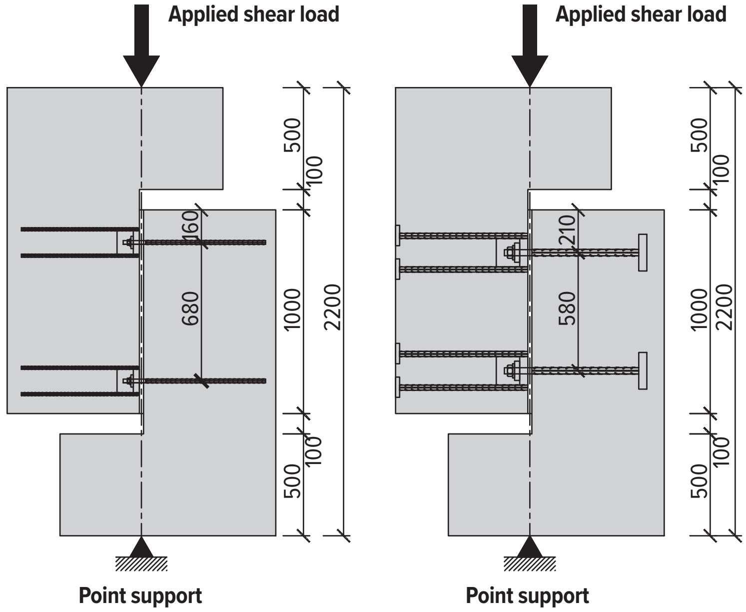


TABLE 1. CONFIGURATIONS OF TEST SPECIMENS

Specimen	SUMO® Size	Concrete grade	Surface of joint	Specimen	SUMO® Size	Concrete grade	Surface of joint
P31	SUMO® 16	C20/25	Very Smooth	P21*	SUMO® 30	C20/25	Very Smooth
P32	SUMO® 16	C20/25	Very Smooth	P22	SUMO® 30	C20/25	Very Smooth
P33	SUMO® 16	C20/25	Rough	P23	SUMO® 30	C30/37	Rough
P34	SUMO® 16	C20/25	Rough	P24	SUMO® 30	C30/37	Rough
P35	SUMO® 16	C30/37	Rough	P25*	SUMO® 30	C20/25	Rough
P36	SUMO® 16	C30/37	Rough	P26	SUMO® 30	C20/25	Rough
*Specimens with attached strain gauges on anchor bolts.							

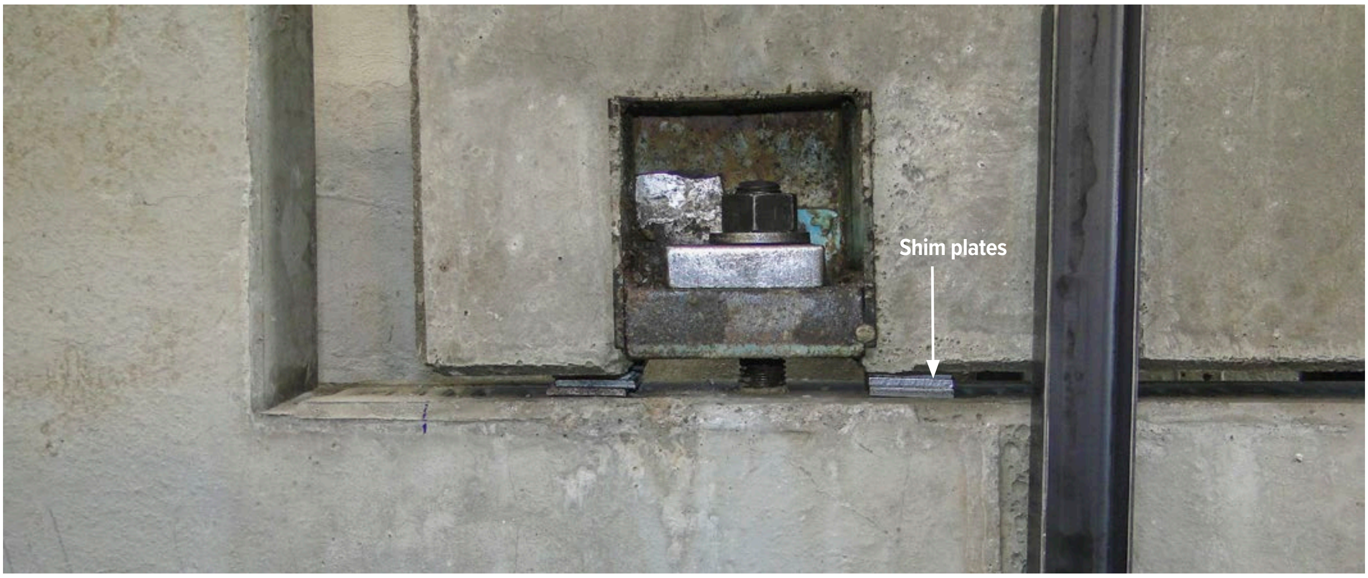
Very smooth surface shown in Figure 4 was used to simulate conventional arrangement of the wall joint. The surface roughened using Peikko GRIP is shown in Figure 5. Peikko GRIP is a steel sheet with profiled steel that is placed into the concrete wall formwork prior to casting. The depth and spacing of the imprinting are designed to create a surface that can be classified as rough in terms of EN 1992-1-1; section 6.2.5 [1].

The joint between test specimen was assembled and grouted in horizontal position to simulate real conditions on-site. The joint thickness of 20 mm was secured by shim plates installed close to bolts (see Figure 6). Joint was then grouted with low expansion grout with measured mean compressive strength $f_{c,grout}$ = 52MPa.

FIGURE 4. TESTS SPECIMENS WITH VERY SMOOTH SURFACE OF THE JOINT

FIGURE 5. TEST SPECIMEN WITH ROUGH SURFACE OF THE JOINT

FIGURE 6. ARRANGEMENT OF JOINT WITH SHIM PLATES BEFORE GROUTING



Test set-up is shown in Figure 7. Test specimen was supported by point bearings. Load was applied in the vertical axis of the specimen. This arrangement secured that the wall-to-wall interface was loaded by shear load only. Each tests specimen was loaded monotonically until failure. Loading and related deformations of the joint were continuously recorded.

