Application referring to the effect of continuous deck occurring in the joint used in the ceiling structure

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Abstract. The usage of hybrid structures brings advantages in their application. Structures with appropriately combined materials within the supporting structure are able to withstand higher loads and overcome larger spans. Effective structural solutions can also be achieved by combining materials such as cross laminated timber, concrete, and steel. The result is the achievement of a more efficient construction and at the same time achieve an aesthetic, but also an ecological structure, furthermore, creating a slimmer ceiling structure can ensure financial savings. In order to achieve the maximum use of the potential of the structure, it is necessary to create suitable structural connections. By creating a suitable joint among the ceiling decks and the beam, it is possible to create a load-bearing ceiling structure that behaves like a continuous deck. In this paper, numerical analysis of selected types of joints are performed and compared. During the examination, an adjustment has been made for alternative joint variation. After updating the proportions of components in this specimen, alternative sample of joint was able to withstand loads applied during analysis. Examined joint connection offers alternative to original joint connection.

1 Introduction

Due to emphasis of using sustainable materials witch are also able to withstand high construction standards is hybrid construction appropriate option. Main idea of designing hybrid structures is using combination of materials in their best possible way of their application [1]. Combining steel with concrete or even also with timber are mainly used combinations in this type of constructions. Effective combination of materials allows to obtain a structure that is able to accept higher loads and also withstand longer spans of the ceiling structure [2].

The effective design of the ceiling load-bearing structure allows to reduce the height in the ceiling, the easiest way to get the best solution is creating a slim-floor [3]. The limitation of the usage of continuous deck is a frequent problem that arises when applying a slim-floor system. Appropriate detail of ceiling connections is the key to a troubleshooting.

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2 Hybrid structure

To achieve more and more efficiency of hybrid ceiling systems, it is necessary to achieve a result with the most capable modules of each component within the system. By using suitable combination of materials is possible to get more efficient structure, especially with ceiling constructions, the height of the floor construction also plays a significant role [4].

Based on this reason, there is a tendency to create the thinnest possible load-bearing structure, the so-called Slim-Floor, this can be achieved by placing the ceiling panels on the lower flange of the beam. This principle creates reduction in height by the height of the ceiling beam, considering that the ceiling slab are no longer placed on the upper edge of the steel beams (Figure 1). A steel beam combined with massive timber ceiling panels, mostly used cross-laminated timber (CLT), is common combination mostly used in slim floor construction. However, the use of a simple solution consisting of the use of a hot formed H-shaped cross-section has significant disadvantages, especially in a fire situation [5].

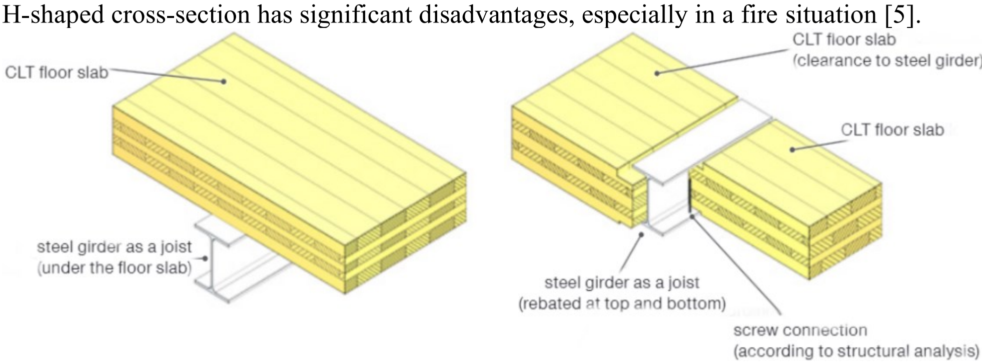

Figure 1: Comparison of regular configuration of hybrid ceiling system and slim-floor system. [5]

2.1 Classification of hybrid structure

Steel cross-section replaced by composite cross-section significantly increases the durability of the structure. Namely DELTABEAM is the steel girder infilled with concrete, that creates durable composite beam. The combination of CLT ceiling slabs and DELTABEAM beam from Peikko has been used since 2011 [6]. Within the system, panels can be applied as simply laid decks or as continuous decks. However, the question arises as to how to interconnect individual decks on the opposite sides of the beam, so that the system can be considered as continuous deck.

