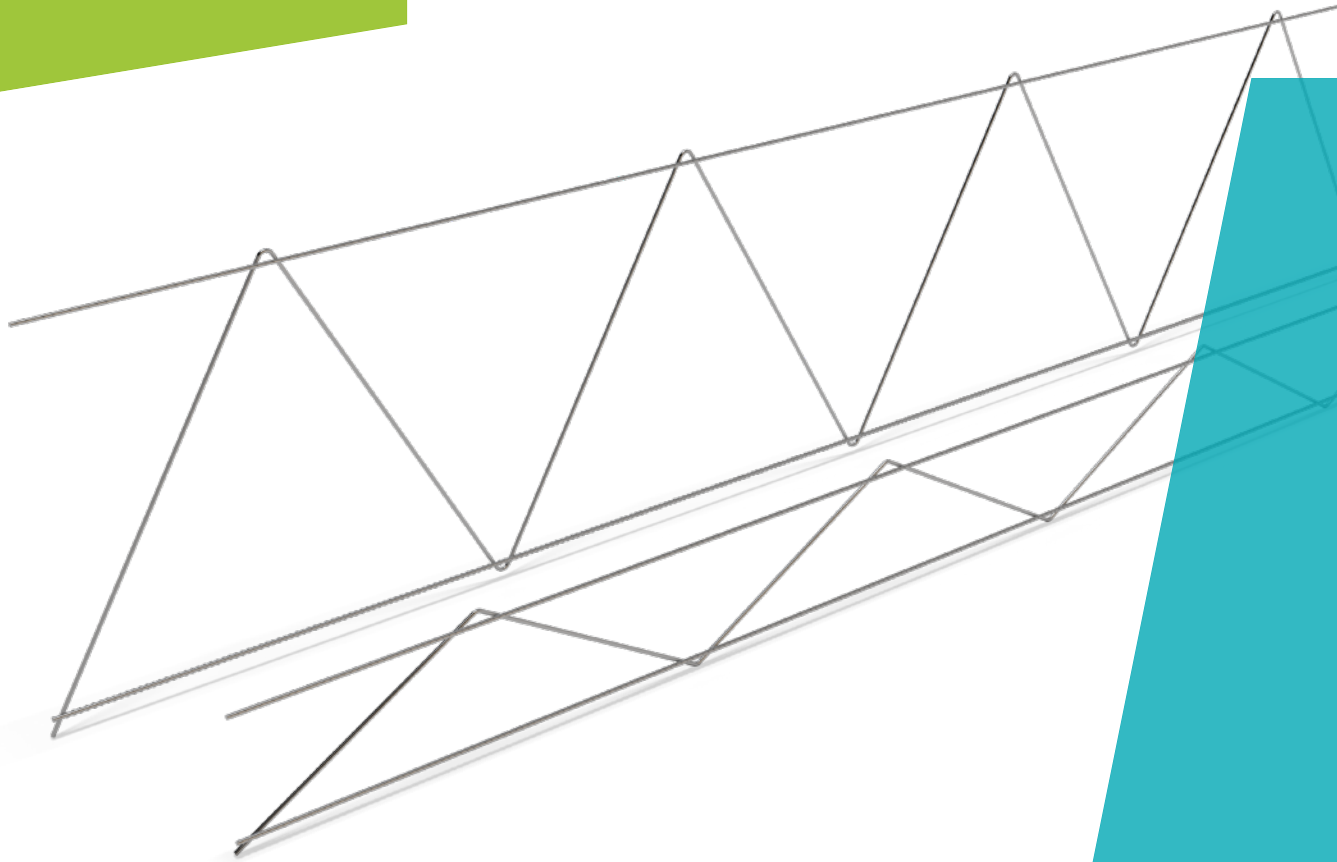
TECHNICAL MANUAL



Diagonal Ties

Connectors for Precast Sandwich Panels

Version GULF 10/2021

peikko®

Diagonal Ties

Connectors for Precast Sandwich Panels

- Coverage of all thermal insulation thicknesses and materials for the future energy-saving constructions
- Reliable, familiar connectors for precast concrete sandwich panels with over 50 years of usage experience
- Easy to install between insulation plates
- Benefits of stainless steel – lower conductivity
- Sizes according to insulation thicknesses
- Prefabricated products guarantee stable, high-quality, accurate deliveries
- Provides effective workflow for the customer
- Low maintenance, low life-cycle costs
- Peikko support in designing the panels.

Diagonal Ties are used to connect the inner and outer layers of precast concrete sandwich panels.

Diagonal Ties are most commonly used in sandwich panels with insulation thicknesses of 40 – 390 mm and recommended dimensions up to 3.5 m high and 7 m wide. In case of using higher or wider sandwich panels than recommended dimensions please contact Peikko support.

Prefabrication allows the use of precise formworks with a high quality of surfaces and dimensions, high repeatability of formwork and production of concrete elements. Production is plan-placed in factory conditions with a controlled indoor environment where the mixing, placing, and curing of the concrete is easy to control. Prefabrication enables sandwich panels to be created with high-quality wall surfaces.

CONTENTS

1. Product properties

Ties are bent and welded wire connectors are used to connect concrete layers of precast sandwich panels. Ties are usually uniformly distributed through thermal insulation plates and anchored in both of the layers of a sandwich panel.

Diagonal ties are available in several standard models to cover a wide range of precast panel thicknesses.

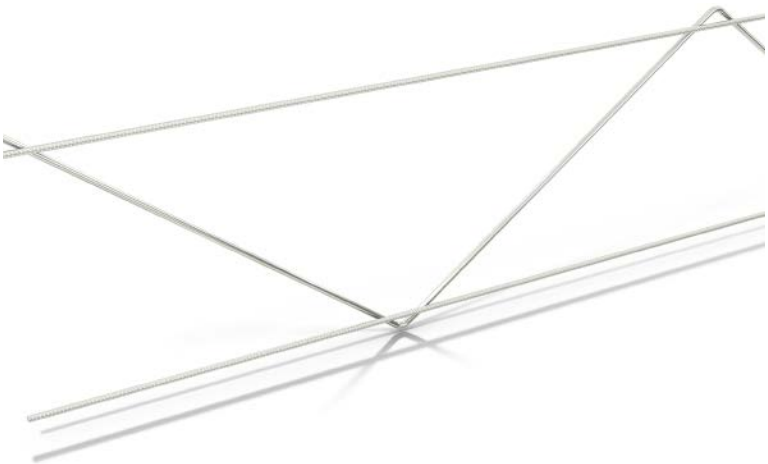


Figure 1. Diagonal Tie.

The **Diagonal Tie** is a single lattice girder used to connect the outer and inner layers of sandwich panels. The lattice girder consists of stainless diagonals and flanges made either of stainless or reinforcing steel. The flange material depends on the exposure class and concrete cover of the flanges.

PDM Diagonal Tie: both flanges are made of reinforcing steel. The PDM Diagonal Tie is used in cases where concrete cover is adequate for both flanges. If another material type is requested please contact Peikko support for further assistance (e.g. HDG steel).

PD Diagonal Tie: the outer flange is made of stainless reinforcing steel for cases when the concrete cover in the outer layer is not sufficient. The inner flange of the PD Diagonal Tie is made of reinforcing steel.

PDR Diagonal Tie: both flanges are made of stainless reinforcing steel.

1.1 Structural behavior

Ties are used to provide structural interaction between the concrete layers of sandwich panels and enable the sandwich panel to transfer loads and displacements that are most typically imposed to the structure by the following effects:

- Lifting and transport
- Self-weight of the concrete layer
- Shrinkage deformation
- Horizontal loads
- Temperature deformation
- Adhesion of the formwork.

The structural effects are likely to be combined during the different stages of the lifecycle of the precast sandwich panel. The precast panel must be designed to withstand the effects of the most unfavorable load combinations.

In the manufacturing stage, the Ties will be subject to tensile forces resulting from the self-weight of the sandwich panel during lifting and transportation.

In normal use cases, Ties are likely to be exposed to the action of self-weight of the outer layer, shrinkage deformation in the outer and inner layers, and environmental loads such as wind load and deformation of the outer layer due to temperature changes.

Self-weight during lifting and transportation

In the manufacturing stage, adhesion between the sandwich panel and the formwork will result in tensile forces in the connectors while the panel is lifted from the formwork. Once the sandwich panel is lifted from the formwork, the tensile forces in the connectors will correspond to the self-weight of the layer that is hanged on them (*Figure 2*). During the transportation stage, the forces in the connectors due to self-weight must be multiplied due to dynamic effects.

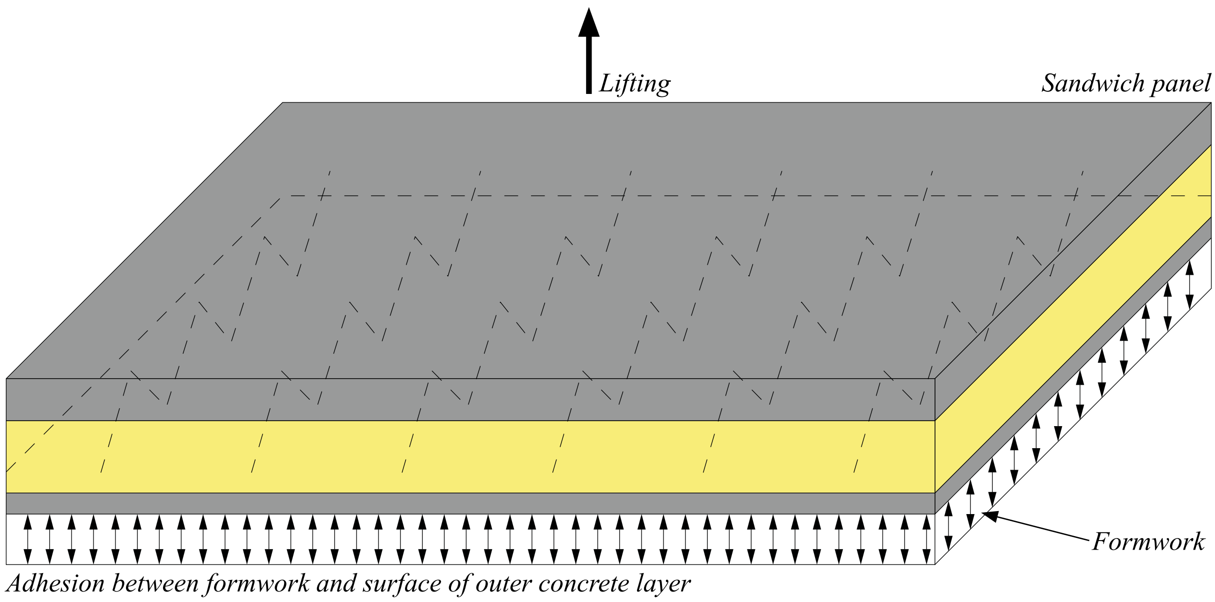


Figure 2. Principle of adhesion between concrete and formwork.