Strain gauges were attached to anchor bolts of two test specimens with very smooth surface and with roughened surface using Peikko GRIP (Figure 8). The target was to observe the potential influence of the surface roughness on the strains in the bolts.

FIGURE 7. TEST SET-UP
LEGEND OF MEASURES:
1;2 – VERTICAL DEFORMATION
3;4 – HORIZONTAL DEFORMATION

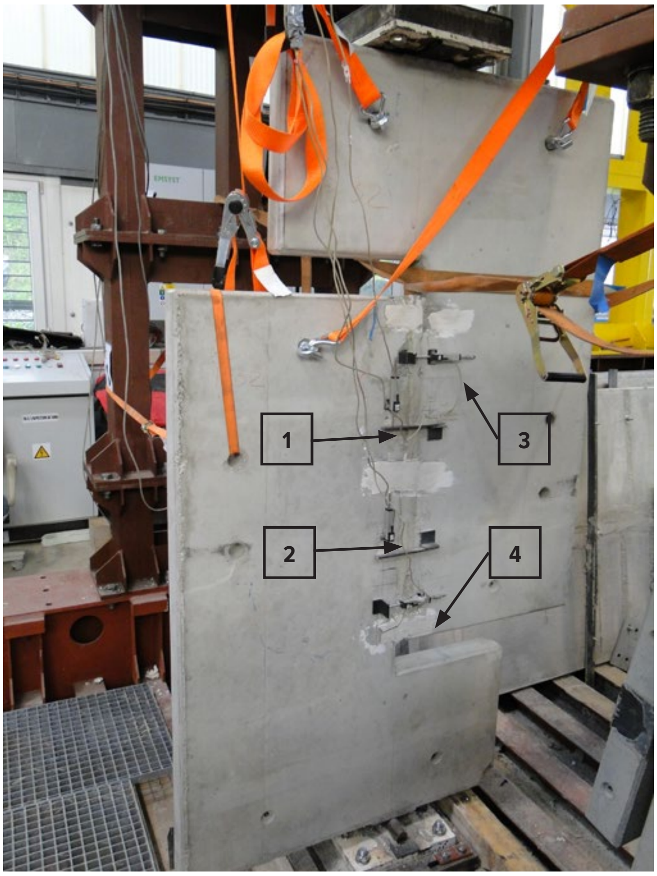
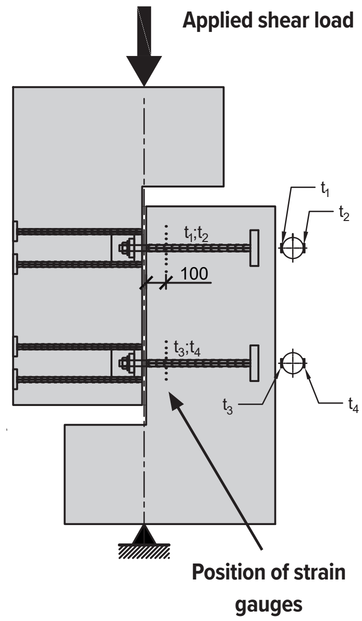


FIGURE 8. POSITION OF STRAIN GAUGES AT CONCRETE SPECIMENS



RESULTS

The load displacement of all tested specimens follows a similar pattern (see Figures 9 and 10). The initial response of the joint is linear and rigid up to a load level corresponding to roughly half of the maximum load. The maximum load is reached with shear deformations in between 0.5-2 mm as showed in Table 2. After that the load starts to decrease with increasing deformations. Ultimate failure occurs at deformation 5-8 mm by rupture of anchor bolts.

FIGURE 9. LOAD DISPLACEMENT CURVE FOR SUMO® 16

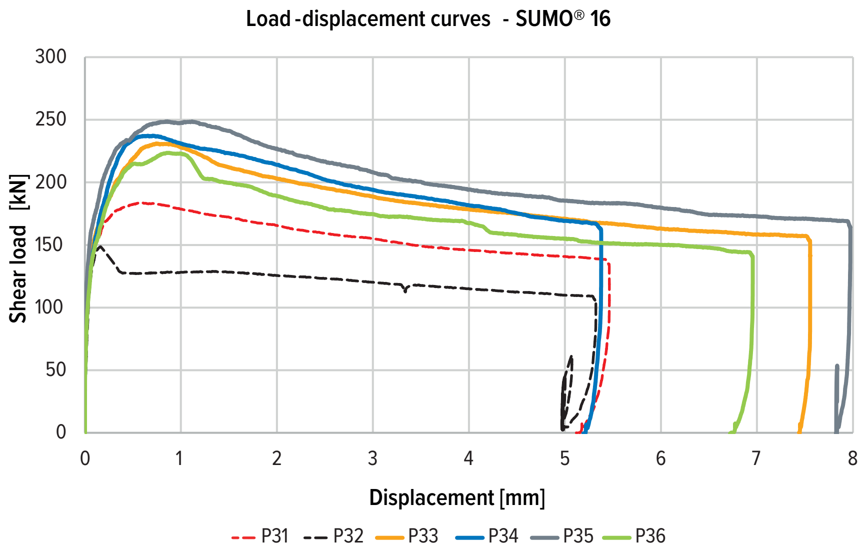
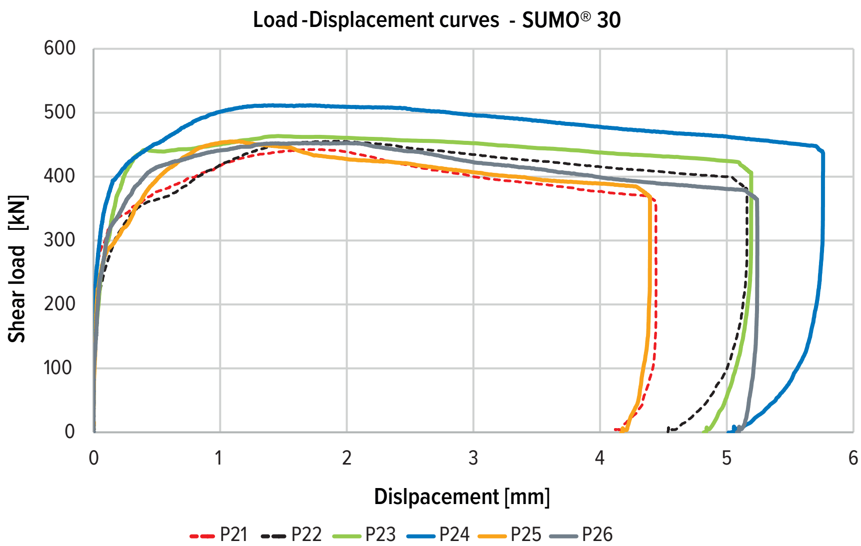


