*Acta Polytechnica CTU Proceedings* **49**:55–59, 2024
https://doi.org/10.14311/APP.2024.49.0055


# A SIMPLIFIED DESIGN OF A CONCRETE SANDWICH STRUCTURE CONTAINING A REINFORCING RIB

Jan Macháček[a,*], Eliška Kafková[a], Věra Kabíčková[a,b], Tomáš Vlach[a,b]

[a] *Czech Technical University in Prague, Faculty of Civil Engineering, Department of Architectural Engineering, Thákurova 7, 166 29 Prague, Czech Republic*

[b] *Czech Technical University in Prague, University Centre for Energy Efficient Buildings, Třinecká 1024, 273 43 Buštěhrad, Czech Republic*

[*] corresponding author: jan.machacek@fsv.cvut.cz

Abstract. This article presents the use of a strut and tie analogy for modelling the behaviour of a concrete sandwich structure, which is formed by thin outer concrete layers made of high-performance concrete and reinforcing ribs. The beams transmitting shear are made of a rigid material with low thermal conductivity (Purenit) in combination with a carbon fibre reinforced polymer. The purpose of these ribs is to ensure reliable shear interaction of the outer concrete layers regardless of the thermal insulation of the sandwich structure. A simplified model using the truss analogy in the Scia Engineer software was used for the design of this structure. Furthermore, this design was verified experimentally on a section of the sandwich panel where the feasibility and functionality were tested by a four-point bending test. Finally, the theoretical values from the model were compared with the experimental results. This also includes a simple evaluation of whether this simplified modelling of the structure's behaviour is appropriate. The paper contains a summary of the conditions that could have affected the results.

Keywords: High performance concrete, precast concrete, sandwich panels, composite reinforcement, shear reinforcement, rigid heat insulation, strut-and-tie model.

## 1. Introduction

Precast concrete sandwich panels are formed from two thin outer layers made of concrete (nowadays from high performance concrete) which are connected by some kind of shear connectors between which is placed thermal insulation. The connectors where historically from steel [1] but due to high thermal conductivity of steel which resulted in significant heat bridges, which depreciated value of heat transfer coefficient (U-value) of construction, we are trying to replace them. So nowadays they are mostly from some kind of fibre reinforced polymers like for example CFRP, GFRP etc. or is used only rigid thermal insulation placed between concrete layers. The shear connections methods are investigated by many scientists all over the world, for example Richard O'Hegarty [2, 3], Abdelghani Benayoune [4], Kamil Hodicky [5], Mathias Flansbjer [6] and many others [7, 8]. In this case is the shear connection solved by reinforcing ribs composed from rigid heat insulation (specially from purenit) and braids from CFRP. The problem is that it is very hard to predict behaviour of panels during loading because of panels composition from many components which have different properties. This article deals with the use of strut and tie model for modelling of precast sandwich concrete panel behaviour. The first step was to test mechanical properties of materials which are used in sandwich panel. Then was created strut and tie model in Scia Engineer with values gained from material tests and was created panel section sample. In the last step the panel section was tested by a four-point bending test and the theoretical values from the model were compared with the experimental results.

| Mix content | $kg\,m^{-3}$ |
|---|---|
| Cement I 42.5R | 650 |
| Technical silica sand | 1 200 |
| Elkem microsilica 940 U-S | 100 |
| Technical quartz powder ST 6 | 235 |
| Superplasticizer based on PCE | 18 |
| Water | 190 |
| Total | 2 393 |

Table 1. HPC mix design.

## 2. Materials used in panel section sample and properties tests

### 2.1. High performance concrete

Thin outer layers of PCSP are from HPC in this case specifically from the HPC who's mix design is listed below. This mixture was developed in department of civil engineering at CTU in Prague and later improved in UCEEB at Buštěhrad. For determining panel's behaviour during loading test as accurately as possible was necessary to test concrete's properties. 6 samples were tested in total. 3 cubes with