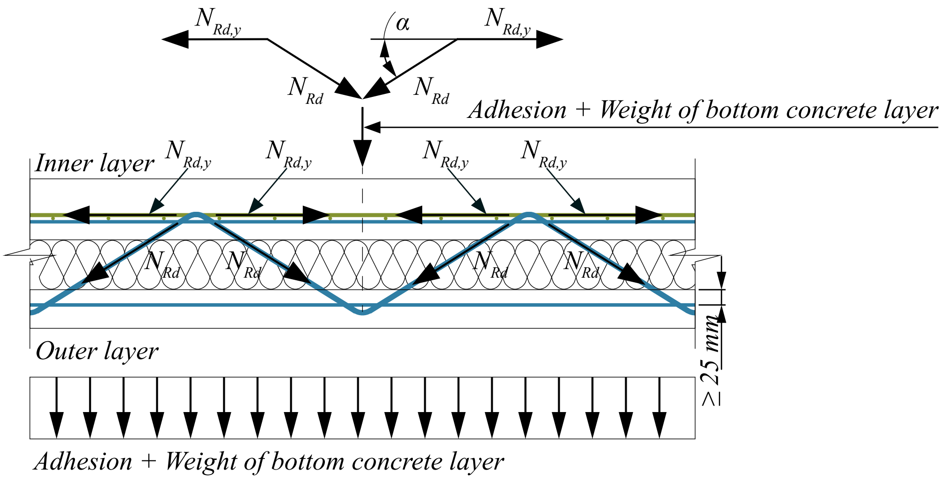


Figure 3. *Force flow in Diagonal Ties related to formwork adhesion.*

Self-weight of the concrete layer

The outer layer of the sandwich panel is most typically hanged on the inner layer (*Figure 4*). The self-weight of the outer layer acts as a dead load and generates vertical forces G_d in the sandwich panel. These vertical forces are resisted by the tensile resistance of diagonals and the compression resistance of the thermal insulation layer (*Figure 4*).

In case the panel is lifted from inserts that are anchored only to the inner layer, dynamic actions for self-weight of the outer layer should be considered in diagonal tie design during lifting and erection stages.

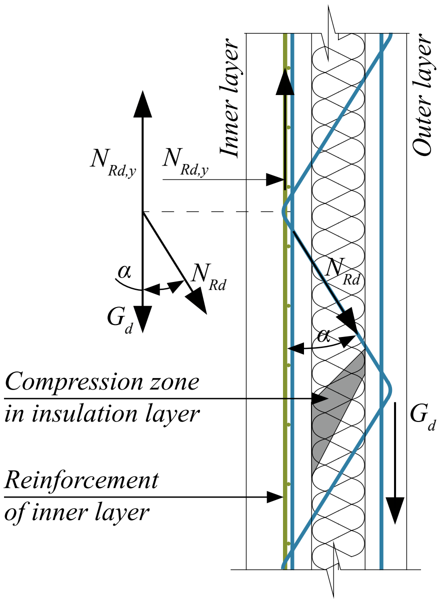


Figure 4. *Forces resulting from the effects of dead load.*

Shrinkage deformation

Shrinkage is a time-dependent deformation of concrete that is mainly influenced by the properties of the precast element (material, dimensions) and humidity of the precast element and surrounding environment. The outer and inner layers of the sandwich panels usually have a different thicknesses and are exposed to environments with different humidity. As a result, they are subjected to different shrinkage deformations. Diagonal Ties are used to ensure the compatibility of shrinkage deformations and prevent interface slip between the two concrete layers of the sandwich panel (see *Figure 5*).

A humidity gradient also exists within the inner and outer sides of each concrete layer of the precast element (*Figure 6*). This is mainly because the evaporation of water is faster on the side of the layer that is exposed to the external environment compared to the side that is in contact with the thermal insulation layer.

The difference between shrinkage strains that is related to this humidity gradient may cause local deformations of the sandwich panel (*Figure 6*).

These deformations may be prevented by placing Diagonal Ties around the edges of the sandwich panel (*Figure 6*).

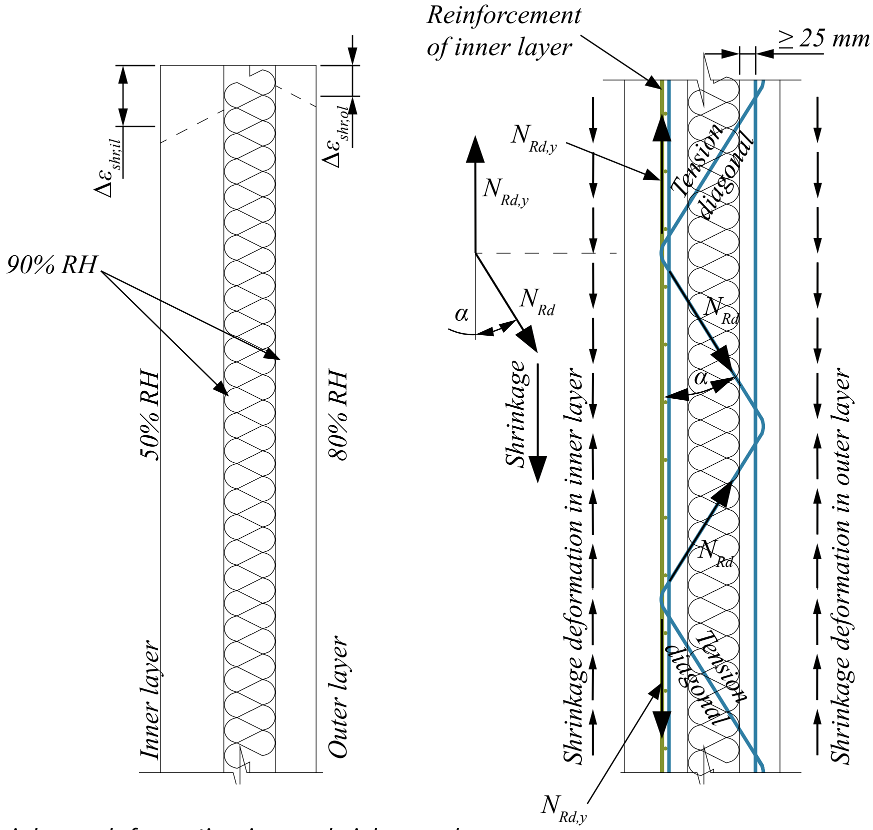


Figure 5. Linear shrinkage deformation in sandwich panel.

Reinforcement of the inner concrete layer restricts the effects of flexural shrinkage deformation, which nullifies this effect on the Diagonal Ties. Diagonal Ties are then loaded by flexural shrinkage deformation from the outer concrete layer.

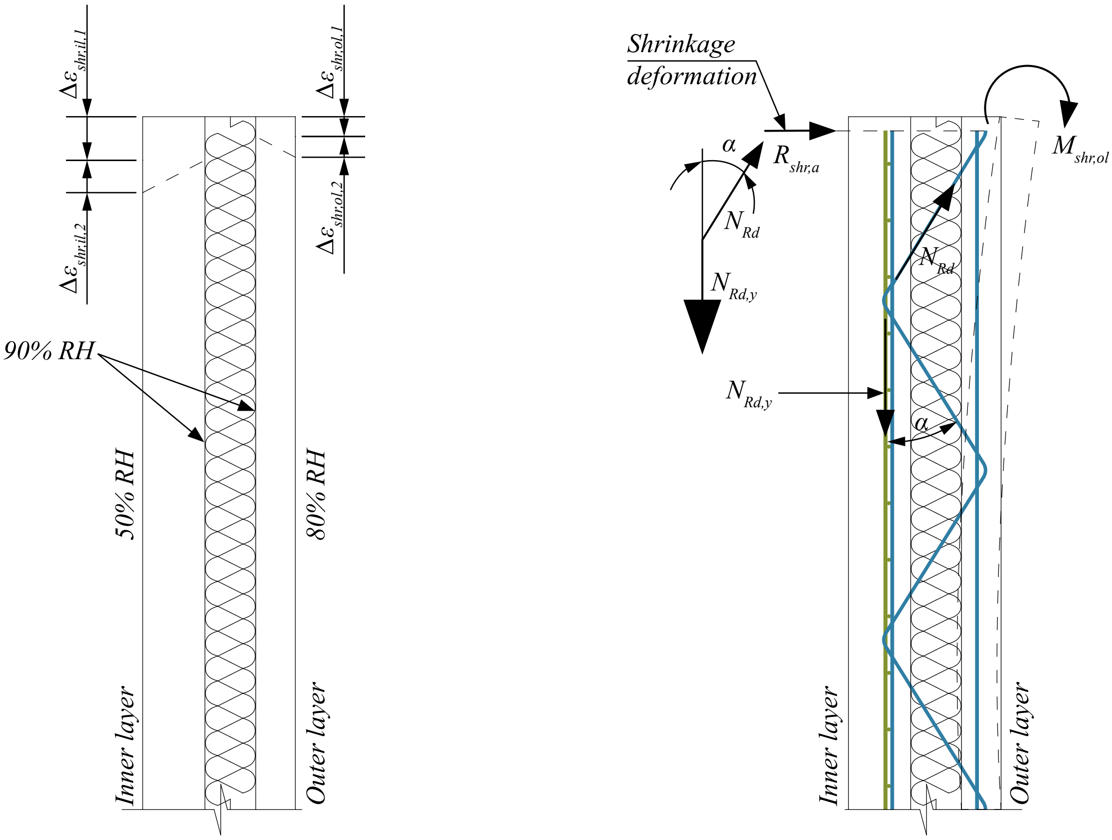


Figure 6. Shrinkage flexural deformation at the end on the outer concrete layer.

Horizontal loads

The outer layer of the sandwich panel may be exposed to wind action, which usually acts as a uniform pressure or suction load perpendicular to the panel surface. Uniform pressure load is transferred from the outer concrete layer via the insulation layer to the inner layer and supports. For this reason, the thermal insulation must have adequate compression strength. The tension loads caused by suction are resisted by diagonals (see *Figure 7*). In both cases, the wind load will result in the sandwich panel bending.