2.2 Previously examined research

Research program focused on DELTABEAM with timber floor solutions was initiated by Peikko [7]. Investigation was focused on the load transfer from the slab to the beam through a compression arch against inclined web it is laboratory research. Full-scale load transfer tests were carried out [8]. Three main groups of specimens were examined. In the first group of samples (A1-A4), a floor joint consisting of DELTABEAM and a timber slab was applied. DELTABEAM composite timber slabs were used as samples in the second (B1-B4) and third assembly of the group (C1-C2). As shown in the Figure 2 CLT panels are laid on the downstand within the C series. During this set of experiments was inclination of timber edge examined to. Verification has occurred by using specimens with vertical and also inclined edge of panel. In latter case was fire situation examined. The supporting lower ledge with the inclined timber edge in order to simulate the fire conditions was removed. In fact, the steel ledge loses a major part of stiffness and resistance when exposed to fire. Used cross-sections for all specimens are described in the Figure 2.

	Specimen	Timber edge	Ledge
DELTABEAM® Timber slab	A1	Vertical	yes
	A2	Inclined	yes
	A3	Inclined	no
	A4	Inclined with pockets	no
DELTABEAM® Composite Timber slab	B1	Vertical	yes
	B2	Inclined	yes
	B3	Inclined	no
	B4	Inclined with chamfers	yes
	C1	Vertical	yes
	C2	Inclined	yes

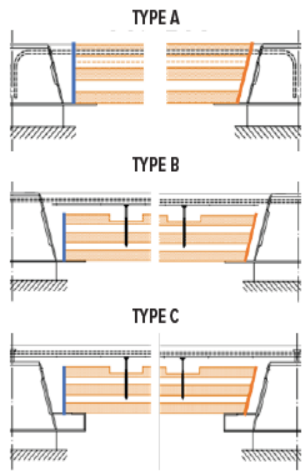

Figure 2: Overview of the specimens [8].

Group A has an applied the design load level corresponding to a 6 x 6 m grid with 3 kN/m^2 live load. The design load level corresponding to a 7 x 7 m grid with 3 kN/m^2 live load was applied during examination of B and C group of specimens [8]. The test set-up is shown in Figure 3.

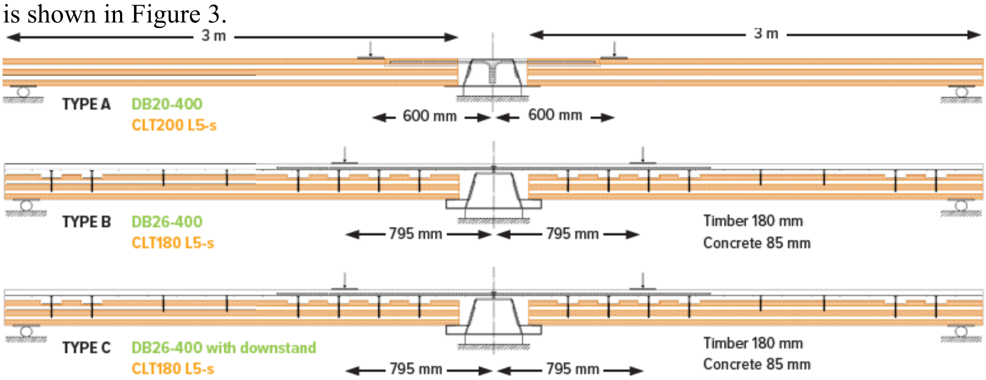

Figure 3: Test set-up [8].

The results of the experiments proved that each case are able to obtain to design load level and moreover get the peak load approximately three times greater. Indeed, the results confirmed the hypothesis about application of inclined edge of the panel. This confirmation is clearly visible in graphs (Figure 4).

