PEIKKO

WHITE PAPER

DESIGN RECOMMENDATIONS FOR HOLLOW CORE SLABS SUPPORTED ON DELTABEAM®

POSITION OF SUPPORT REACTION FORCES

AUTHORS:

Oliver Beckmann
Dipl.-Ing. (FH)
R&D Engineer
Peikko Group Corporation

Ronald Klein-Holte
R&D Manager
Consolis VBI
The Netherlands

INTRODUCTION

Floors with hollow core slabs supported on DELTABEAM® is a commonly used structural slab system. The design of this integrated flooring system is done by separate parties working together in the same building project. To have an integrated flooring system behaving as assumed, a common understanding of the interaction and the design assumptions must exist. In this paper, a safe and reliable simplification for the position of support reaction forces for the hollow core slab on the DELTABEAM® is presented. Peikko and Consolis have agreed on this design approach, based on engineering mechanics, standards, and test evaluations for the different design stages.

It should be noted that the design codes mentioned in this paper are valid within Europe. In areas outside Europe, other design rules may apply. Nevertheless, the mechanical background for the presented design approach is valid also in other countries.

SHORT DESCRIPTION OF THE TWO MAIN COMPONENTS

HOLLOW CORE SLAB FLOOR

Floor consisting of precast concrete elements with longitudinal voids and with only longitudinal prestressing tendons. No shear, transverse or spalling reinforcement is used in hollow core slabs. The vertical shear capacity is based on the main tensile strength of the concrete. Due to transmission of the prestressing force, tensile stresses occur in the webs. Normally hollow core slabs have a width of 1.20 m. After assembly of the elements, the joints are filled with concrete.

FIGURE 1 EXAMPLE OF A HOLLOW CORE SLAB CROSS SECTION

DELTABEAM® INTEGRATED COMPOSITE BEAM

DELTABEAM® is a slim floor composite beam which is integrated into the (hollow core) floor. The beam is filled with concrete on site. The infill concrete and DELTABEAM® form a composite structure after the concrete has hardened. DELTABEAM® acts as a steel beam before the infill concrete has reached the required strength. It can be used with all common floor types. Its integrated fire proofing consists of the concrete-encased steel beam and, if required, factory-installed reinforcement inside the boxed cross section which is activated when the bottom plate is heated and loses most of its strength during a fire incident.

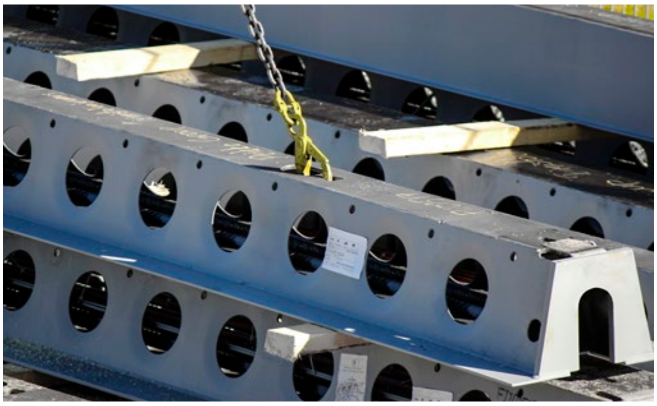


FIGURE 2 EXAMPLE OF A DELTABEAM® CROSS SECTION

VERTICAL SHEAR RESISTANCE OF HOLLOW CORE SLABS

DIRECT, RIGID SUPPORT

The vertical shear resistance of hollow core slabs for single span application is based on the uncracked (principal tensile stress) situation. The formula describing the physical stress state is given in the product standard for hollow core slabs, EN 1168 [1]. Starting point of the design is a directly and rigidly supported hollow core slab (e.g. on a brick or concrete wall). Shear test results based on EN 1168 [1], Annex J comply with the given formula and are also based on a direct and rigid support.