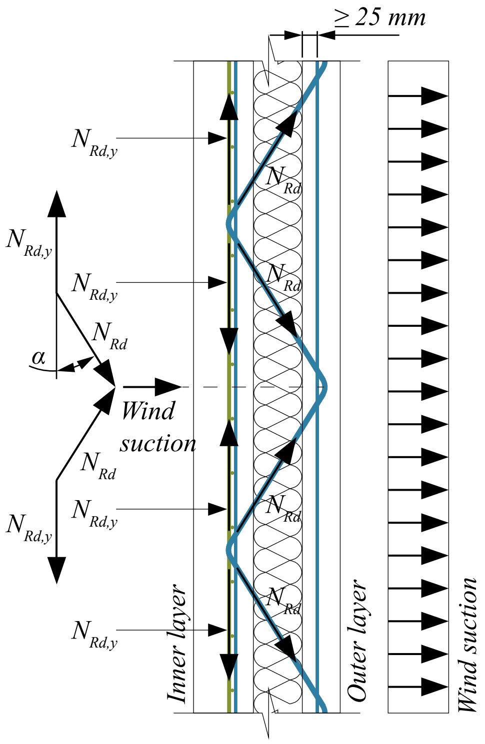


Figure 7. Transfer of wind suction to inner layer.

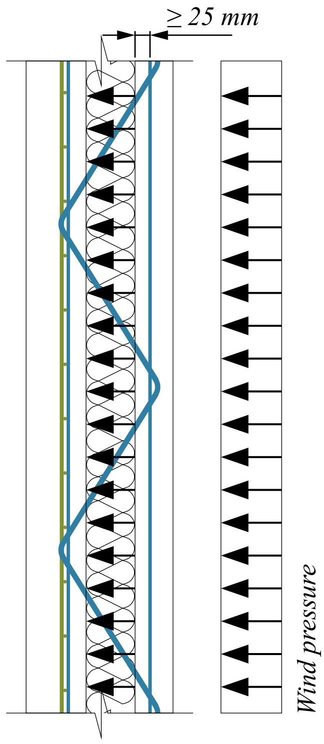


Figure 8. Transfer of wind pressure to inner layer.

Temperature deformation

As a building envelope, the sandwich panel is exposed to frequent temperature changes during day and night and during different seasons. An example of the temperature flow in a sandwich panel is shown in *Figure 10*. Since the temperature variations in the inner layer of the sandwich panel (inside the building) are assumed to be relatively low, the temperature gradient of the sandwich panel principally depends on the daily or annual temperature fluctuation in the outer layer. Linear temperature deformation causes extension (during summer) and contraction (during winter) of the outer concrete layer. Diagonal Ties are used to resist the deformations of the outer concrete layer and prevent movement differences between layers of sandwich panels (*Figure 9*).

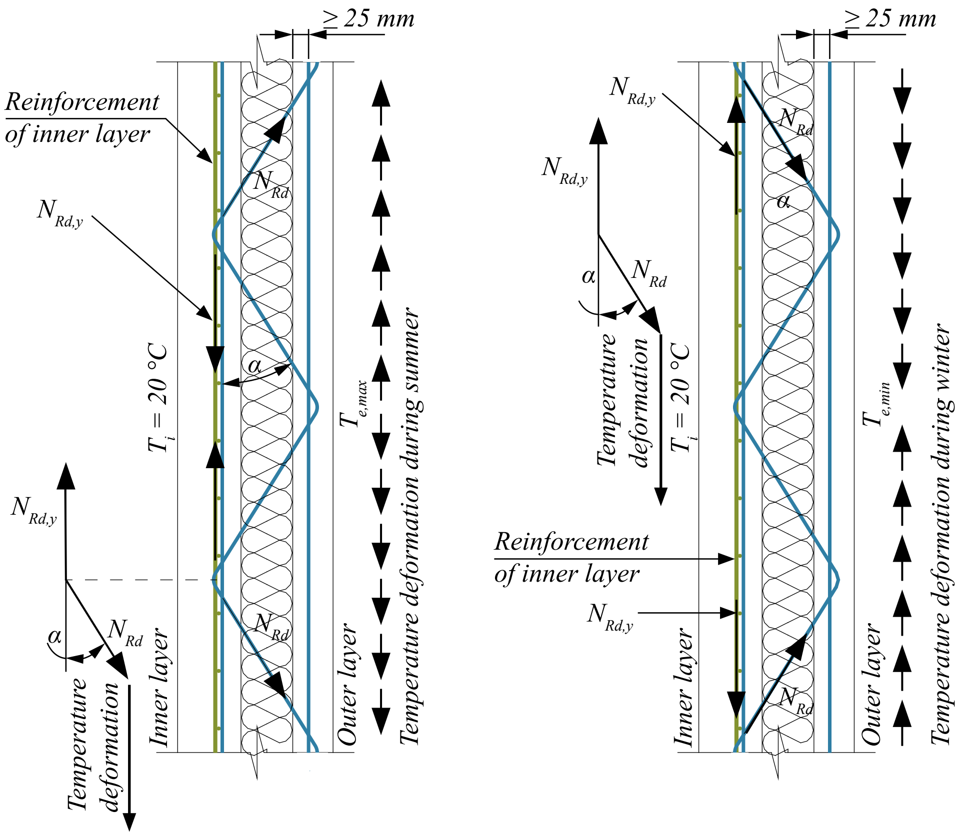


Figure 9. Force flow during summer and winter season in sandwich panel.

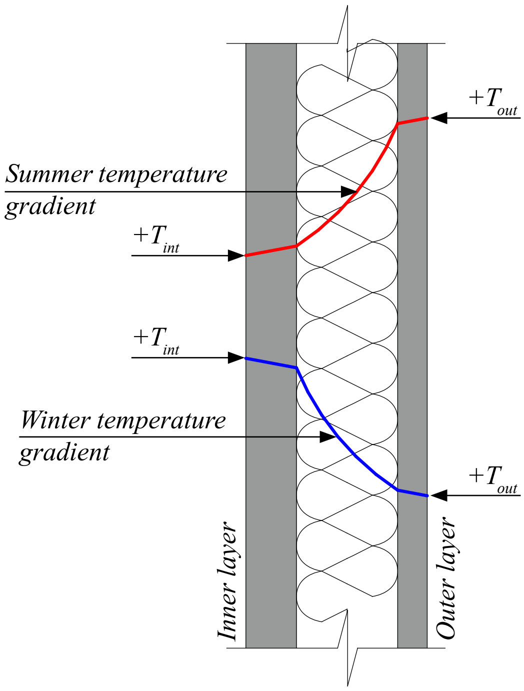


Figure 10. Seasonal temperature gradient in sandwich panel.

A certain temperature gradient exists also through the depth of each concrete layer. This temperature gradient may result in local deformations of the concrete layers. The orientation of deformation depends on the season and ambient temperature (see *Figure 11*). Such local bending may be prevented by placing Diagonal Ties near the edges of the precast panel (*Figure 12*).

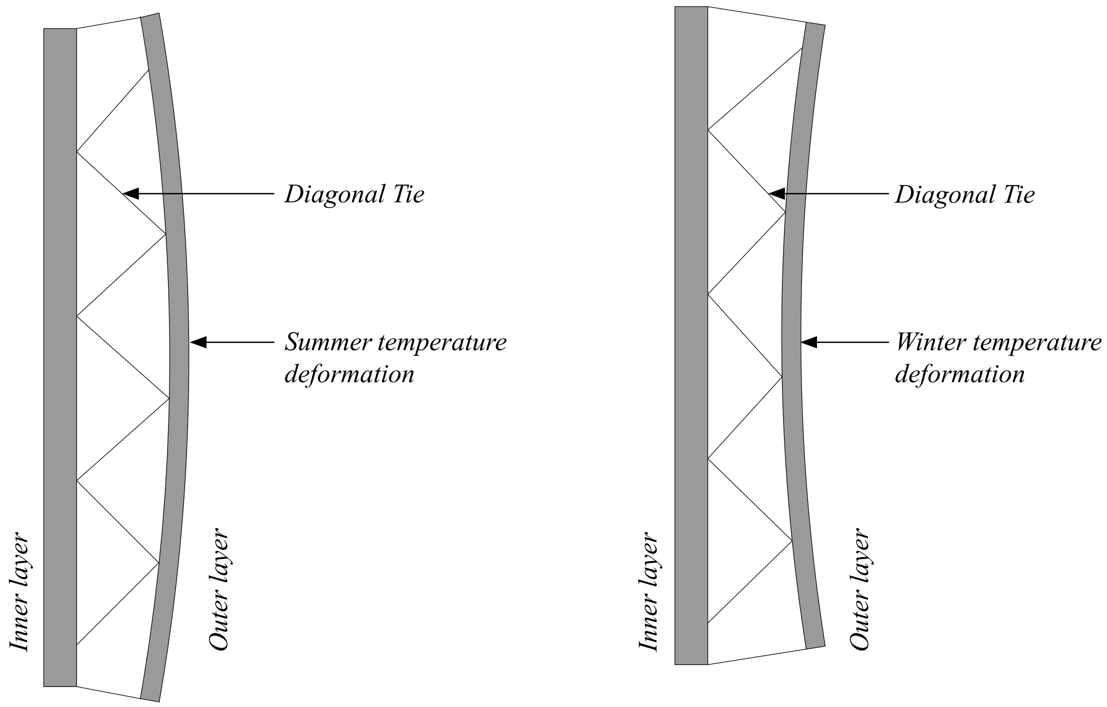


Figure 11. Annual temperature deformation of a sandwich panel.

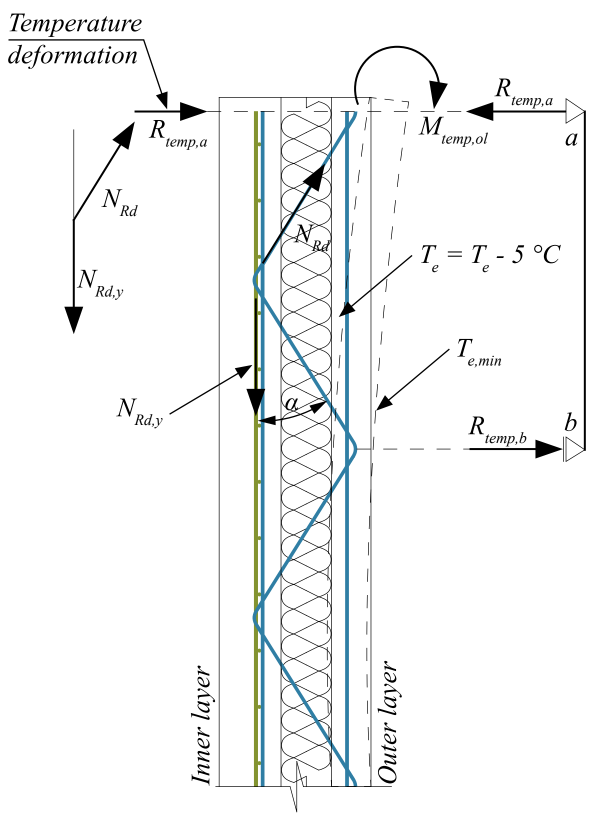


Figure 12. Temperature flexural deformation in the outer layer during winter.