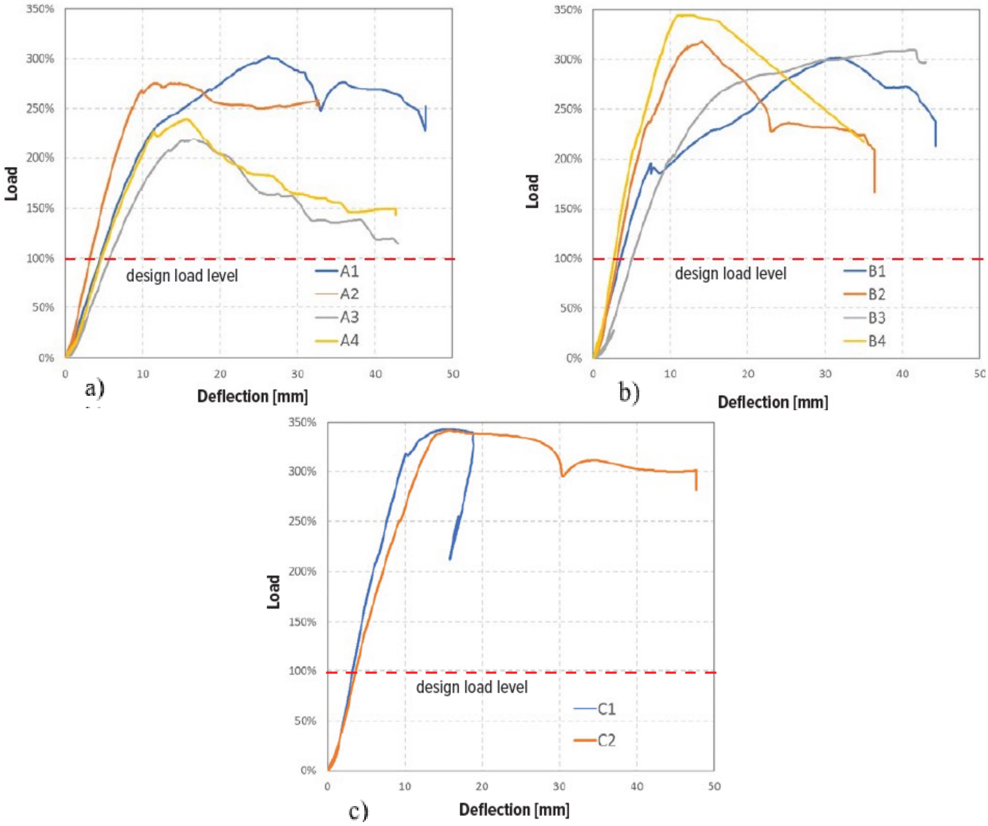

Figure 4: Load- deflection curves of specimens. a) Timber slab (A series) b) Composite timber slab (B series) c) Composite timber slab with downstand (C series) [8].

Based on this hypothesis, it can be said, that choosing an inclined edge is an effective solution, also due to more effective load transfer mechanism through a compression arch (Figure 5).

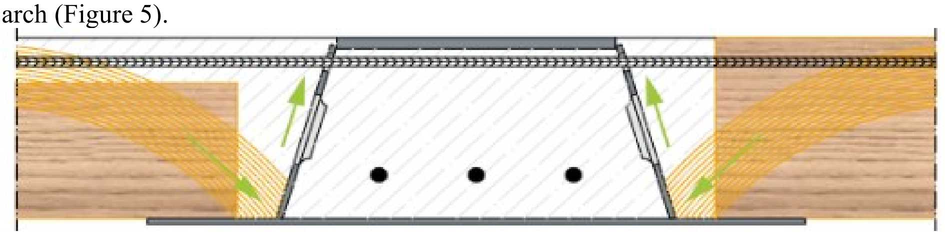

Figure 5: Load transfer mechanism in final situation [7].