INFLUENCE OF AN INDIRECT SUPPORT

In case of an indirect support (connection of slabs without a support pressure underneath the slab end), the webs of the hollow core slab are loaded with additional stress on top of the stress state caused by the transfer of prestress, vertical shear forces and bending moments. For indirect support, there is some design information available (*fib* Bulletin 6 [2]), but capacity goes down to the level of cracked shear. This type of support is critical due to the strong dependency on the concrete tensile strength and should be avoided. Therefore, in most European countries, a direct support is required.

INFLUENCE OF A NON-RIGID (FLEXIBLE) SUPPORT OF HOLLOW CORE FLOORS

A non-rigid or flexible support occurs if the member supporting hollow core slabs may bend from slab loads. More than 30 full scale tests have been carried out to assess the effect of flexible support, including tests with DELTABEAM®. Based on these tests, several modified design methods were developed in different European countries, still based on the principal tensile stress approach. Additional stress due to composite action between the HCS and the supporting beam is applied in these models (= transverse shear stress in the hollow core slab webs)

FIGURE 3 SUPPORT OF HOLLOW CORE SLAB ON DELTABEAM® LEDGE

FLEXIBLE BUT DIRECT SUPPORT FOR HOLLOW CORE SLABS

In case of a flexible support on beams (e.g. DELTABEAM®), the Finnish design approach given in Codecard 18 [3] suggests a direct support of the hollow core slabs for its application in the design process (see Figure 4b). The same can be assumed for other European design approaches like Dutch CUR/BmS Aanbeveling 104 [4], German Roggendorf dissertation [5] etc., since they are all derived from the same principal tensile stress formula.

For design of hollow core slabs supported on DELTABEAM®, a direct support is suggested in the following sections of this paper.

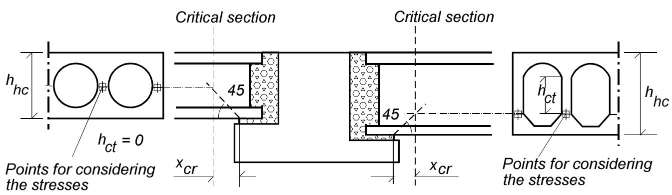


FIGURE 4 ASSUMPTIONS OF SUPPORT SITUATION IN FINNISH CODECARD 18 [3]

PARAMETERS DETERMINING THE POSITION OF SUPPORT REACTION RESULTANT FORCES

Transverse bending of the steel bottom plate ledge (outer part of the DELTABEAM® bottom plate) supporting the hollow core slabs causes a shift of the hollow core slab's support reaction towards the beam. A smaller stiffness of the ledge increases this shift. On the other hand, a deflection of the hollow core slab from slab bending, an increased stiffness of the steel flange or concrete cracking shifts the position of the reaction forces away from the beam. This demonstrates that the exact position of the support reaction is the result of an equilibrium state based on hollow core slab deflection, DELTABEAM® ledge deflection and load level. In composite stage, several additional details like connecting reinforcement, concrete cracking etc. have an influence on the resulting position.

The suggested design approach simplifies this complex interaction and provides a safe design solution. It can be furthermore stated that the position of the support reaction is self-equilibrating and small changes in its final position do not have a significant impact on design results of HCS.

SUPPORT LENGTH OF HOLLOW CORE SLABS

Chapter 10.9.5 of Eurocode 2 [6] gives guidance for the design of the minimum bearing length (at ambient temperature) of the supported hollow core floor with: a_1=30 mm / a_2=a_3=0 / Δa_2=15 mm / Δa_3=8 mm.

The result is a ≥ 50 mm based on formula 10.6 in Eurocode 2 [6]. Product manuals or local regulations may give additional information.
The assumed position of the reaction force shall be in accordance with the European design rules for the bearing length.

Other recommendations may apply outside Europe.