1.2 Application conditions

The Ties were developed for use in precast sandwich panels assuming the following limitations:

- Recommended maximum dimensions of the precast panel: 3.5 × 7 m.
- Minimum concrete grade following *Table 1*.
- Minimum anchorage depth following *Table 1*.
- Recommended minimum thickness of outer concrete layer: 60mm.
- Recommended minimum mesh reinforcement of outer concrete layer: 133 mm^2/m (when $d_{ol} \leq 70$ mm).
- Recommended minimum edge reinforcement of inner concrete layer: Ø8 (see *Figure 13*).
- Design of transverse Diagonal Ties if the panel is rotated during lifting (see *Figure 14*).
- The uniform casting of a top concrete layer to avoid local differences in thickness and compression of thermal insulation.
- The use of a plasticizer is recommended to reduce the water-to-cement (w/c) ratio.

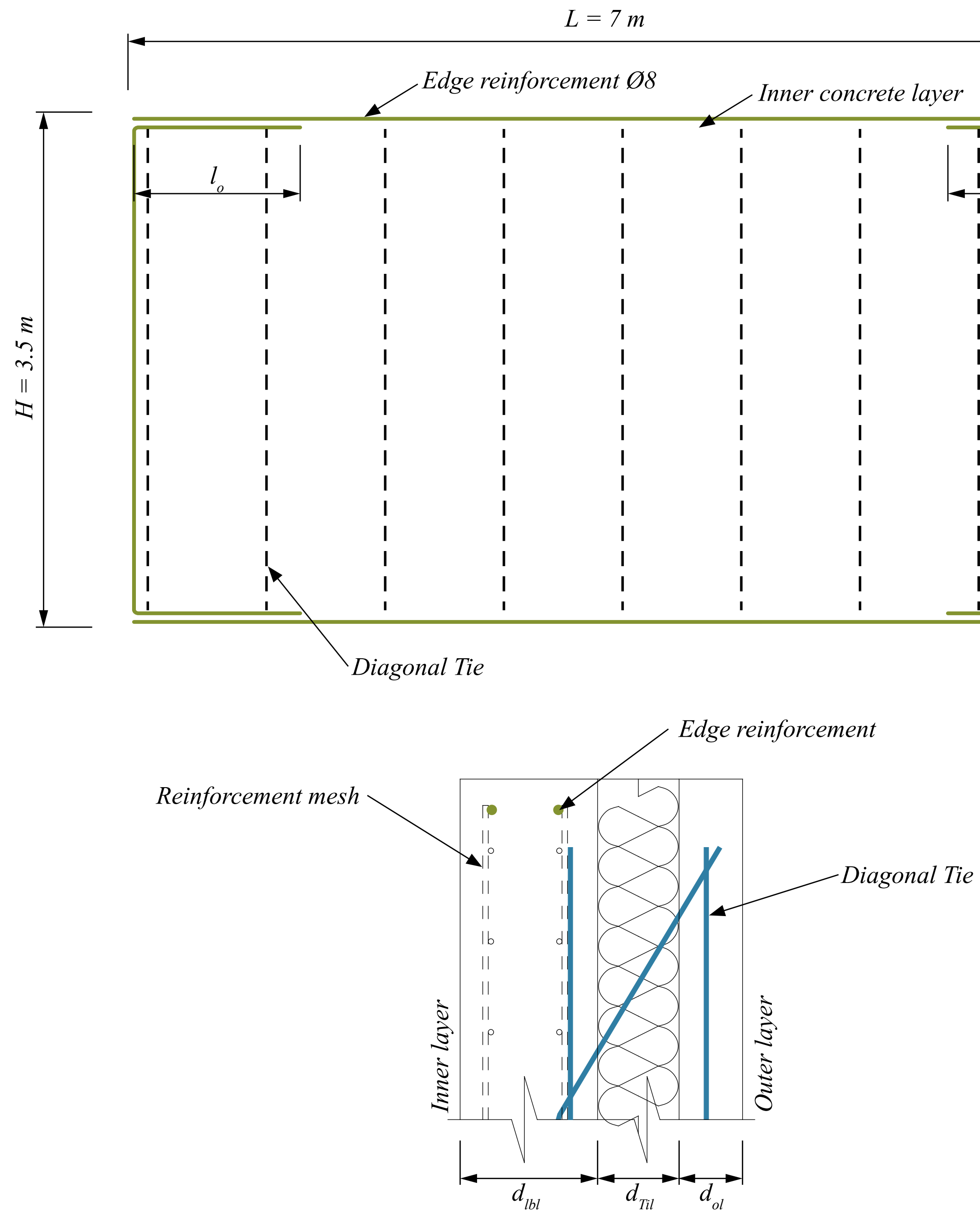


Figure 13. Placement of the edge reinforcement in the inner layer.

l_o - lap length of edge reinforcement is calculated according to EN1992-1-1, the local requirement can be applied.

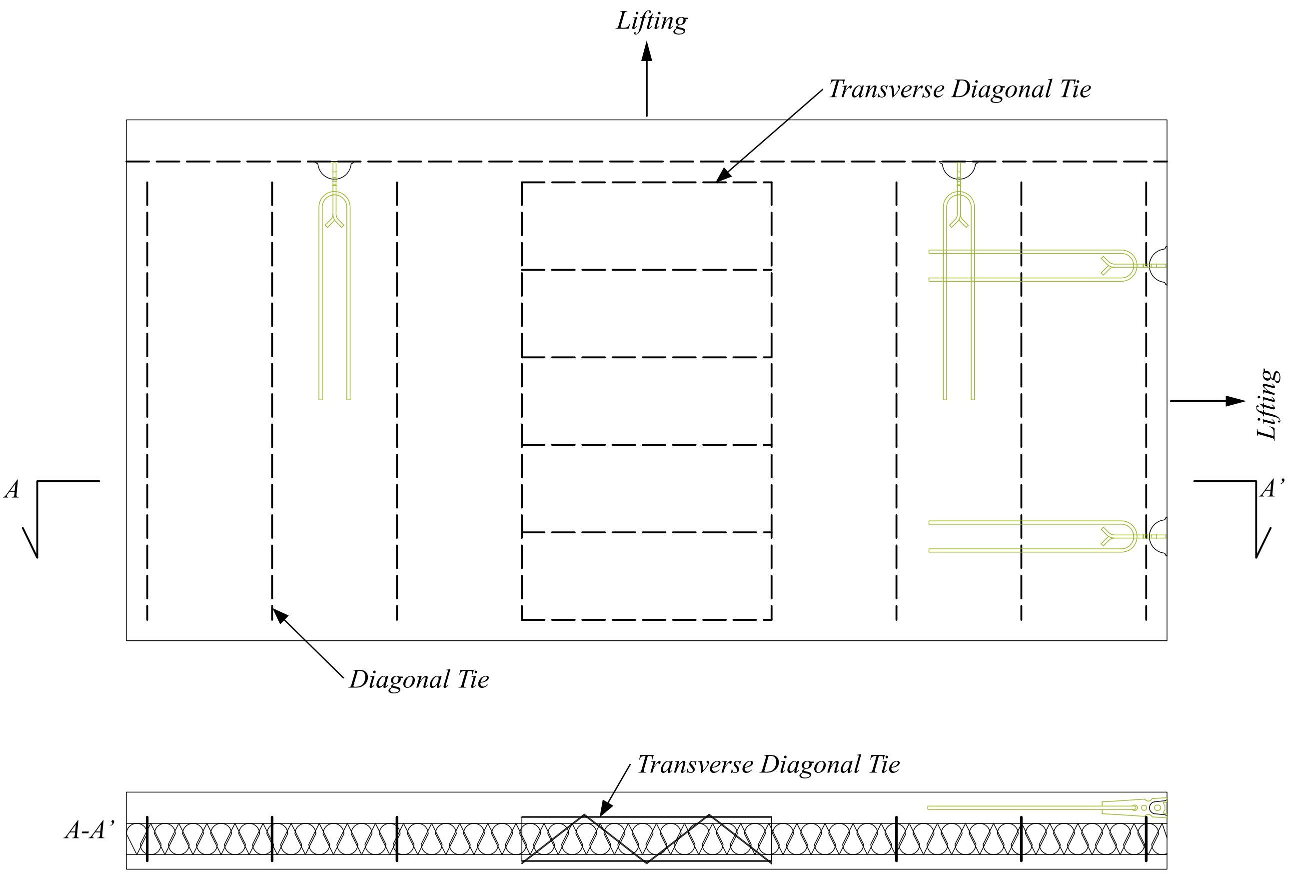
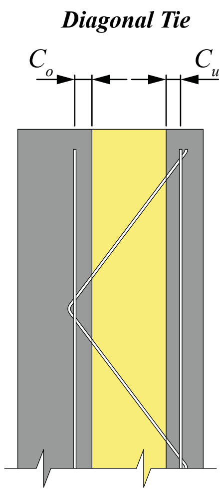


Figure 14. Using transverse Diagonal ties during lifting.

The minimum anchorage depth and material properties of concrete following *Table 1* must be secured to provide proper functioning of Ties.

Table 1. Concrete cover of Ties with minimum concrete grades.

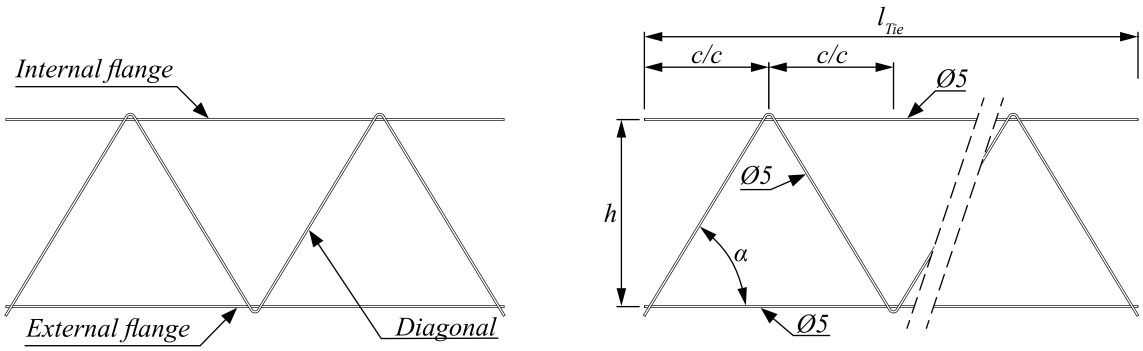


Type of connector	Anchorage depth (c_o/c_u)	Minimum concrete grade (Anchorage point of view)
Diagonal Tie	≥ 25/25	f_c ≥ C20/25*
* Minimum compressive strength of concrete before stripping from the formwork is f_c = 16MPa.		