3 Forthcoming research

Inclined edge will be used in this case, based on the assumption of the appropriateness from previous research mentioned in previous chapter. This part of the experiment will be focused on verifying the behaviour of the connection between slab and beam. Based on this, it is possible to reduce the overall dimensions of the specimens. Reinforcement would be centre of focus. Effectivity of ability of carrying tension forces will by observed. Grooves were cut into the CLT panels for placing the rebars. Effectivity of interaction between rebar, concrete and the shape of groove will be examined.

3.1 Test setup

Within of the prepared experiment, it will follow up on the knowledge obtained from the previously mentioned research. In the first phase of case will be used two types of specimens. The first sample is assembled as in the previous research, exactly sample A2. In this case it will have label A (Figure 6 a)). Based on the similarity of the specimens, comparable results are expected. This sample will continue to be considered as a reference sample. CLT panels have similar thickness (200 mm), each of them with a 5-layer assembly. This panels have grooved longitudinal notches (in the direction of span) for rebars, reinforcement is going through the DELTABEAM D20-400 to the panel on the other side of the beam. At the end, the hollow parts are filled with concrete C 20/25. By growing notch in shape U is created wedge part of CLT panel and is activated too. Rebars are bend in corresponding shape with notches too. Based on this hypothesis, sample B was created (Figure 6 b). Each specimen will be examined with corresponding test set-up.

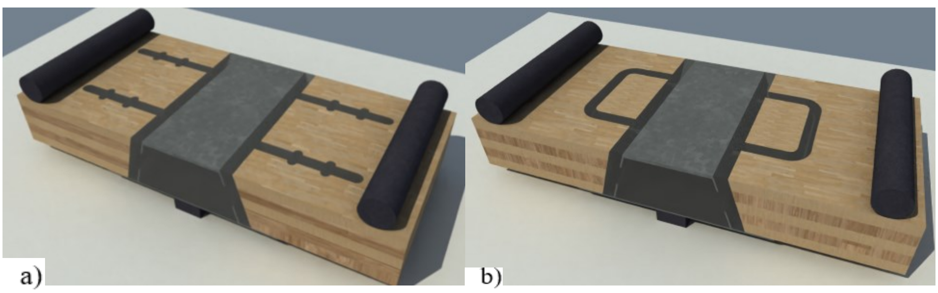

Figure 6: Specimens set-up. a) sample A b) sample B.

Support is applied centric under the beam. The samples will be loaded with line load applied at a distance from the centre line of DELTABEAM that equals three times the thickness of the slab, so to maximize the shear in the area close to the beam (Figure 7). Each specimen has an applied the design load level corresponding to a 6 x 6 m grid with a load of 3 kN/m^2. Load was two times increased to final load of 9 kN/m^2 during numerical analysis.

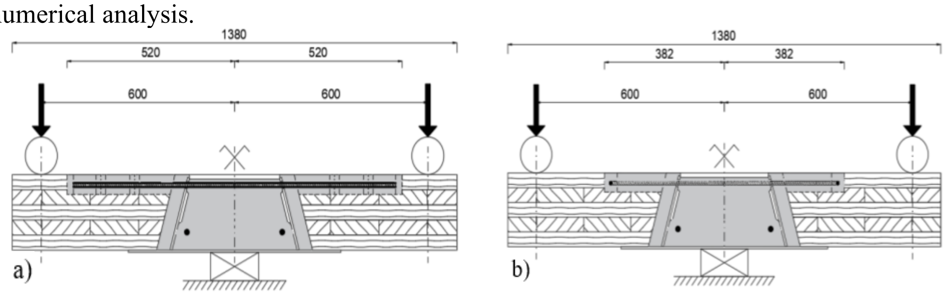

Figure 7: Test set- set up and specimens dimensions. a) Sample A b) Sample B.