FIGURE 10. LOAD DISPLACEMENT CURVE FOR SUMO® 30



Figures 11 and 12 shows comparison between load displacement curve and stresses calculated from strain gauges. The diagrams show that anchor bolts are activated in the load transfer after deformation exceeds the rigid zone of the connection. This statement is supported by Figure 13 and Figure 14, which show comparison between the load displacement curve and the horizontal deformation of the joint, measured in the position of anchor bolts (Figure 8).

FIGURE 11. LOAD DISPLACEMENT CURVE VS. STRESS DISPLACEMENT FOR STRAIN GAUGES, SPECIMEN P21

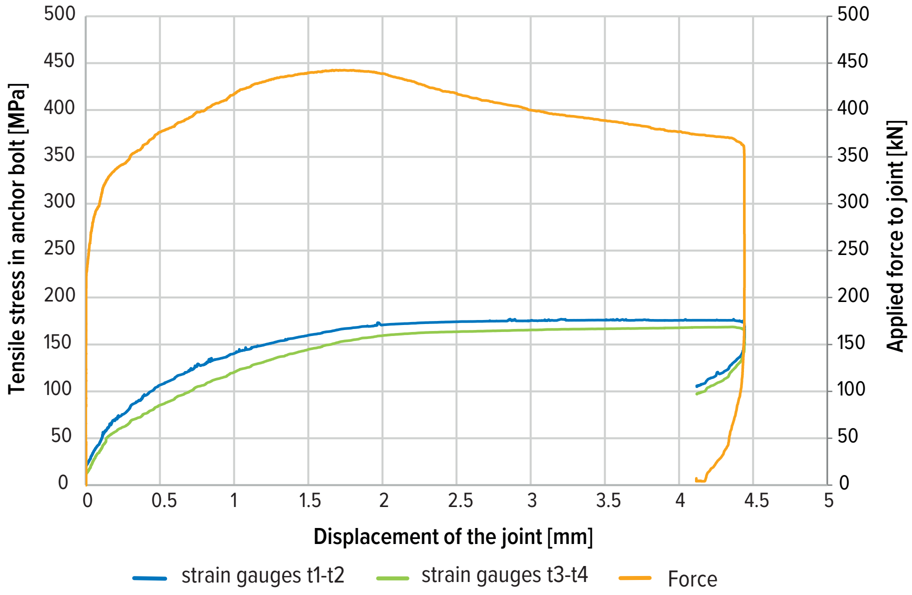


FIGURE 12. LOAD DISPLACEMENT CURVE VS. STRESS DISPLACEMENT FOR STRAIN GAUGES, SPECIMEN P25

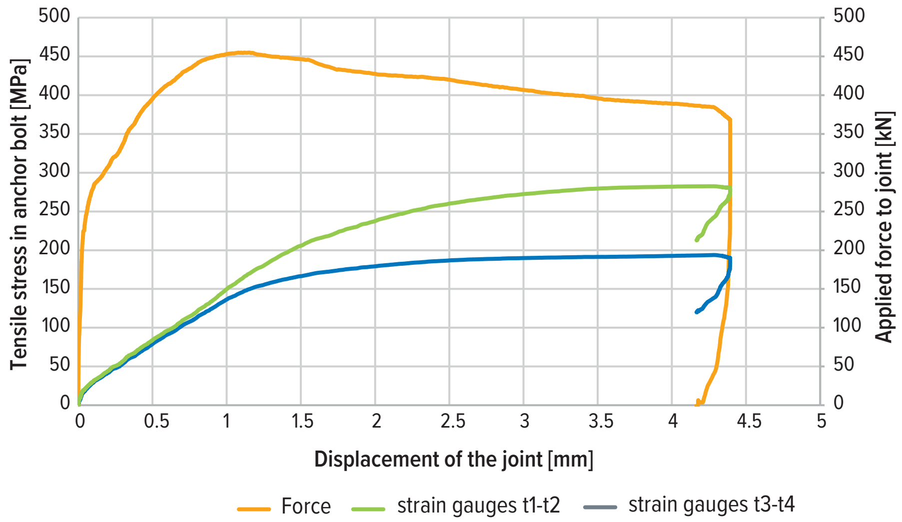


FIGURE 13. LOAD DISPLACEMENT CURVE VS. TRANSVERSE DEFORMATION DISPLACEMENT CURVE OF THE JOINT, SPECIMEN P21

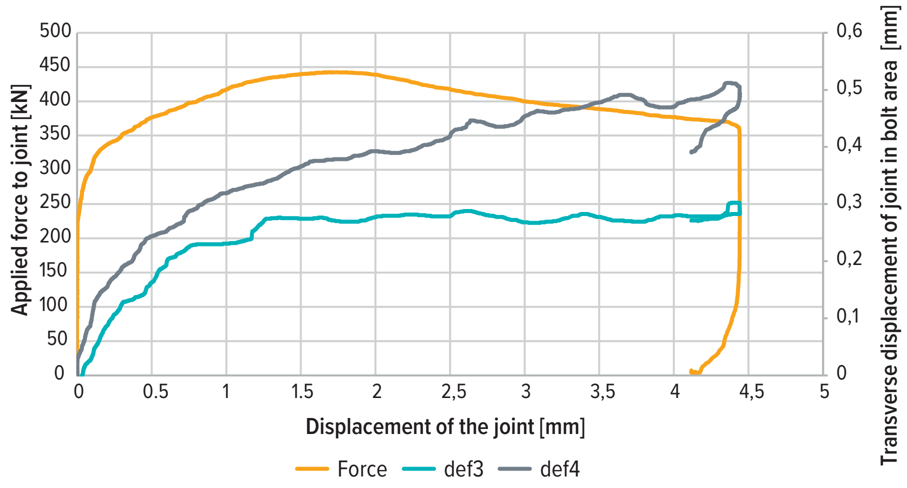


FIGURE 14. LOAD DISPLACEMENT CURVE VS. TRANSVERSE DEFORMATION DISPLACEMENT CURVE OF THE JOINT, SPECIMEN P25

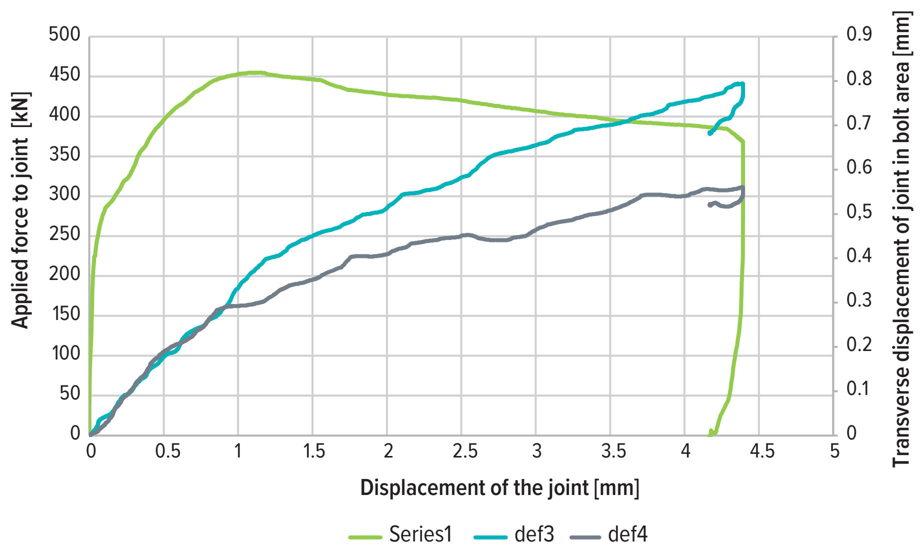
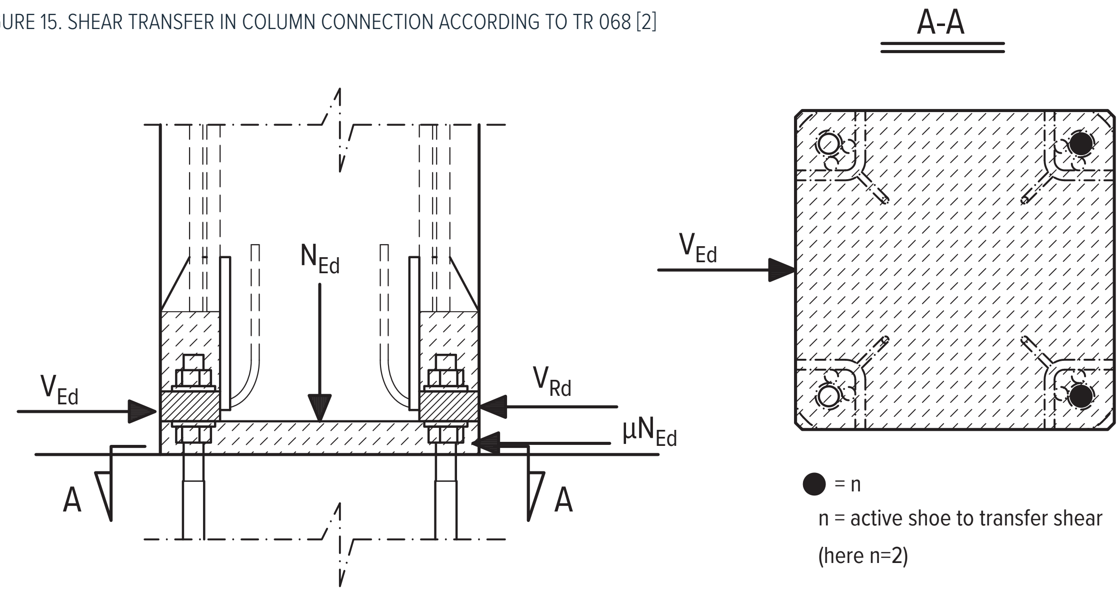