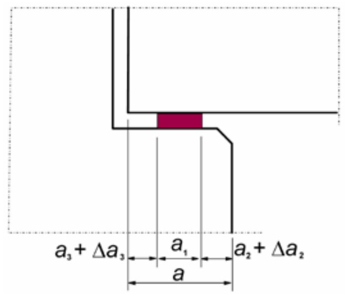


FIGURE 5 BEARING LENGTH ACC. TO FIGURE 10.6 IN EUROCODE 2 [6]

USE OF NEOPRENE STRIPS

The need of using a neoprene bearing strip between the hollow core slab and the steel ledge is depending on national regulations of the EU country, e.g.

- Germany: obligatory according to former approvals and DAfStb design guide [7]
- The Netherlands: not obligatory and not always recommended by hollow core industry
- Finland, Denmark: not applied and not recommended

For the application of the suggested design approach, the thickness of neoprene strips should not be less than 8-10 mm. This ensures proper concrete filling of the gap between the steel flange and the soffit of the slab behind the neoprene strip. If this minimum thickness cannot be applied, it is suggested to not use any neoprene strip.

DIFFERENT SUPPORT SITUATIONS THROUGHOUT THE CONSTRUCTION PROCESS AND LIFETIME

Regardless of the design phase described below and the actual support reaction position applied for design, the assumptions for the support detailing and the position of the reaction force for designing DELTABEAM® and hollow core slabs must match or be assumed on the safe side.

Three different phases for evaluating the support reaction are distinguished:

- Construction stage (absence of joint filling)
- Final stage (ULS), ambient temperature (joints are filled and hardened and cracked due to loading of the floor)
- Fire situation (reduced design load and high temperatures at the soffit of the floor)

HOLLOW CORE SLAB DESIGN – POSITION OF THE SUPPORT REACTION FORCE AND DESIGN RECOMMENDATIONS FOR THE EFFECTIVE BEARING LENGTH OF HOLLOW CORE SLABS

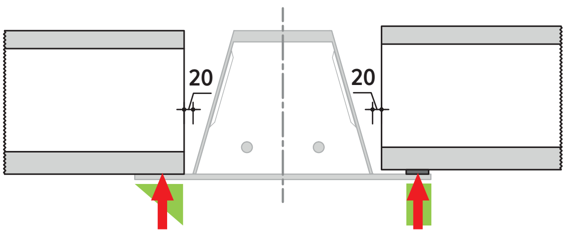
If no national guidelines or approvals apply and these do not give conflicting information, the following recommendations can be followed with respect to the position of the reaction force of the hollow core slab on DELTABEAM®'s steel bottom plate ledge and the effective bearing length.

In the following schemes, the slab support with (right side) and without (left side) a neoprene strip is combined in one figure.

The **red** arrows indicate the position of the support reaction force. The **green** shape indicates the assumed support stress distribution. The suggested position of the support reaction shall in all cases be equivalent with a direct support for the hollow core slab.

CONSTRUCTION STAGE – ASSEMBLY OF SLAB ELEMENTS

Nominal distance between slab end and the web of the DELTABEAM® is not more than 20 mm. The hollow core slabs are simply supported on the bottom plate ledge of the DELTABEAM®.



No bearing strip

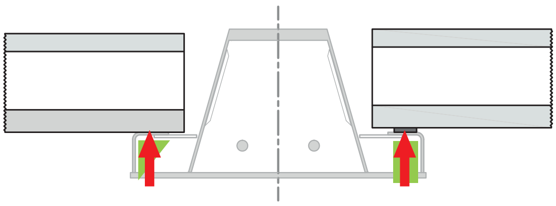
1/3 of support length

With neoprene strip

Center of neoprene strip

FIGURE 6 SUPPORT SITUATION IN CONSTRUCTION STAGE, DURING ASSEMBLY

Special case of downstand profile on DELTABEAM® flange



No bearing strip

1/3 of support length
(inverse from normal!)