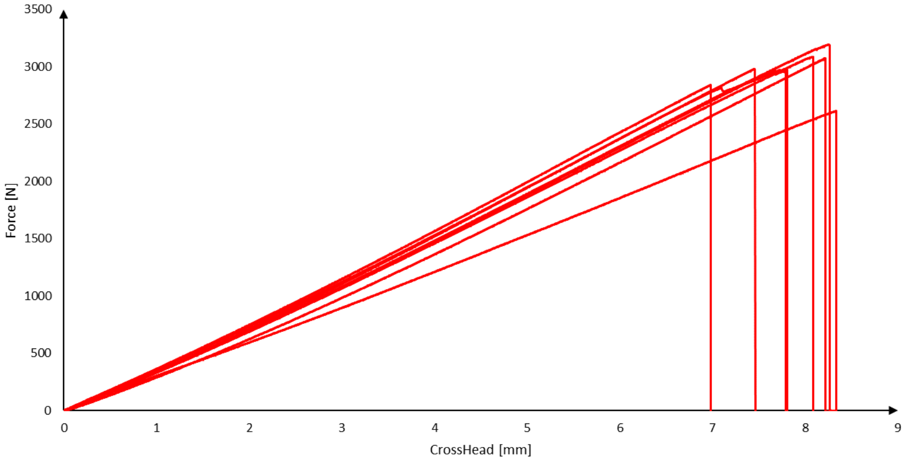


Figure 1. Tensile test of carbon composite reinforcement.

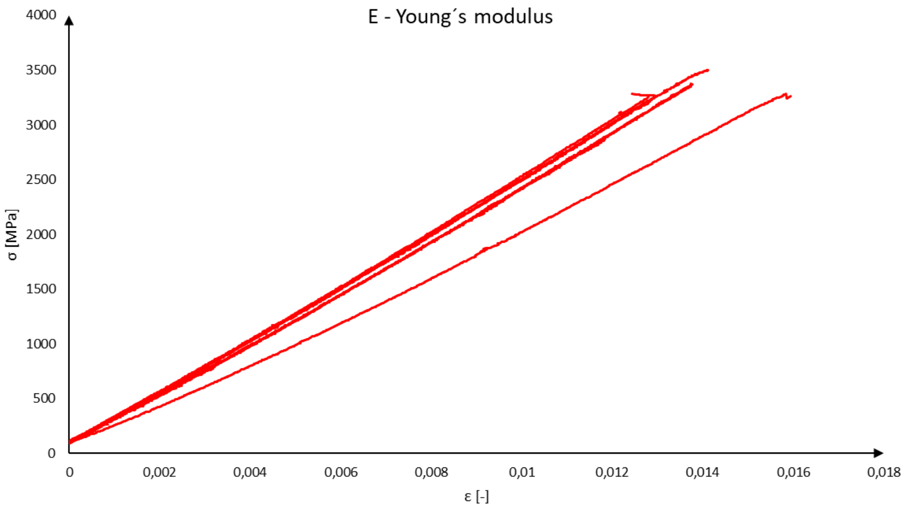


Figure 2. Young's modulus of carbon composite reinforcement.

an edge of 100 mm and 3 beams with the dimensions 40 × 40 × 160 mm. The cubes were tested in compression according to ČSN EN 12390-3 [9] and the beams were subjected to three-point bending test according to ČSN EN 12390-5 [10].

The test measured the average strength of concrete in central pressure at cube 97.42 MPa according to ČSN EN 12390-3 [9] and the average tensile strength of the concrete under bending measured on beams at 15.51 MPa according to ČSN EN 12390-5 [10]. Modulus of elasticity was known from previous tests which was done in UCEEB during developing of the mixture and its value is 45.00 GPa. These values were used for calculations.

### 2.2. Carbon fibre reinforced polymer

As a shear reinforcement of the panel which is subject of this article is used a composite reinforcement consisting of epoxy resin and carbon fibres TenaxTH – E STS40 F13 24k 1600 tex from TEIJIN. Before creation of panel were created 8 samples of this reinforcement which were tested by uniaxial simple tension on the test equipment. The maximum force at material failure was monitored (bearing capacity) and the dependence of the relative deformation on stress (approximate Young's modulus of elasticity). The results of test are presented in the Figure 1: Tensile test of carbon composite reinforcement and Figure 2: Young's modulus of carbon composite reinforcement.

Tensile tests of carbon composite reinforcement revealed that the rovings achieve average tensile strength of 2 968.30 N which corresponds to a stress of 3.28 GPa and that the average Young's modulus is 237.60 GPa. These values were used in the following calculations.

### 2.3. Purenit

As part of this work the behaviour of purenit under pressure loading was tested, specifically 3 samples of width 100 mm, thickness 30 mm and height 180 mm. These dimensions were accurately measured by calliper at 3 locations and from the measured values the average value was calculated. After measure the samples were loaded at a speed of 1 mm per minute until failure. From the loading tests was obtained the working diagram of purenit which were used in following calculations.