1.3 Other properties

The dimensions of standard models of Ties are summarized in *Table 2*.

Table 2. Dimensions of Diagonal Tie.



Diagonal Tie model	*h* 1)	*c/c*	Recommended insulation thickness	Length 2)	*α*	Weight
	[mm]	[mm]	[mm]	[mm]	[deg]	[kg]
PD/PDM/PDR 120	120	300	60	3000	26	1.48
PD/PDM/PDR 140	140		80		29	1.49
PD/PDM/PDR 150	150		90		31	1.50
PD/PDM/PDR 180	180		120		35	1.53
PD/PDM/PDR 200	200		140		38	1.54
PD/PDM/PDR 210	210		150		39	1.59
PD/PDM/PDR 220	220		160		40	1.59
PD/PDM/PDR 240	240		180		42	1.59
PD/PDM/PDR 260	260		200		44	1.60
PD/PDM/PDR 280	280		220		46	1.63
PD/PDM/PDR 300	300		240		48	1.65
PD/PDM/PDR 320	320		260		50	1.68
PD/PDM/PDR 340	340		280		52	1.70
PD/PDM/PDR 360	360		300		53	1.73
PD/PDM/PDR 380	380		320		55	1.75
PD/PDM/PDR 400	400		340		56	1.78

1) The standardized height *h* of ties is based on anchorage depths 30 + 30 mm into the concrete layers. Dimension *h* is measured from the central axis to the central axis of flanges.

2) The standard length of Diagonal Ties l_{Tie} is 3000 mm. Ties can be manufactured in multiples of 300 mm.

Manufacturing tolerances

Tie length	± 10 mm
Tie width	± 5 mm
Diagonal or cross bar distance	± 5 mm
Diagonal's straightness between bars	± 2 mm

Materials

Types of connectors		Type of steel	Standard
Diagonal Ties	**Diagonals**	1.4301 (smooth)	EN 10088-2
	Flanges	B500B (ribbed) B600XB (ribbed)	EN 10080 SFS 1259

Table 3. Material options of flanges of Diagonal Ties.

Type	Structural part	Material		
		B500B	B600XB	1.4301
PDM	External flange	X		
	Diagonal			X
	Internal flange	X		
PD	External flange		X	
	Diagonal			X
	Internal flange	X		
PDR	External flange		X	
	Diagonal			X
	Internal flange		X	

Diagonals are mechanically bent and welded to flanges by using a resistance welding process. The lattice girder is cut mechanically to the correct length.

Each package of Ties bears the emblem of Peikko Group, the type and quality of the product, and the manufacturing date.

Package sizes: Diagonal Ties: 500 – 900pcs.

Peikko Group's production units are controlled externally and audited periodically based on the production certificates and product approvals provided by various independent organizations.

2. Resistances

The resistances of Ties are determined by a design concept that refers to the following standards:

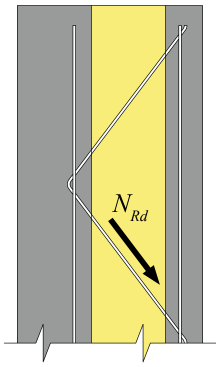
- EN 1992-1-1:2004/AC:2010
- EN 10080:2005.

The tensile resistance of one single diagonal in a Diagonal Tie is given in *Table 4*. The characteristic value of the tensile resistance is defined as the minimum of the steel resistance of the diagonal, the welding joint resistance between the diagonal, or the anchorage resistance of the diagonal into concrete. The load-bearing direction of the sandwich panel connectors is shown in *Table 5*.

Table 4. Resistance of Diagonal Ties.

	Design value N_{Rd}
Tension resistance of Diagonal Ties	5.6

Table 5. Load-bearing direction of the sandwich panel connectors.



Diagonal Tie

The height (h dimension) of the Tie is selected according to the insulation thickness and required anchoring depth. The recommended height for the Tie is the insulation thickness plus the concrete cover ($c_u + c_o$) for anchoring (see *Table 1*, *Table 2*).

The horizontal edge distance R (see *Figure 15*) must be 100 – 300mm. The vertical distance V (see *Figure 15*) from the upper and bottom edges should be $c_{min,dur} \leq V \leq 200\ mm$, where $c_{min,dur}$ is determined according to EN 1992-1-1.

The c/c spacing of the ties is typically the same as the width of the thermal insulation panels to simplify assembly and minimize wastage. The recommended c/c spacing is 100 – 1000 mm. In narrow spaces such as columns (width of column zone 300 – 600 mm), it is recommended to use two ties to eliminate the risk of column buckling (see *Figure 15*).

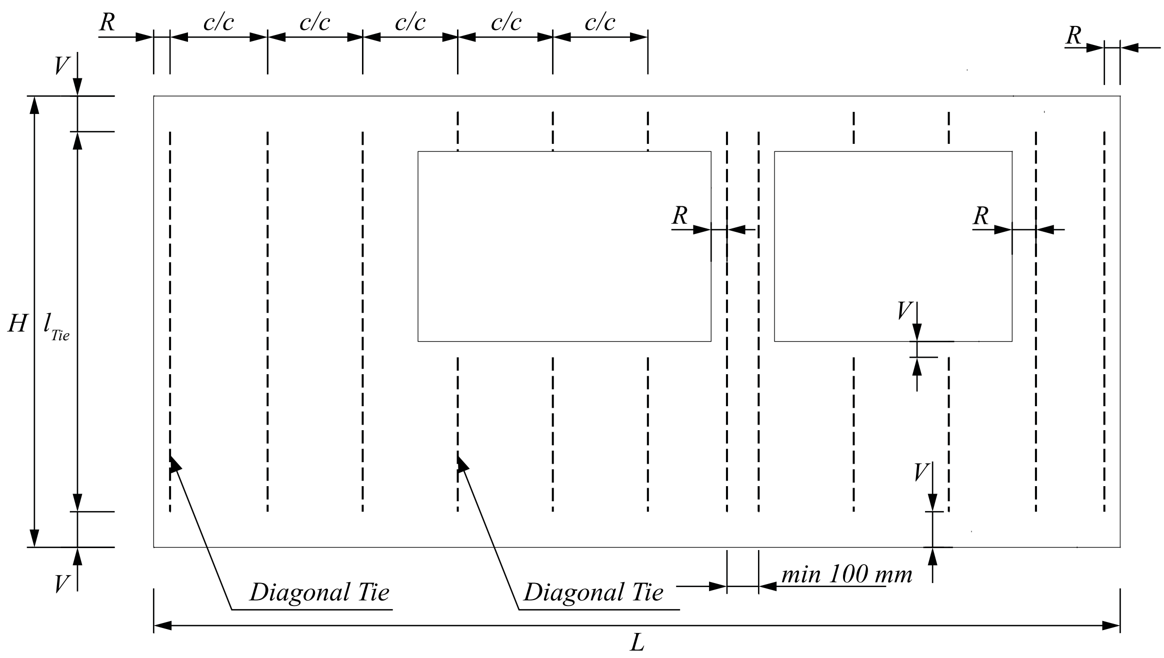


Figure 15. Placement of the Ties in the panel.

Diagonal Ties should be placed near the horizontal edges of the panel (R ≤ 100mm) to prevent deformations of the panel edges due to temperature and shrinkage effects.

For panels within the scope of application-defined in part 1.2 of this technical manual, it is recommended that the resistance of the Diagonal Ties be verified concerning the effects of structural actions using the interaction curves in Annex A.

After selecting the dimension and model of Ties, a product code describing the product may be defined according to the description in *Figure 16*. Please use this code when ordering the product from Peikko's Sales Service.

Figure 16. Product code of Diagonal Ties.

Annex A – Design Curves

The design curves may be used to verify the resistance of Diagonal Ties in sandwich panels with a scope of application as defined in part 1.2 (Application conditions) of this technical manual. Additional application conditions are defined separately for each design curve. The following design example is used to illustrate the use of design curves.

Properties of sandwich panel

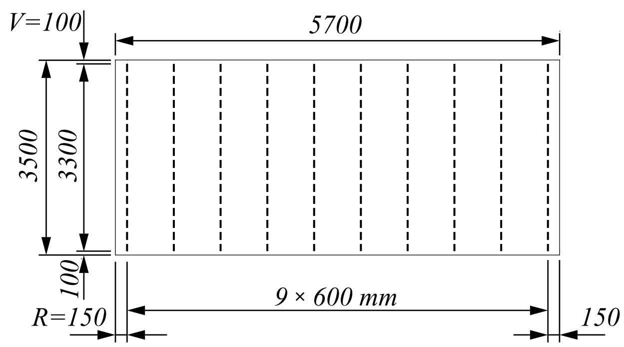
Length of the panel	5700 mm
Height of the panel	3500 mm
The thickness of the inner layer	140 mm
The thickness of the thermal insulation layer	120 mm
The thickness of the outer layer	60 mm
Spacing of the Ties	600 mm
Concrete grade of the outer layer	C25/30
Concrete grade of the inner layer	C25/30
Thermal insulation	EPS or XPS
Environment class	XS1
Reinforcing mesh in the outer layer	150 × 150 - Ø6 (A_s=188 mm^2/m)

Loads:

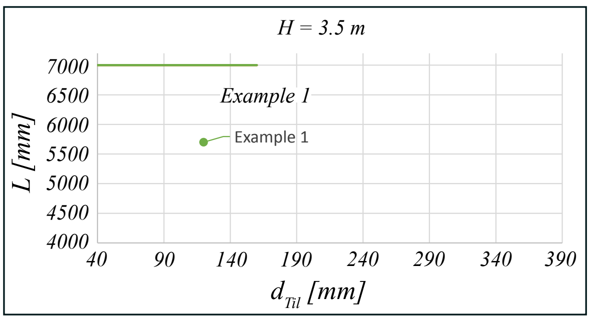
Wind suction	-0.5 kN/m^2
Maximum temperature of the outer layer	76 °C
Minimum temperature of the outer layer	5 °C
Adhesion of the formwork	1 kN/m^2
Dynamic factor during transportation	2.5

The properties and loads of the sandwich panel fulfill the conditions of the design curve on Page 20.