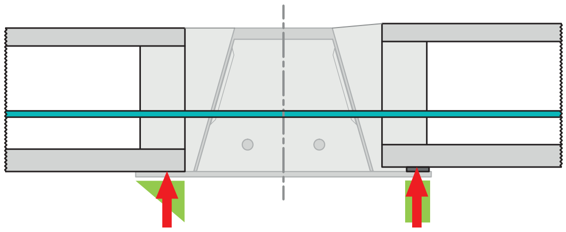
With neoprene strip

Center of neoprene strip

FIGURE 7 SUPPORT SITUATION IN CONSTRUCTION STAGE – SPECIAL CASE OF DOWNSTAND PROFILES

CONSTRUCTION STAGE – AFTER GROUTING CONCRETE

The joints are filled and hardened, and no significant additional loads are applied.



No bearing strip

1/3 of support length

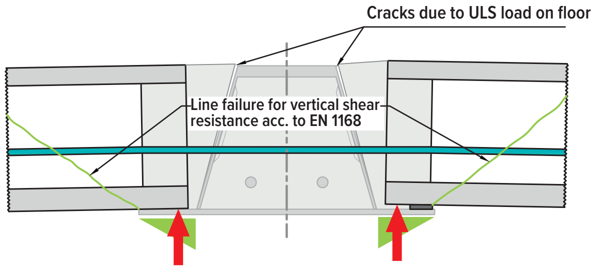
With neoprene strip

Center of neoprene strip

FIGURE 8 SUPPORT SITUATION IN CONSTRUCTION STAGE, AFTER GROUTING WITH CONCRETE

FINAL STAGE (ULS) AT AMBIENT TEMPERATURE

The verification of hollow core slabs can be done based on the stress distribution and location of the support reaction as shown in Figure 9. Basis for this design is a simply supported slab. In case of reinforced top concrete, a dilatation zone should be established to limit hogging bending moments in the slabs. A straight horizontal connecting reinforcement is applied to keep the hollow core slab and DELTABEAM® from separating and to ensure a safe load transfer.



No bearing strip

1/3 of support length
(=ledge length)

With neoprene strip

1/3 of support length
(≈ledge length)

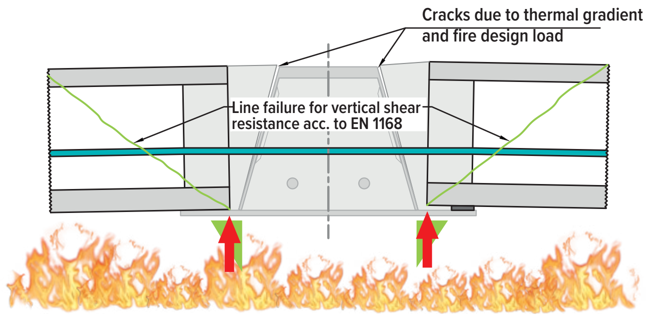
FIGURE 9 SUPPORT IN THE FINAL STAGE – AMBIENT TEMPERATURE

The line of failure for calculating the vertical shear resistance of hollow core slabs may be assumed to be starting at the outer edge of the supporting bottom plate ledge.

Please note that the crack width between DELTABEAM® and concrete grout is enlarged in figures 9 and 10 for better visibility.

IN CASE OF A FIRE INCIDENT

The reaction force shifts towards the DELTABEAM® web due to heating of the bottom plate. The support reaction can be assumed to be located at the end of the slab. The horizontal connecting reinforcement causes an inclined compression strut between slab end and the web of the DELTABEAM®. This activates the bearing length starting from the web of the DELTABEAM®.



No bearing strip — Reaction force just under slab end

With neoprene strip — Reaction force just under slab end

FIGURE 10 SUPPORT SITUATION IN CASE OF A FIRE INCIDENT

The line of failure for calculating the vertical shear resistance of hollow core slabs in fire situation is described in the following section. On the safe side, it may be assumed to start at the bottom end of the slab elements with an inclination of 45° according to EN 1168 [1], Annex G.