Based on the results of loading tests the average breaking strength of purenit is 8.25 MPa as presented

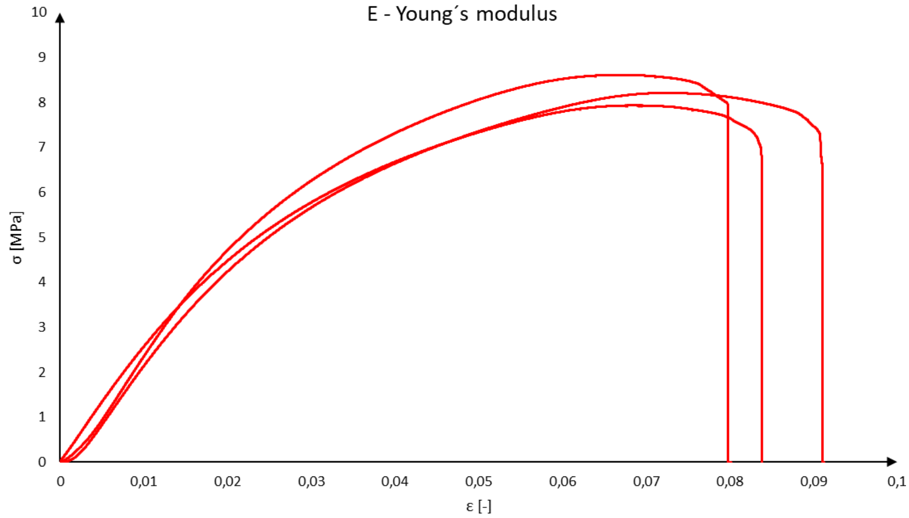


FIGURE 3. Young's modulus of purenit.

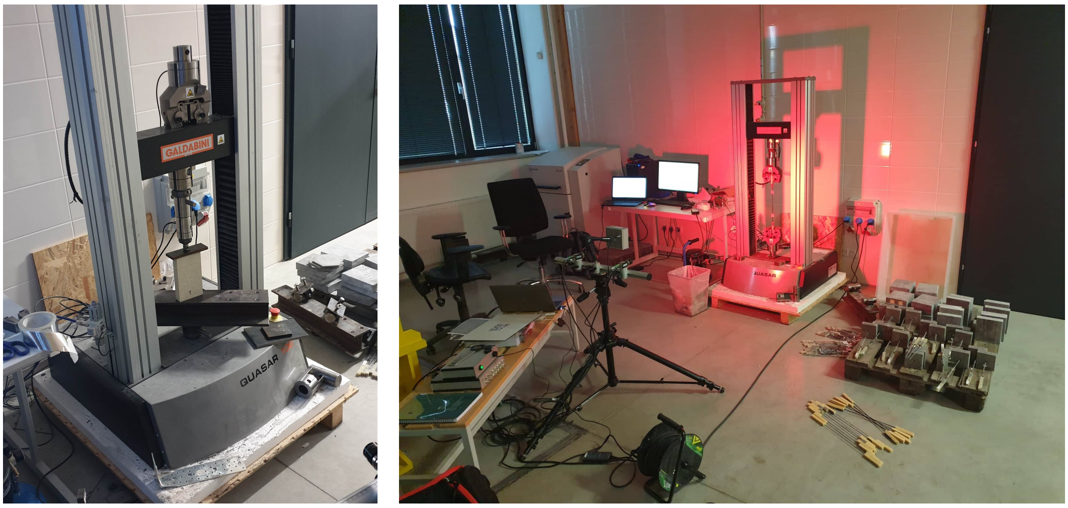


FIGURE 4. Photos from materials tests.

in Figure 3 and the modulus of elasticity is 226.28 MPa, which approximately corresponds to the data in the technical sheet from manufacturer [11]. After exceeding the load-bearing capacity, the material literally flew to pieces. To the value of 3.50 MPa the material's behaviour was elastic.

## 3. STRUT-AND-TIE MODEL

For the calculation purpose the entire panel was significantly simplified. In calculation model the panel construction is represented by strut-and-tie model which is essentially a rib's longitudinal section. The strut-and-tie model works as follow: the upper compression bar and lower tension member represents outer concrete layers, so in the calculation model they are from concrete profiles which are 2 cm high, 50 cm wide and have properties which were measured on concrete samples. The diagonals represent shear reinforcement, so their area and properties correspond to area and measured properties of the used reinforcement from CFRP and the shafts represent purenit.