Placing of Diagonal Ties in sandwich panel.



Verification for the resistance of the Diagonal.



The minimum concrete cover of reinforcement for exposure class XS1 is $c_{min,dur}$ = 30mm
The concrete grade of the outer layer doesn't fulfill requirements for environment-class XS1, stainless steel shall be used in the outer layer.

Selection of Diagonal Tie height h:
$d_{Til} + c_u + c_o = 120 + 25 + 25 = 170$ mm ⇨ standardized height h of Diagonal Tie 180 (concrete cover 30 mm)
Outer concrete cover $c_{o,out} = 80 - 30 - Ø5/2 - 2 \times Ø6 = 35$ mm $> c_{min,dur}$ ⇨ Unfavorable placing of mesh reinforcement is assumed.

Selection of PD Diagonal Tie length:
Maximum Tie length ⇨ minimum edge distance $V_{min} = c_{min,dur}$
$l_{Tie,max} = H - 2 \times V_{min} = 3500 - 2 \times 30 = 3440$ mm ⇨ round down to a multiple of 300 mm ⇨ l_{Tie} = 3300mm

Verification of vertical edge distances:
$V = (H - l_{Tie}) / 2 = (3500 - 3300) / 2 = 100$ mm ⇨ OK, distance V is in interval $c_{min,dur} \leq V \leq 200$ mm

Selected model of Diagonal Ties: **PD 180 – 3300 (2400 + 900)**

Application conditions of the design curve

Design boundaries:

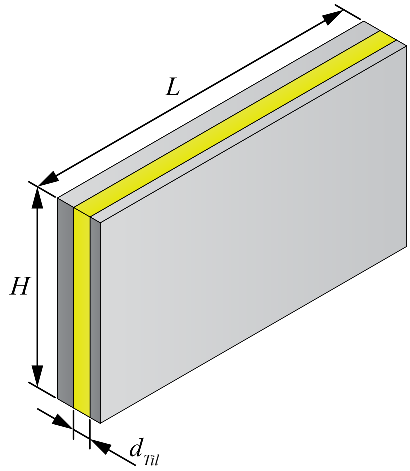
Concrete grade:	C25/30
Thickness of outer layer:	60 mm
Spacing of Diagonal Ties:	1000 mm
Maximal surface temperature:	76 °C
Temperature gradient:	$\Delta T = \pm 5$ °C
Wind suction:	-1.0 kN/m^2
Adhesion of formwork:	1 kN/m^2
Dynamic factor:	2.5

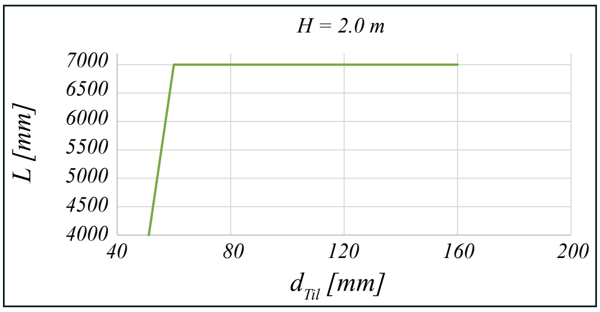
The minimum surface temperature of the outer concrete layer:

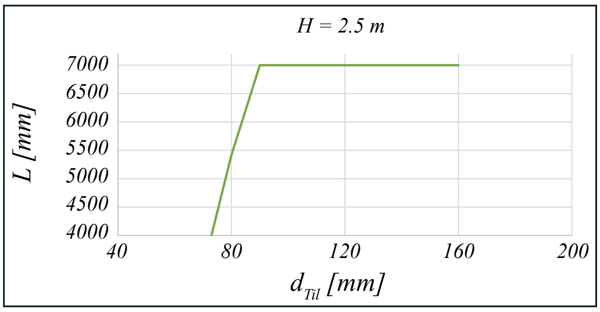
0 °C

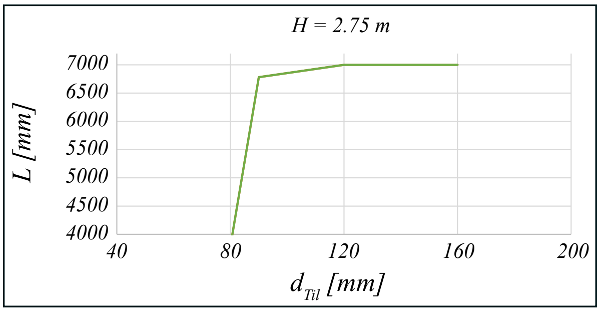
+5 °C

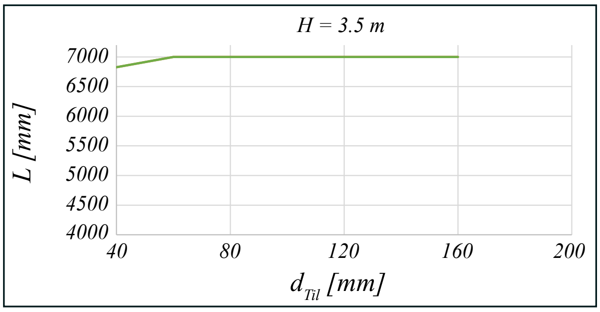
L = Length of the panel
H = Height of the panel
d_{Til} = Thickness of thermal insulation











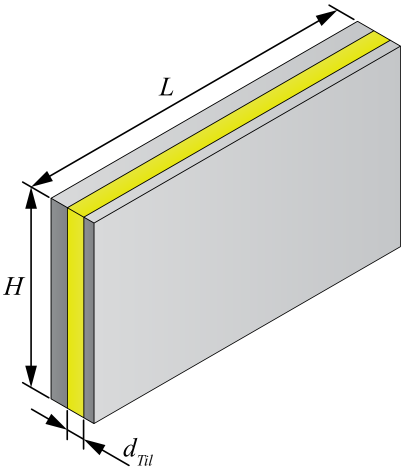
Design boundaries:

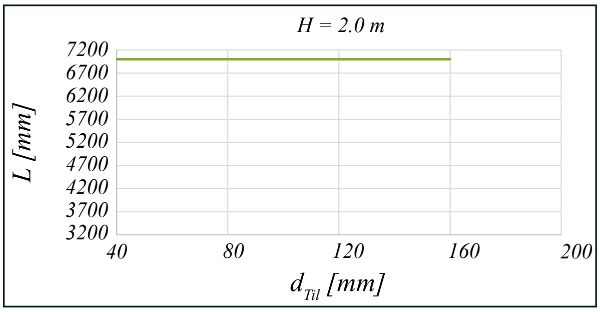
Concrete grade:	C25/30
The thickness of the outer layer:	60 mm
Spacing of Diagonal Ties:	600 mm
Maximal surface temperature:	76 °C
Temperature gradient:	$\Delta T = \pm 5$ °C
Wind suction:	-1.0 kN/m^2
Adhesion of formwork:	1 kN/m^2
Dynamic factor:	2.5

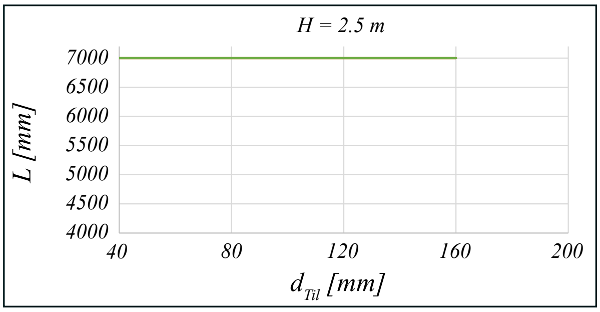
The minimum surface temperature of the outer concrete layer:

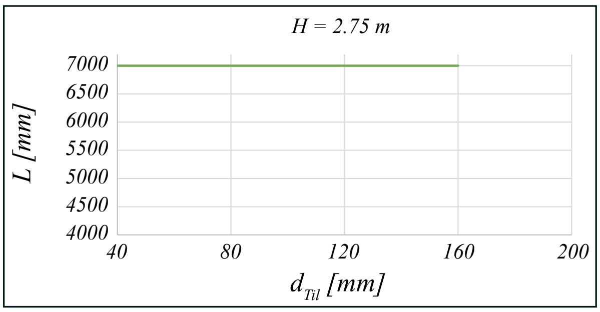
- (red line) 0 °C
- (green line) +5 °C

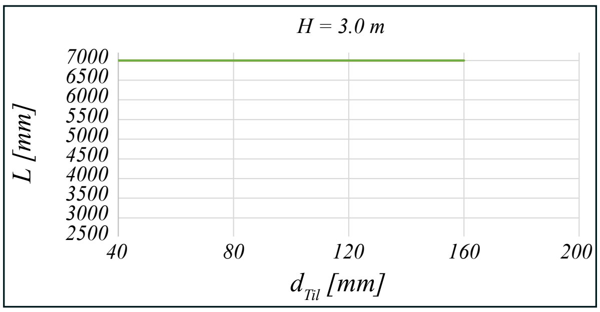
L = Length of the panel
H = Height of the panel
d_{Til} = Thickness of thermal insulation

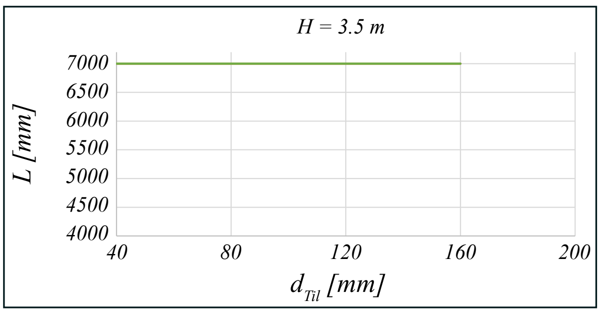












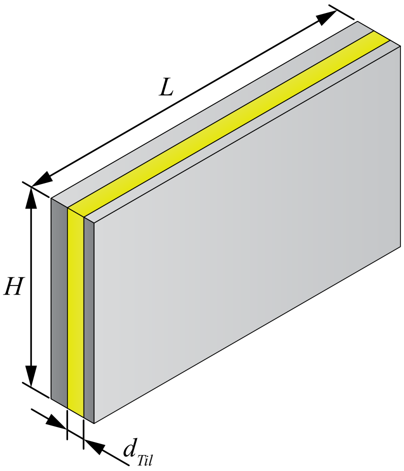
Design boundaries:

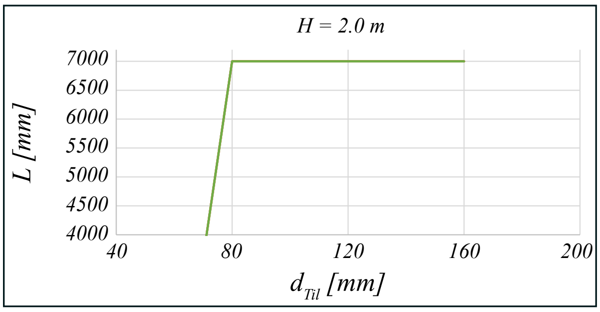
Concrete grade:	C25/30
The thickness of the outer layer:	60 mm
Spacing of Diagonal Ties:	1000 mm
Maximal surface temperature:	88 °C
Temperature gradient:	$\Delta T = \pm 5$ °C
Wind suction:	-1.0 kN/m^2
Adhesion of formwork:	1 kN/m^2
Dynamic factor:	2.5

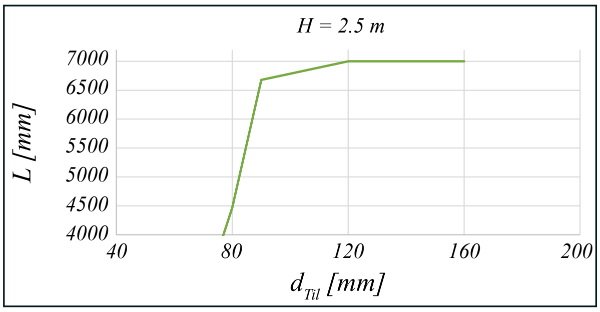
The minimum surface temperature of the outer concrete layer:

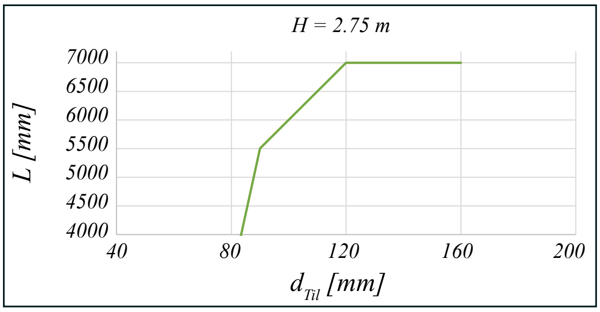
- red line: 0 °C
- green line: +5 °C

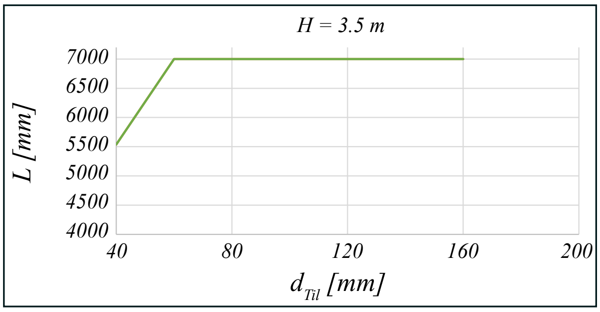
L = Length of the panel
H = Height of the panel
d_{Til} = Thickness of thermal insulation











ANNEX A

Design boundaries:

Concrete grade:	C25/30
The thickness of the outer layer:	60 mm
Spacing of Diagonal Ties:	600 mm
Maximal surface temperature:	88 °C
Temperature gradient:	$\Delta T = \pm 5$ °C
Wind suction:	-1.0 kN/m^2
Adhesion of formwork:	1 kN/m^2
Dynamic factor:	2.5

The minimum surface temperature of the outer concrete layer:

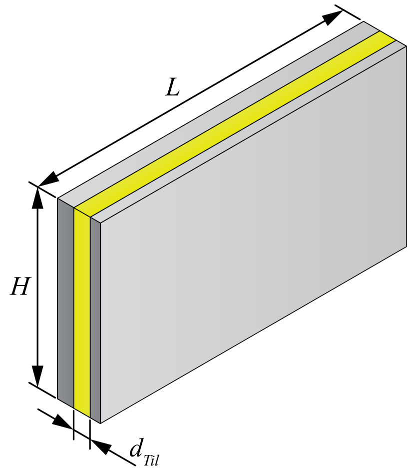
0 °C (red line)

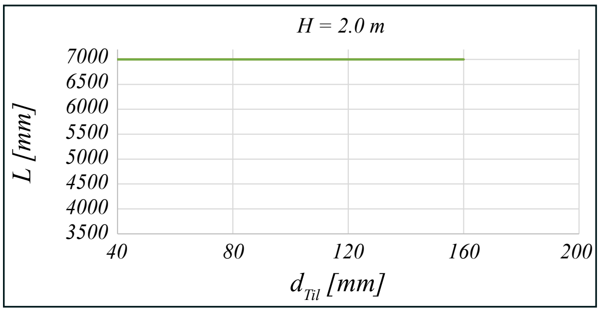
+5 °C (green line)

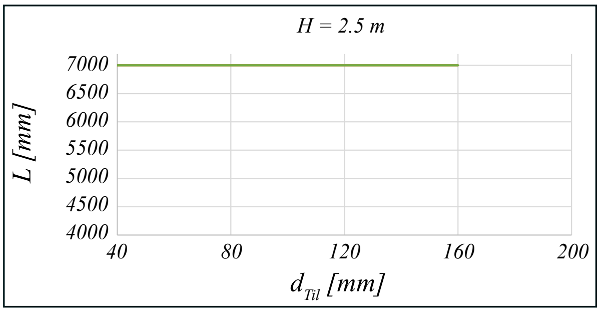
L = Length of the panel

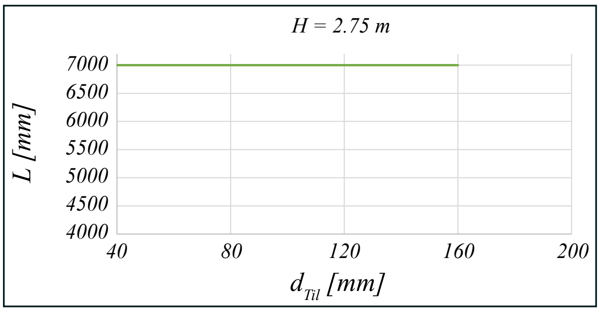
H = Height of the panel

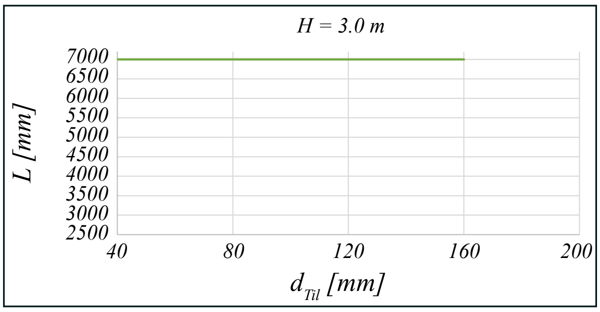
d_{Til} = Thickness of thermal insulation

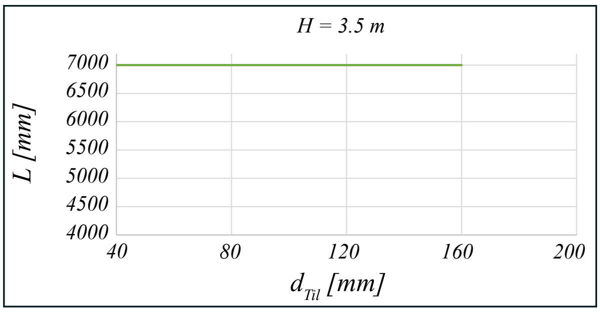












Design boundaries:

Concrete grade:	C25/30
The thickness of the outer layer:	60 mm
Spacing of Diagonal Ties:	600 mm
Maximal surface temperature:	76 °C
Temperature gradient:	ΔT = ±5 °C
Wind suction:	-1.5 kN/m^2
Adhesion of formwork:	1 kN/m^2
Dynamic factor:	2.5

The minimum surface temperature of the outer concrete layer:

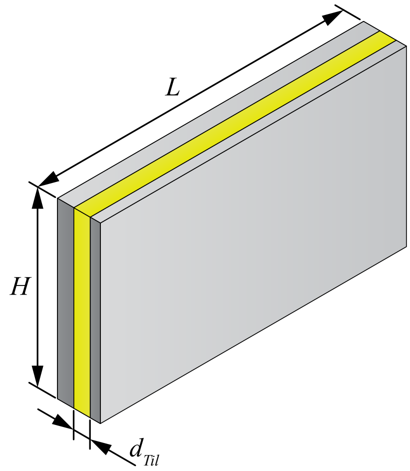
0 °C

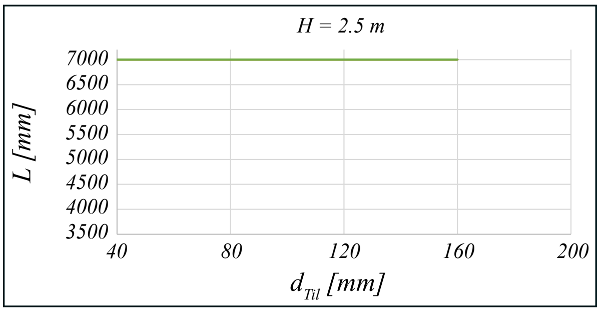
+5 °C

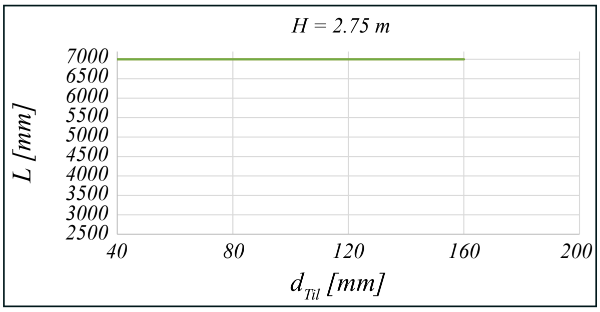
L = Length of the panel

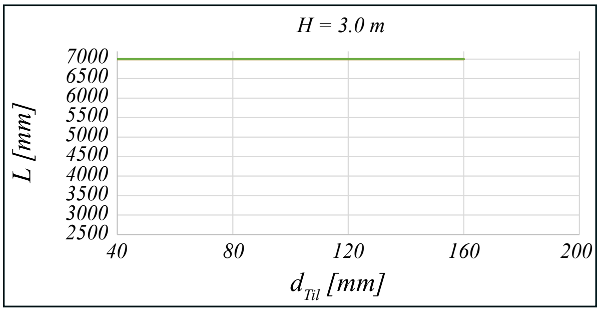
H = Height of the panel

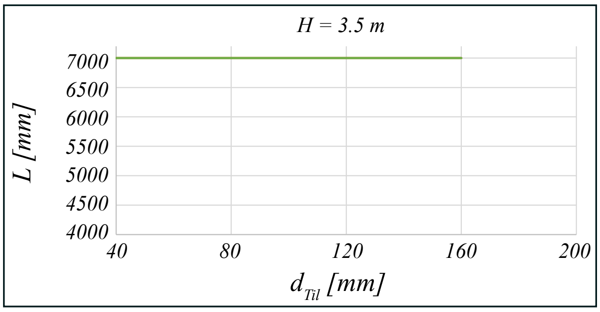
d_{Til} = Thickness of thermal insulation