TABLE 2. MAXIMUM FAILURE LOAD OF THE JOINT AND RELATED VERTICAL DEFORMATION

Specimen	SUMO® Size	Maximum failure load F_{max} [kN]	Deformation at F_{max} [mm]	Specimen	SUMO® Size	Maximum failure load F_{max} [kN]	Deformation at F_{max} [mm]
P31	SUMO® 16	183.7	0.581	P21	SUMO® 30	442.6	1.661
P32	SUMO® 16	148.6	0.161	P22	SUMO® 30	455.4	1.884
P33	SUMO® 16	231.0	0.747	P23	SUMO® 30	463.5	1.457
P34	SUMO® 16	237.3	0.709	P24	SUMO® 30	511.7	1.417
P35	SUMO® 16	248.7	0.857	P25	SUMO® 30	455.1	1.151
P36	SUMO® 16	214.9	0.878	P26	SUMO® 30	452.6	1.674

FIGURE 15. SHEAR TRANSFER IN COLUMN CONNECTION ACCORDING TO TR 068 [2]



SHEAR RESISTANCE OF JOINT

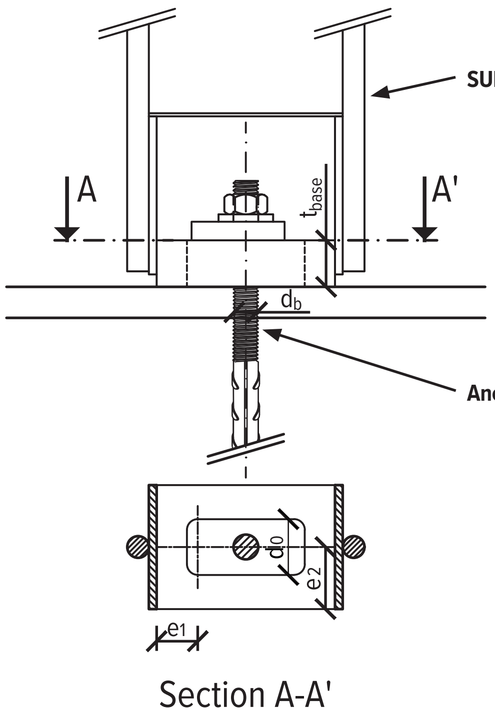
As of today, there exists no harmonized standard for the design of the assessment of the shear capacity of bolted precast wall-to-wall connections. The closest available reference is the TR 068 [2] applicable for the design of bolted connections of precast concrete columns, where the shear resistance of such connection shall satisfy:

$$\frac{V_{Ed} - \mu \cdot N_{Ed}}{n} \leq \frac{V_{Rk,s}}{\gamma_{M2}} \qquad (1)$$