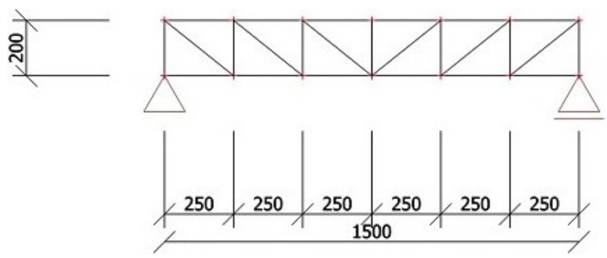


FIGURE 5. Strut-and-tie model.

The model as presented in Figure 5 and Figure 6 has been loading by 2 forces operating in thirds of the truss beam until the calculated stress in diagonals has the breaking strength value [12].

Because strut-and-tie model represent only one rib and experimental panel has two, the forces must be summarized and multiplicated by two. So, the prediction based on the strut-and-tie model is that after force on the press reaches 36.52 kN the shear reinforcement will break and then the panel collapses due to shear failure of the rib from purenit.

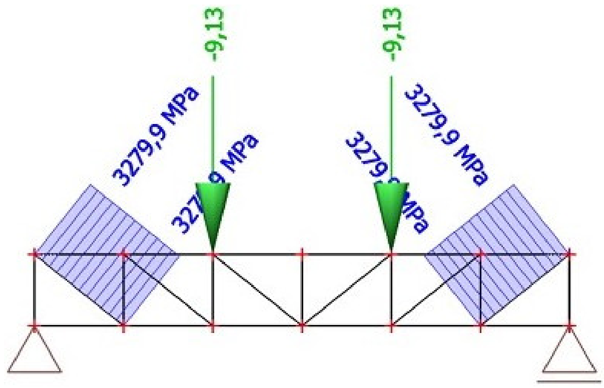


Figure 6. The breaking strength.

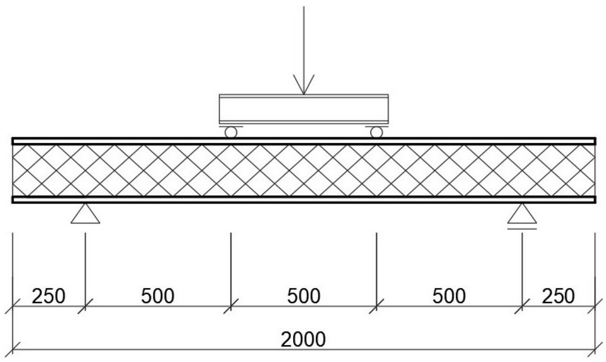


Figure 7. Schema of four-point bending test.

Figure 8. Photo from four-point bending test.

Figure 9. Detail of the purenit rib shear failure.

## 4. Experiment

The load test of the panel took place at UCEEB and were carried out using a press from which the force was transmitted through a pair of welded I-sections to achieve a four-point bending load. Scheme of four-point bending test is presented in Figure 7 and photo from testing procedure in Figure 8. Loading was carried out at a rate of 3 mm per minute, and it continued until the structure failed.

The first shear reinforcement failed when the force on the press was 30.00 kN, after that panel's behaviour stopped being linearly elastic and composite reinforcement gradually began to fail until finally the structure collapsed due to the shear failure of the purenit ribs as presented in Figure 9. The maximum force on the press was 54.58 kN.

## 5. Comparison

As you can see in presented Figure 10 below, the strut-and-tie model predicted, that the panel will collapse when the force on the press will be 36.52 kN due to failure of the shear reinforcement. It is very close to the real force 30.00 kN at which the shear reinforcement started to fail but strut-and-tie model didn't deal with plastic reserve. Panel collapsed when the force on the press was 54.58 kN which is much more than was expected. The same we can say about deformation which were smaller than was expected, because purenite with a large cross-sectional area also has large effect.

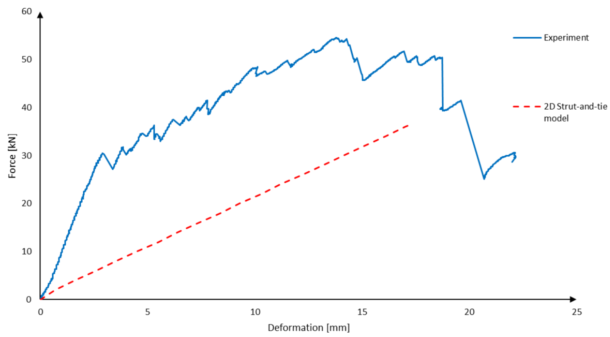


Figure 10. Experiment vs. strut-and-tie model.