3.2 Numerical analysis

Numerical models have been created for each variant. Detailed analyses were made in program ANSYS Workbench [9]. Equal methodology of test set-up was used. By monitoring their behaviour through deformation is the most suitable way of comparing the specimens. Specimen A was used as reference (Figure 8), and it is primary used to compare samples. During analysis was examined that application of wedge (B) was not so effective as it was predicted (Figure 9).

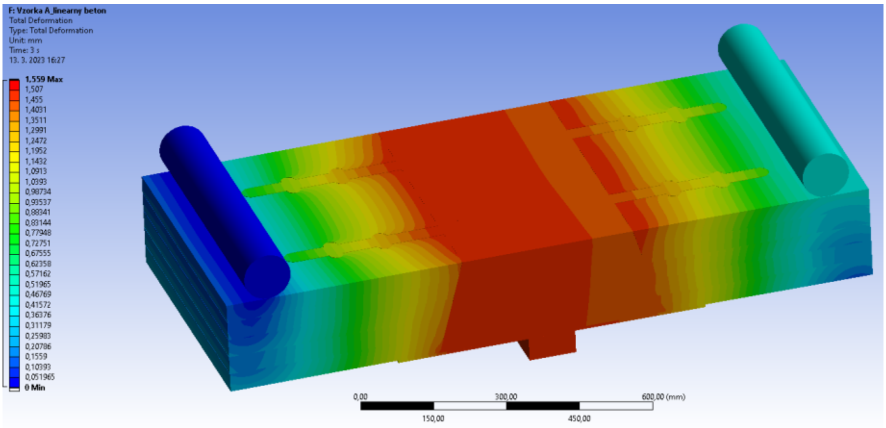

Figure 8: Global deformation of specimen A.

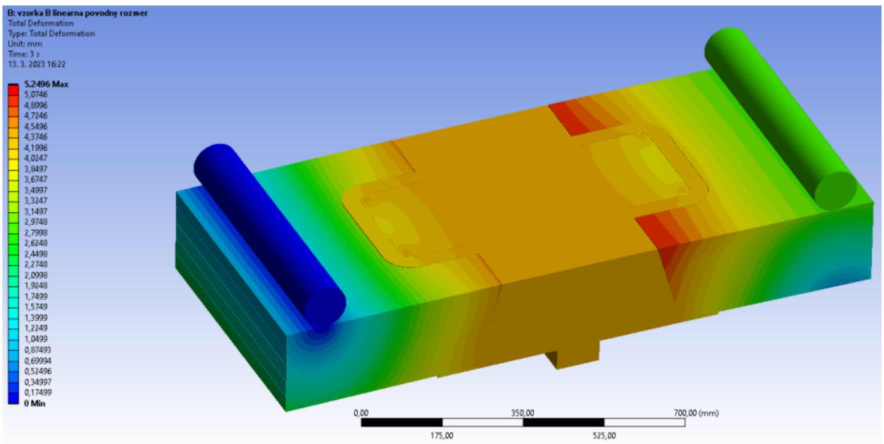

Figure 9: Global deformation of specimen B.

Due to this result the length of wedge was modified to maximal its length. This editing had as consequence to increase of effectivity of connection. It is possible to observe in Figure 10.

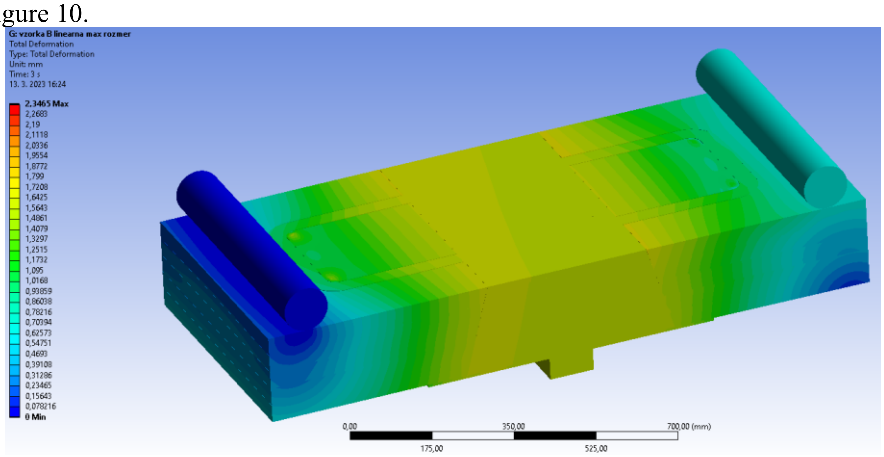

Figure 10: Global deformation of modified specimen B (B2).