Where:

n	=	Number of active bolts in compression for shear load transfer [pcs]
V_{Ed}	=	The design value of the total shear force [kN]
N_{Ed}	=	The design value of the total axial compressive force [kN]
	=	If the joint is loaded by a tensile axial force, $\mu \cdot N_{Ed} = 0$
μ	=	Friction coefficient between base plate and grout = 0.20 (EN 1993-1-8, Chapter 6.2.2) [-]
$V_{Rk,s}$	=	The characteristic shear resistance of single bolt [kN]; eq.(2)
γ_{M2}	=	Partial safety factor for joint [-]

FIGURE 16. DIMENSIONS OF THE BOLTED WALL CONNECTION



The characteristic resistance of a single bolt is defined as follows:

$$V_{Rk,s} = k_s \cdot min\left[\alpha_b \cdot f_{u,b} \cdot A_{bolt}; 0.8 \cdot k_1 \cdot a_b \cdot f_{base,u} \cdot d_b \cdot t_{base}\right] \quad (2)$$

$$\alpha_b = 0.44 - (0.0003MPa^{-1}) \cdot f_{y,b} \quad (3)$$

$$a_b = min\left(\frac{e_1}{3d_0}; 1.0; \frac{f_{u,b}}{f_{base,u}}\right) \quad (4)$$

$$k_1 = min\left(2.8\frac{e_2}{d_0}; 2.5\right)$$

Where:

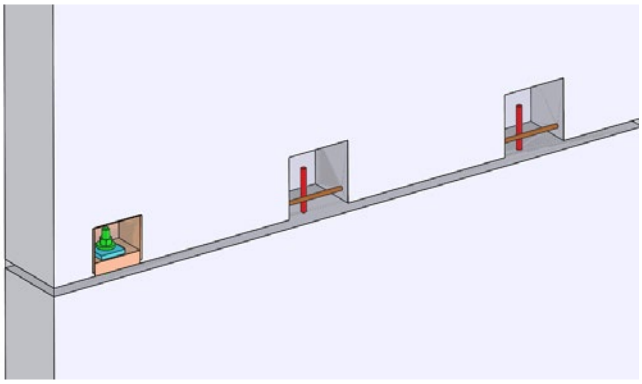
A_{bolt}	=	Cross section area of the bolt in thread section [mm²]
$f_{u,b}$	=	Tensile resistance of the bolt; 550MPa [MPa]
α_b	=	Factor [-]
$f_{y,b}$	=	Yield strength of the bolt, 500MPa [MPa]
γ_{M2}	=	Partial safety factor for steel, 1.25 [-]
k_s	=	1.0 for shear resistance [-]
k_1, a_b	=	Coefficients calculated as in EN 1993-1-8, table 3.4 [-]
$f_{base,u}$	=	The ultimate strength of the base plate, 510MPa [MPa]
d_b	=	Diameter of nominal stress area in the thread of anchor bolt [mm]
t_{base}	=	Thickness of the base plate [mm]
e_1, e_2	=	Edge distances of the hole [mm]
d_0	=	Diameter of the hole [mm]

TABLE 3. CHARACTERISTIC SHEAR RESISTANCE OF HPM® BOLTS

		HPM® 16	HPM® 20	HPM® 24	HPM® 30	HPM® 39
V_{Rk}	[kN]	25.0	39.1	56.3	89.5	155.7

So far, it has been unclear whether the methods of TR 068 [2] could be applicable to wall to wall connection, among other due to the large slotted hole of SUMO® Wall Shoes. For instance, the Finnish Concrete Industry Association [3] recommends to use steel dowels to be used in addition to SUMO® Wall Shoes to secure the transfer of shear forces through the joint (Figure 17).

FIGURE 17. FINNISH RECOMMENDATION FOR SHEAR DOWELS IN WALL-TO-WALL CONNECTION [3]



Within the present study, the loads transferred through the joints in tested specimen are relatively high and the ultimate load occurs with relatively large deformations. Thus, it can be concluded that the joint does possess a certain shear transfer capacity while being ductile and robust even in the absence of such additional dowel connectors used for longitudinal shear load transfer. Moreover, the use of Peikko GRIP elements further increases the stiffness and load bearing capacity of the joint.

A comparison between load-displacement curves and characteristic shear resistance of two anchor bolts determined in accordance with TR 068 [2] is presented in Figure 18 and Figure 19. Comparison shows that the load level corresponding to the characteristic resistance of two anchor bolts is significantly lower than the maximum load and is associated with very small deformations (ratio F_{max}/V_{Rk}). The comparison for F_{max}/V_{Rk} is done separately for SUMO® 30 and SUMO® 16, and statistically evaluated to 5% fractile [5].