SUPPORT LENGTH FOR HOLLOW CORE SLAB DESIGN IN FIRE SITUATION

According to EN 1168 [1], Annex G, the support length of the hollow core slabs defines the position of the critical section and the effective anchorage length “x” of the prestressing tendons, see Figure 11. Based on the position of the support reaction described in the previous sections and derived from fire test results (e.g. [8], [9], [10]), the length of the slab support is gradually reduced during fire exposure when the bottom plate of the supporting beam is heated. Nevertheless, it could be observed that the remaining support pressure under the end of the slab is able to ensure initial anchorage of the prestressing tendons.

The exact support length in fire situation is yet depending on many parameters and cannot be specified easily.

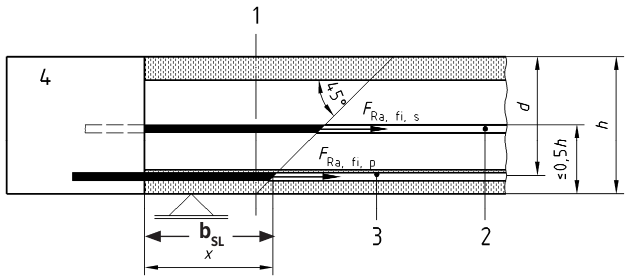


FIGURE 11 CRITICAL SECTION FOR VERTICAL SHEAR RESISTANCE IN FIRE CASE, EN1168 [1], FIGURE G.2

For design of the vertical shear resistance of hollow core slabs, it is therefore suggested as an approach on the safe side to assume a support length of

$$b_{SL} = 0\ mm$$

for calculating the slab’s vertical shear resistance. For this reason, an additional connecting reinforcement is required to maintain the required level of vertical shear resistance of the hollow core slab, based on EN 1168 [1], Annex G. The connecting reinforcement has to be properly anchored behind the inclined critical section shown in Figure 11 in the slab joints or in opened voids with concrete infill. The shear connection of the interface between concrete grout and slab concrete is sufficiently strong if the minimum anchorage length of 700 mm is met. The anchorage of the connecting reinforcement must be separately verified according to Eurocode 2 [6], which can result in a higher anchorage length. According to *fib* bulletin 6 [2], the minimum anchorage length in joints between slab elements must be at least 100*d_s.

CONNECTING REINFORCEMENT

A straight connecting reinforcement between slab elements and DELTABEAM® is required to ensure proper load transfer, avoid separation and to ensure vertical shear resistance of the hollow core slabs in fire situation, as described in the previous section. Table 1 gives an overview of the components that need to be regarded for design of the connecting reinforcement in different design situations.

TABLE 1 DESIGN COMPONENTS TO BE CONSIDERED FOR CONNECTING REINFORCEMENT

No	Component for reinforcement design
1	Torsion from unequal loading on both sides of the DELTABEAM®
2	Load transfer from slab to beam (strut-and-tie model)
3	Vertical shear resistance of hollow core slabs in fire case (EN 1168 [1], Annex G)
4	Other requirements (e.g., robustness, accidental situations, progressive collapse, etc.)

The responsibility for defining the required total amount of reinforcement has to be agreed for each project. This way, the reliability of the overall structure is secured. A generally valid rule for distributing the responsibility cannot be given here due to differences in roles and practices in different countries. Merely component 3 can be clearly assigned to the designer of hollow core slabs.

The combination rules applied should be assessed by the participating design engineers. In absence of any additional other requirements, the amount of reinforcement obtained for components 1 and 2 should be summarized. Component 3 is only required in fire situation and only the maximum amount of reinforcement for component 3 or a combination of the other components must be applied. For component 2, the amount of reinforcement must not be less than 94 mm^2/m (e.g. 1 Ø 12 mm / 120 cm), but a higher value may apply based on design calculations.