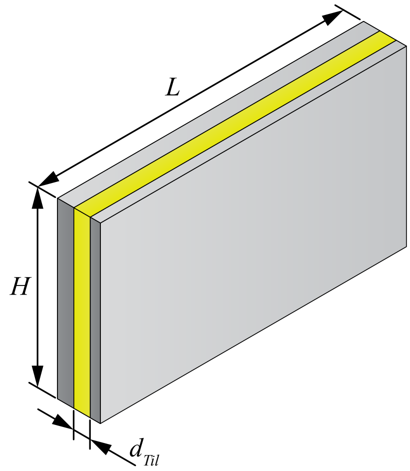
Design boundaries:

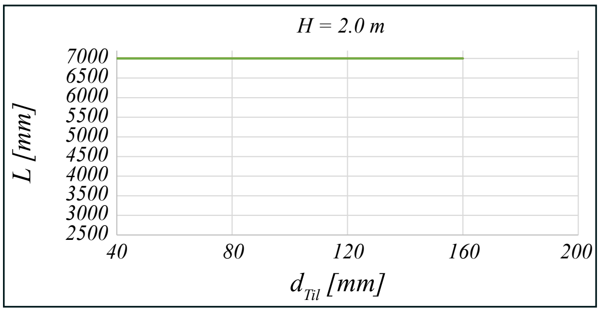
Concrete grade:	C25/30
The thickness of the outer layer:	60 mm
Spacing of Diagonal Ties:	600 mm
Maximal surface temperature:	88 °C
Temperature gradient:	$\Delta T = \pm 5$ °C
Wind suction:	-1.5 kN/m^2
Adhesion of formwork:	1 kN/m^2
Dynamic factor:	2.5

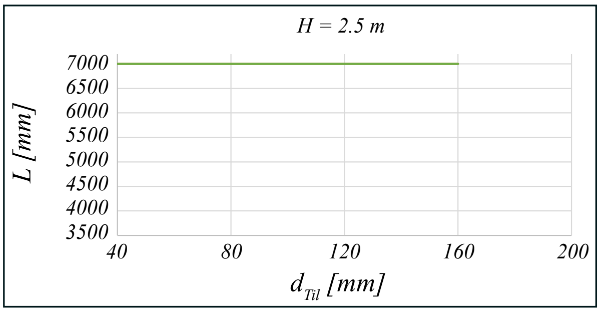
The minimum surface temperature of the outer concrete layer:

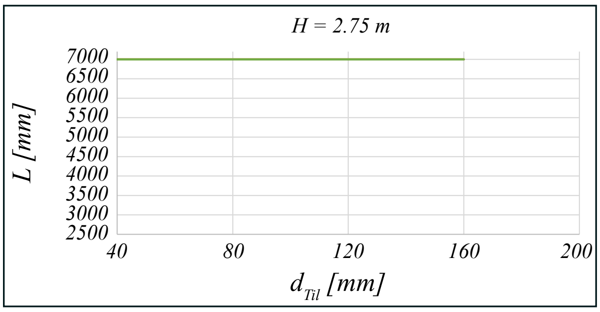
- 0 °C
- +5 °C

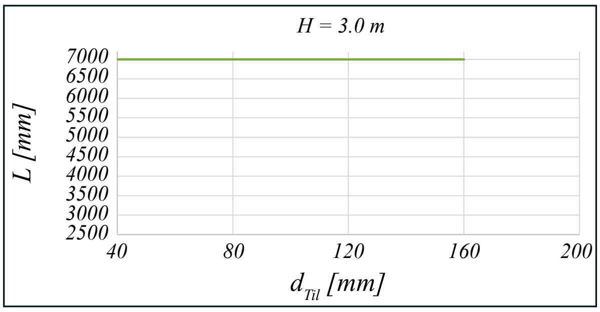
L = Length of the panel
H = Height of the panel
d_{Til} = Thickness of thermal insulation

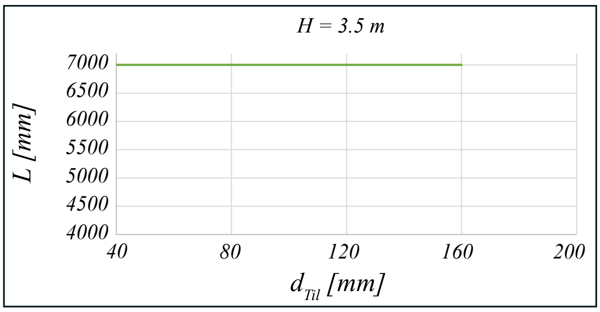












For panels outside of the scope of application defined in Section 1.2 of this Technical Manual, a customized design may be made by Peikko's Customer engineering service.

Installing Diagonal Ties

Alternative installation method no. 1

The Ties are installed into fresh concrete in turns with insulation panels. This ensures that the correct required anchoring of the tie occurs in the lower concrete panel. Ties must not be inserted through the insulation. The designed anchoring depth (see *Table 1*) of the Ties must stay above the insulation. The insulation panel is installed tightly against the tie so that there is no gap around the tie. If hard insulation materials are being used, diagonals create a gap between the insulation panels (see *Figure 17*).

Alternative Installation method no. 2

Alternatively, the Diagonal Ties can also be installed with mesh. After finishing the outer layer and pouring with concrete inner layer mesh reinforcement is bind to Diagonal Ties. Then cut insulation according to the spacing of ties and pour the inner layer with concrete. Top mesh can be installed directly on Diagonal Ties (see Figure 18).

The standard length of Diagonal Ties is 3000 mm and the maximum thickness of insulation panels is 150 mm. Multiple Diagonal Ties may be placed in one row without splicing (see Figure 19).

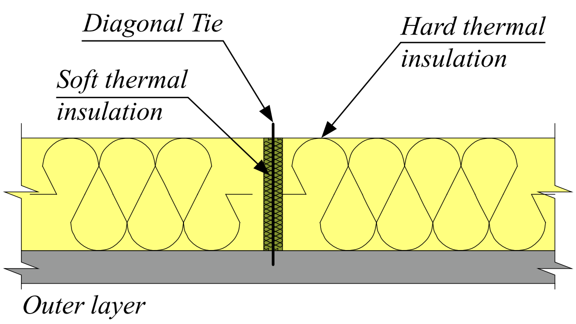


Figure 17. Soft thermal insulation between hard thermal insulation.

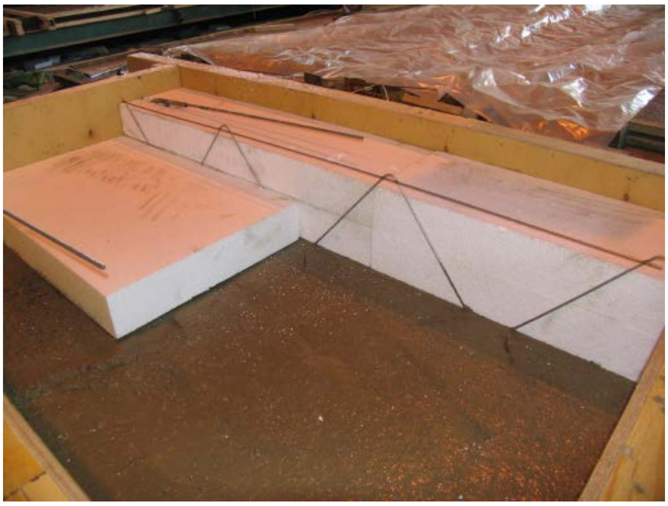


Figure 18. Installation of Diagonal Ties.

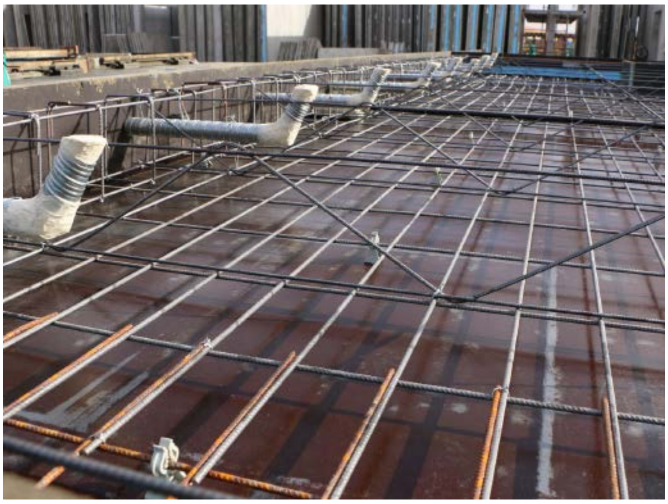


Figure 19. Diagonal ties installation with mesh.

Figure 20. PD ties after installation of insulation.

NOTES

Revisions

Version: GULF 10/2021. Revision: 002

- Diagonal Tie width range limited from 120 mm to 400 mm.
- Document brought up to date with current styles.

Version: AE, SA 08/2018. Revision: 001*

- New cover design for 2018 added.

Resources

DESIGN TOOLS

Use our powerful software every day to make your work faster, easier, and more reliable. Peikko design tools include design software, 3D components for modeling programs, installation instructions, technical manuals, and product approvals of Peikko's products.

peikko.com/design-tools

TECHNICAL SUPPORT

Our technical support teams around the world are available to assist you with all of your questions regarding design, installation, etc.

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APPROVALS

Approvals, certificates, and documents related to CE-marking (DoP, DoC) can be found on our websites under each products' product page.

peikko.com/products

EPDS AND MANAGEMENT SYSTEM CERTIFICATES

Environmental Product Declarations and management system certificates can be found in the quality section of our websites.

peikko.com/qehs