TABLE 4. RATIO BETWEEN FAILURE LOAD AND CHARACTERISTIC RESISTANCE OF BOLTS

	SUMO® size	Failure load of the connection F_{max} [kN]	Characteristic shear resistance of two bolts V_{Rk} [kN]	F_{max}/V_{Rk} [-]
P21	SUMO® 30	442.6	179.0	2.5
P22	SUMO® 30	455.4	179.0	2.6
P23	SUMO® 30	463.5	179.0	2.6
P24	SUMO® 30	511.7	179.0	2.9
P25	SUMO® 30	455.1	179.0	2.5
P26	SUMO® 30	452.6	179.0	2.5
			Mean	**2.6**
			COV	**5.2%**
			$(F_{max}/V_{Rk})_{5\%}$	**2.2**
P31	SUMO® 16	183.7	50.0	3.7
P32	SUMO® 16	148.6	50.0	3.0
P33	SUMO® 16	231.0	50.0	4.6
P34	SUMO® 16	237.3	50.0	4.7
P35	SUMO® 16	248.7	50.0	5.0
P36	SUMO® 16	214.9	50.0	4.3
			Mean	**4.2**
			COV	**17.96%**
			(F_{max}/V_{Rk})5%	**1.9**

FIGURE 18. CHARACTERISTIC RESISTANCE OF 2 X HPM® 16 COMPARE TO EXPERIMENTS

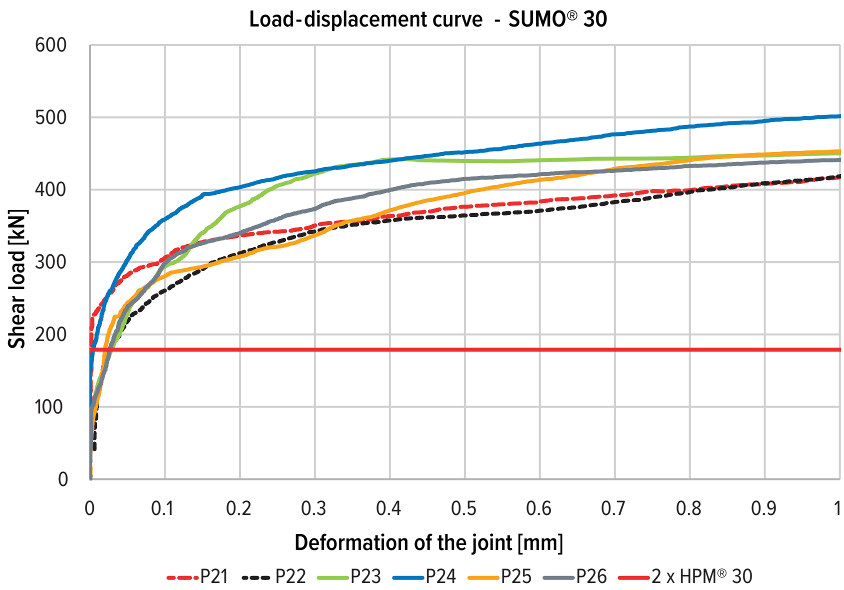
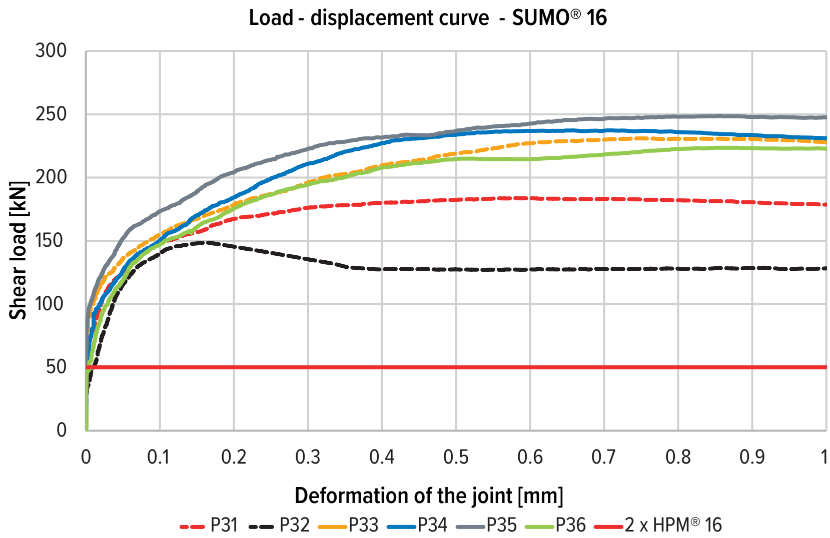


FIGURE 19. CHARACTERISTIC RESISTANCE OF 2 X HPM® 30 COMPARE TO EXPERIMENTS



DESIGN RECOMMENDATIONS FOR SUMO® WALL SHOE IN SHEAR JOINT

The following practical recommendations could be derived from the presented tests:

- The calculation of shear resistance in accordance with TR 068 [2] is applicable and conservative even for precast wall-to-wall connections in longitudinal direction.
- The design recommendations are applicable for range SUMO® 16H up to SUMO® 39H.
- The design approach is applicable for n ≥ 2 anchor bolts per joint.
- Connection wasn't tested in transverse shear direction. Therefore, shear resistance of the bolt is not applicable in transverse direction of joint.
- Peikko GRIP improves the stiffness of the precast joint.
- Low expansion grouting with minimum compressive strength equal to strength of concrete used in precast concrete element.
- In case one of the bolts is carrying a tensile load, it is recommended to neglect its contribution to the shear resistance, as within this study, the effect of tensile load has not been tested. The shear load transfer will be carried only by bolts under compression.

CONCLUSION

The test program presented in this paper shows that wall-to-wall bolted connections using SUMO® Wall Shoe do have a capacity to transfer shear loads. The capacity is positively affected by using Peikko GRIP profiles to roughen the wall to wall contact surface. The behavior of the tested specimen is ductile. A design of shear resistance using the methods of TR 068 [2] is conservative with a ratio of $(F_{max}/V_{Rk})_{5\%}$= 2.2 for SUMO® 30 and $(F_{max}/V_{Rk})_{5\%}$= 1.9 for SUMO® 16. This makes SUMO® Wall Shoe a very versatile product, which can be used also for wall connection transferring shear loads. This approach creates safe and reliable bolted connection.