4 Results and discussion

The effectiveness of the inter-connection within the sample A was confirmed. Longitudinal rebars are acceptable, provided that the role to take horizontal tension forces is provided. Especially it is necessary to take to account the requirement of sufficient anchoring length (Figure 11).

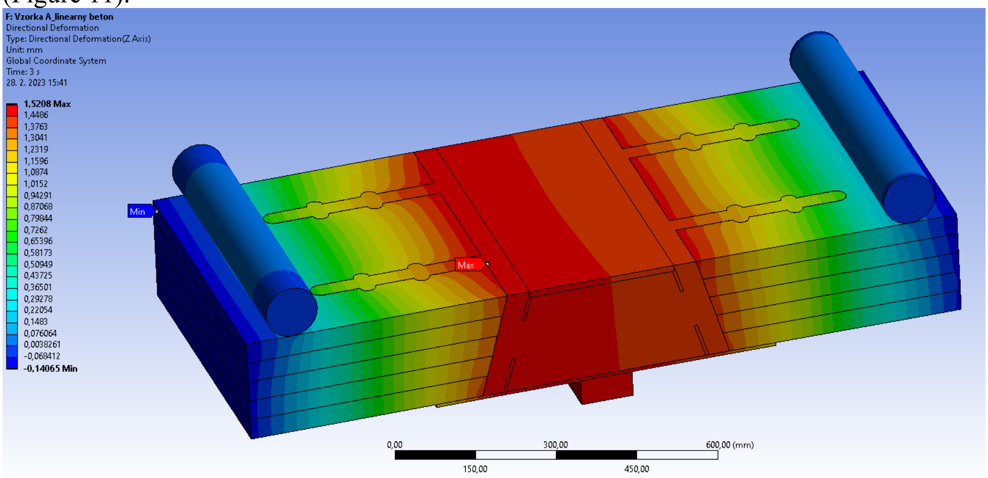

Figure 11: Vertical deformation of specimen A.

During the research process it is possible to state that the initial considered shape of sample B is not very effective (Figure 12). However, by adjusting the position of the groove, it is possible to increase the efficiency of the connection (Figure 13). Ensuring that the groove is occupied even beyond the shear area achieved better connectivity in the composite joint. As it is visible in Figure 13, deflection decreased beside to primary B sample. After modification of sample B, i.e. B2, it is possible to state similar resistance of the connection as in the case of sample A.