## 6. Conclusion

The strut-and-tie model provides results which are "on the safe side" so this model could be used for the approximate design of the precast concrete sandwich panels but doesn't perfectly describe the real behaviour. To achieve more accurate results could be useful to use some software for nonlinear analysis like ATENA etc. The results could be affected by geometric differences between strut-and-tie model and the real panel. In the real panel the angle of shear reinforcement was 45°, in the model it was 38.65°. The results also could be affected by violation of the shear reinforcement during the creation of the panel which could lead to former shear reinforcement failure than expected. There is also a problem with small number of samples because the only one sample was tested which means that the result isn't statistically significant.

### Acknowledgements

The work on this paper was supported by Czech Science Foundation Grant No. 22-14942K entitled "Possibilities of using natural fibers for the production of hybrid textile reinforcement in concrete". The authors would like to acknowledge all financial assistance provided to support this research.

### References

[1] A. Einea, D. C. Salmon, G. J. Fogarasi, et al. State-of-the-art of precast concrete sandwich panels. *PCI journal* **36**(6):79–98, 1991. https://doi.org/10.15554/pcij.11011991.78.98

[2] R. O'Hegarty, O. Kinnane, M. Grimes, et al. Development of thin precast concrete sandwich panels: Challenges and outcomes. *Construction and Building Materials* **267**:120981, 2021. https://doi.org/10.1016/j.conbuildmat.2020.120981

[3] R. O'Hegarty, R. West, A. Reilly, O. Kinnane. Composite behaviour of fibre-reinforced concrete sandwich panels with FRP shear connectors. *Engineering Structures* **198**:109475, 2019. https://doi.org/10.1016/j.engstruct.2019.109475

[4] A. Benayoune, A. A. Abdul Samad, D. N. Trikha, et al. Flexural behaviour of pre-cast concrete sandwich composite panel – experimental and theoretical investigations. *Construction and Building Materials* **22**(4):580–592, 2008. https://doi.org/10.1016/j.conbuildmat.2006.11.023

[5] K. Hodicky, T. Hulin, J. W. Schmidt, H. Stang. Structural performance of new thin-walled concrete sandwich panel system reinforced with BFRP shear connectors. In *Proceedings of the 4th Asia-Pacific Conference on FRP in Structures*. 2013. https://doi.org/10.25916/sut.26269924.v1

[6] M. Flansbjer, N. Williams Portal, D. Vennetti, U. Mueller. Composite behaviour of textile reinforced reactive powder concrete sandwich façade elements. *International Journal of Concrete Structures and Materials* **12**(1):71, 2018. https://doi.org/10.1186/s40069-018-0301-4

[7] A. Shams, M. Horstmann, J. Hegger. Experimental investigations on textile-reinforced concrete (TRC) sandwich sections. *Composite structures* **118**:643–653, 2014. https://doi.org/10.1016/j.compstruct.2014.07.056

[8] J.-Q. Huang, J.-G. Dai. Direct shear tests of glass fiber reinforced polymer connectors for use in precast concrete sandwich panels. *Composite structures* **207**:136–147, 2019. https://doi.org/10.1016/j.compstruct.2018.09.017

[9] Czech Office for Standards, Metrology and Testing. ČSN EN 12390-3. Zkoušení ztvrdlého betonu – Část 3: Pevnost v tlaku zkušebních těles [In Czech], 2020.

[10] Czech Office for Standards, Metrology and Testing. ČSN EN 12390-5. Zkoušení ztvrdlého betonu – Část 5: Pevnost v tahu ohybem zkušebních těles [In Czech], 2020.

[11] Izolace-info.cz. Purenit – přesvědčivý funkční materiál s rozmanitým využitím [In Czech]. https://www.izolace-info.cz/technicke-informace/zateplovanifasady-1/22656-purenit-presvedcivy-funkcni-material-s-rozmanitym-vyuzitima.html

[12] J. Macháček. *Vliv smykové kompozitní výztuže na únosnost betonových sendvičových panelu [In Czech; Influence of composite shear reinforcement on bearing capacity of concrete sandwich panels]*. Master's thesis, Czech Techical University in Prague, 2022.