REFERENCES

[1] EN 1992-1-1; Design of concrete structures – Part 1-1: General rules and rules for buildings; CEN, Brussels 2004

[2] EOTA Technical report TR 068; Design of structural connections with Column Shoes, EOTA, Brussels 2018

[3] Concrete industry association guidelines: https://www.elementtisuunnittelu.fi/liitokset/runkoliitokset

[4] EN 1993-1-8; Design of steel structures – Part 1-8: Design of joints

[5] ISO 12491; Statistical methods for quality control of building materials and components

GRIP RECESS PLATE

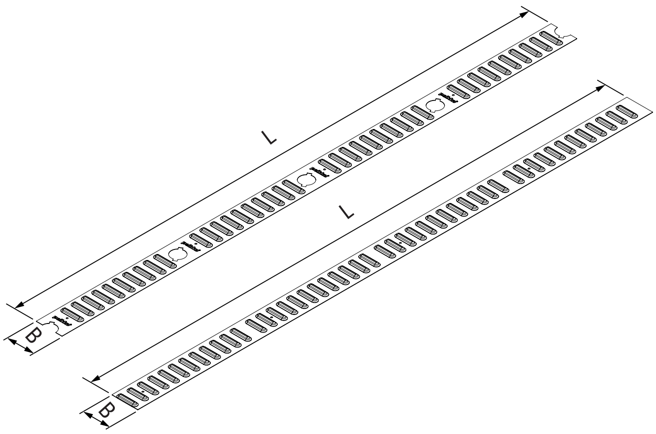
GRIP Recess plate is a building product used to create rough surface treatment of concrete joint. It is targeted to use in combination with SUMO® Wall Shoe in wall-to-wall connection.

The GRIP Recess Plate is a non-loadbearing metal sheet plate with deformed surface. It is installed to formwork, to future joint area, before cast of precast element. Rough surface of the joint is created after removing of the precast element from the formwork. GRIP will stay in the formwork and can be re-used again.

GEOMETRY OF THE GRIP

GRIP Recess Plate is available in one standard dimension. Geometry of the recess plate is shown in following table.

TABLE 1. DIMENSIONS OF GRIP RECESS PLATE



	B [mm]	L [mm]
GRIP	**50**	**1000**

SELECTION

Selection and ordering of the GRIP Recess Plate is covered by product code.

GRIP 250

GRIP = Product name; 250 = Length in "m"

Note:
GRIP is always produced as 1 m long element. Therefore, number in GRIP product codes means number of 1 m long pieces.

INSTALLATION

GRIP Recess plate must be installed on the clean surface of the formwork. Recess plate is placed in the middle of the assumed joint. Recess plate is then attached to formwork either by nails or screws.

FIGURE 1. INSTALLATION OF GRIP TO THE FORMWORK. FREE SPACE IS KEPT FOR PLACEMENT OF THE SUMO® WALL SHOE. GRIP CAN BE SIMPLY CUT BY ANGLE GRINDER AND SCISSORS FROM METAL SHEET PLATE TO CREATE REQUIRED LENGTH FOR FORMWORK.

FIGURE 2. INSTALLATION OF THE WALL SHOE TO THE FORMWORK.

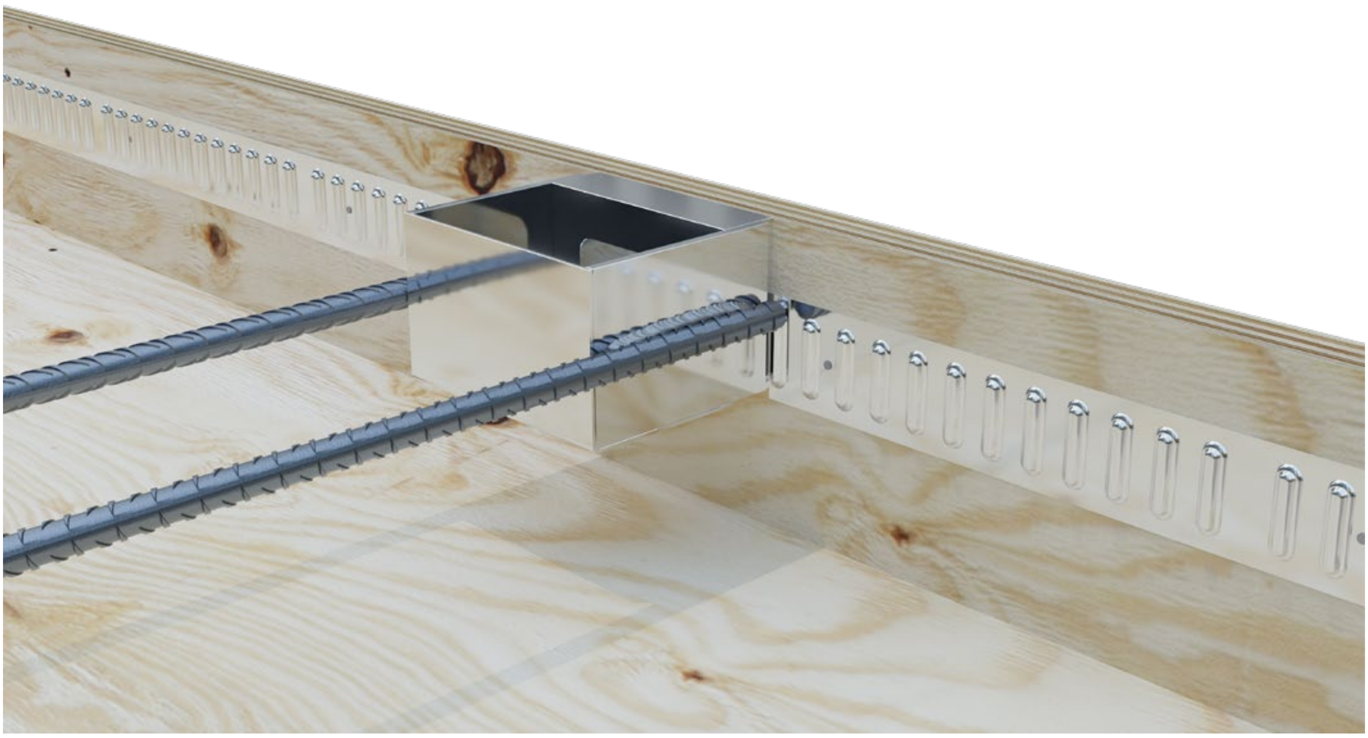


FIGURE 3. CONCRETE WALL IS CAST AFTER PLACEMENT MAIN REINFORCEMENT CAGE IN TO CORRECT POSITION.