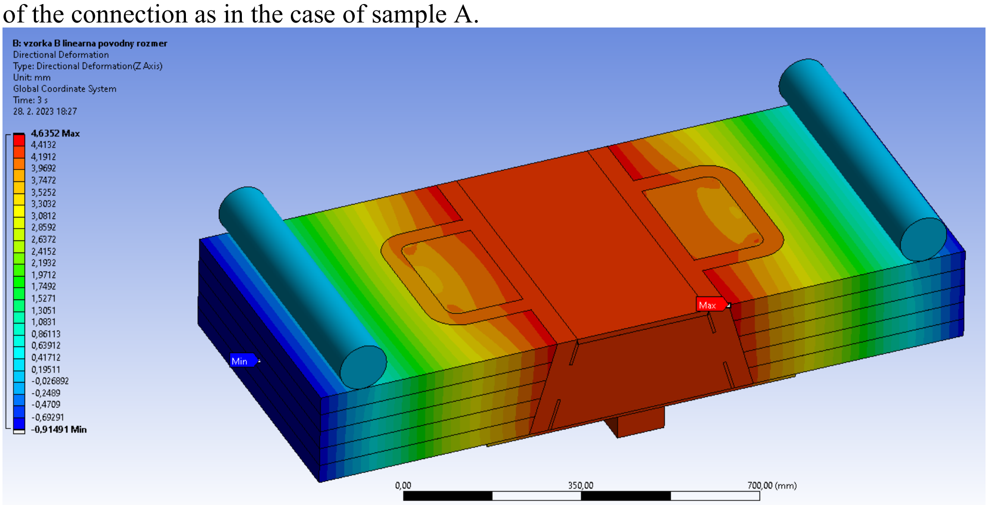

Figure 12: Vertical deformation of specimen B.

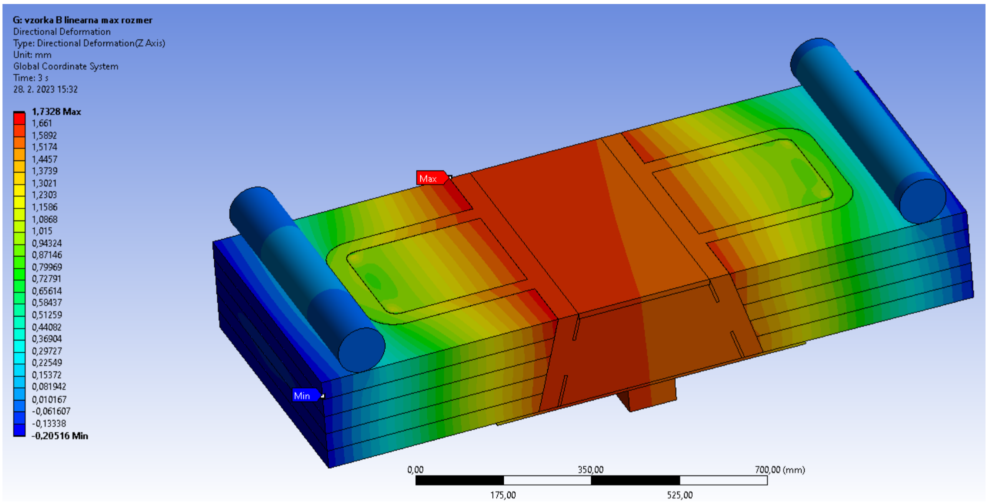

Figure 13: Vertical deformation of modified specimen B (B2).

As it is obvious from previous Figures, specimen A has maximal deflection 1.52 mm and when it is compared to sample B with vertical deformation 4.64 mm, it is obvious that sample A is more tough. After the adjustment of sample B can be stated that the vertical deformation decreased to 1.73 mm. Approximately similar values can be stated as predictor of functional joint connection for updated sample B. Specimen B2 can be stated as legit alternative for slim floor solution. This type of connection sufficiently demonstrates the capability to create inter connection of panels of each side of the DELTABEAM, and effect of continuous deck can by stated.

Based on these results, it can be concluded that the resistance of each joint variation is able to withstand the applied loads. However, it will be necessary to verify these hypotheses based on laboratory experiments which are in process at this time. However, the modification of the connection in the joint demonstrated the possibility of creating an adequate alternative join connection able to withstand during load transfer process which they occur in section around middle support for continuous deck. Of course, the statement has to be verified by series of laboratory experiments.

5 Conclusion

This paper is dealing with problematic of creating an alternative of joint in hybrid ceiling structure. The intention was to achieve a sufficient inter-connection and obtain considerable stiffness so that the effect of the continuous deck could be considered as relevant.

The result of the analysis can be evaluated from several points of view. First of all, creating alternative of the original joint connection with higher shear resistance in longitudinal direction with beam was main reason of creating sample B. Also, was necessary that alternative was able to withstand other loads applied during life of structure. It has been proven, that this is an option to pursue. However, it will be necessary to complete these analyses and continue with the laboratory experiments so that it is possible to say with certainty, that this joint connection is suitable for further use in practice.

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