SUMMARY AND CONCLUSION

The presented paper is a tangible result of common effort and sharing of internal information from both Peikko and Consolis. We as companies together strive for smooth and reliable design processes and for more cooperation between all parties involved in projects worldwide. For a safe and reliable application of innovative solutions and products, a common understanding of their interaction and good communication between the stakeholders are of particular importance.

This document provides a safe and reliable simplification for the position of support reaction forces as well as guidance on the dimensioning of connecting reinforcement between Peikko's DELTABEAM® and hollow core slabs for different design situations.

REFERENCES

[1] CEN - Comité Européen der Normalisation, „EN 1168 - Precast concrete products - Hollow core slabs; Version 2005 + A3:2011," CEN, Brussels, 2011.

[2] fédération internationale du béton (fib), „Bulletin 6 - Special design considerations for precast prestressed hollow core floors," 2000"

[3] Suomen Betoniyhdistys r.y., „Code Card No 18 - Design of hollow core slabs supported on beams," Helsinki, 2012.

[4] CUR/BmS, „Aanbeveling 104 - Vloeren van kanaalplaten med geintegreerde liggers," CUR, Gouda, NL, 2006.

[5] T. Roggendorf, „Zum Tragverhalten von Spannbeton-Fertigdecken bei biegeweicher Lagerung," Rheinisch-Westfälische Technische Hochschule Aachen, Fakultät für Bauingenieurwesen, Aachen, 2010.

[6] CEN - Comité Européen de Normalisation, „EN 1992-1-1 - Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings; Version 2004 + AC:2010," CEN, Brussels, 2010.

[7] DAfStb - Deutscher Ausschuss für Stahlbeton, „DAfStb-Richtlinie Decken und Dächer aus Fertigteilhohlplatten, Teil 2 (unveröffentlichter Entwurf)," DAfStb, not published yet, Stand 05/2021.

[8] MFPA Leipzig GmbH, „Prüfbericht Nr. PB 3.2/19-251-2 - Belasteter Brandversuch," not published, Leipzig, 2020.

[9] MFPA Leipzig GmbH, „Prüfbericht Nr. PB 3.2/19-251-3 - Belasteter Brandversuch," not published, Leipzig, 2020.

[10] SP Technical Research Institute of Sweden, „Fire test of a loadbearing floor construction, P802216A/B/C/D," not published, Boras, Sweden, 2010.

THIS PAPER HAS BEEN DEVELOPED THROUGH COOPERATION BETWEEN:

Voimakatu 3
15170 Lahti, Finland
www.peikko.com

Gjörwellsgatan 30,
11260 Stockholm, Sweden
www.consolis.com

DISCLAIMER

The content presented in this paper has been carefully prepared and thoroughly checked based on existing European design codes, test results and experience from design practice. However, any results from use of content presented in this paper may not be applicable or accurate with regard to the individual circumstances. In any case, the content presented in this paper must be checked for compliance with the project requirements by the professional project engineer.

Neither Peikko Group Corporation, nor Consolis Group, nor, where applicable, their parent, subsidiaries, members, officers, directors, agents and employees, nor authors or publishers of this paper are responsible for any engineering review or evaluation, or any design or the performance thereof.

Neither Peikko Group Corporation, nor Consolis Group, nor, where applicable, their parent, subsidiaries, members, officers, directors, agents and employees, nor authors or publishers of this paper shall be liable for any injury, expenses, loss, or damage, whether direct, indirect or consequential, or any other pecuniary loss or expense arising out of use of the content presented in this paper.

All content presented in this paper is provided in good faith, however no representation or warranty of any kind, express or implied, is given, regarding the accuracy, adequacy, validity, reliability, availability or completeness of any content in this paper.

A faster, safer, and more efficient way to design and build

Peikko is a leading global supplier of slim floor structures, wind energy applications and connection technology for precast and cast-in-situ. Peikko's innovative solutions offer a faster, safer, and more efficient way to design and build.

www.peikko.com

peikko®