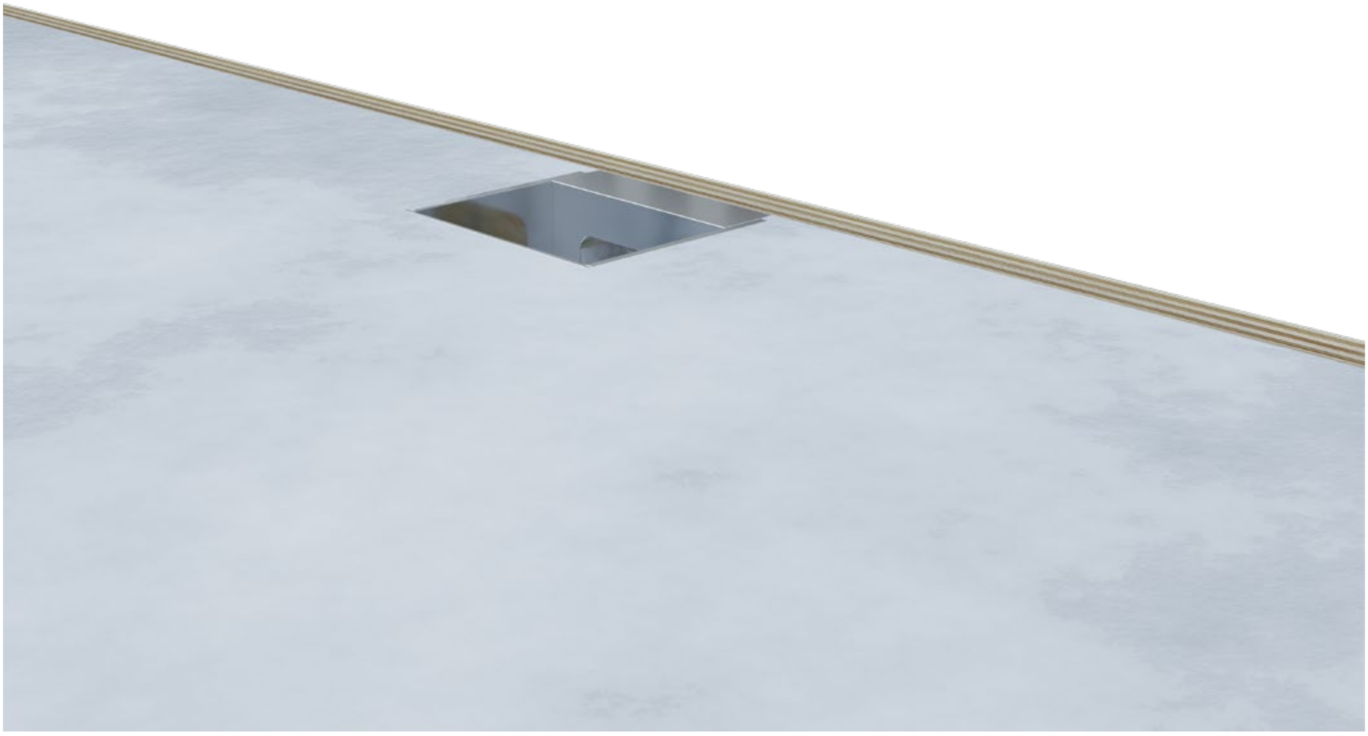


FIGURE 4. REMOVING OF THE PRECAST CONCRETE ELEMENT FROM FORMWORK. GRIP CREATED IMPROVED ROUGH SURFACE IN FUTURE JOINT AREA.

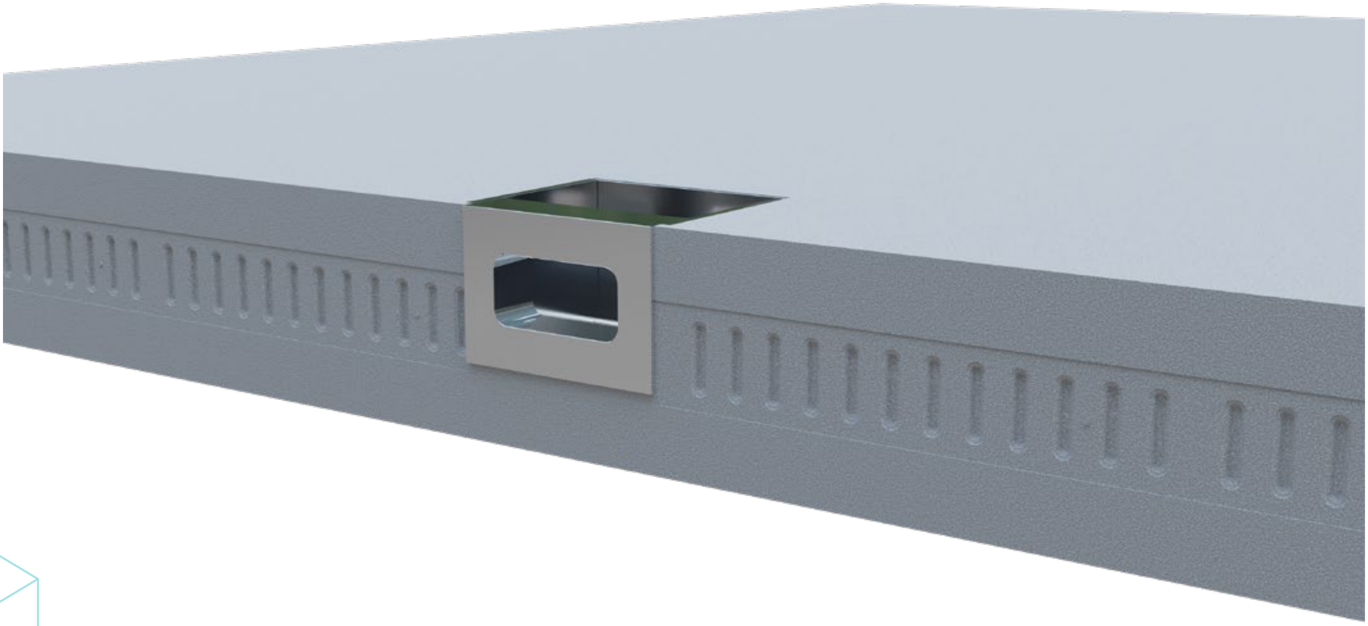


FIGURE 5. GRIP STAYS AT SAME POSITION AFTER REMOVING OF CONCRETE PRECAST ELEMENT. IT CAN BE USED AGAIN AFTER CLEANING OF THE SURFACE FROM CONCRETE DEBRIS.

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