FACTA UNIVERSITATIS
Series: Architecture and Civil Engineering Vol. 21, Nº 2, 2023, pp. 225-239
https://doi.org/10.2298/FUACE230704013M

Original Scientific Paper

APPLICATION OF EXTERNAL PRESTRESSING TO TIMBER-CONCRETE COMPOSITE BEAMS

UDC 624.016:624.011.1+624.012.3(045)=20

Emir Maslak[1], Dragoslav Stojić[2], Esad Mešić[3], Radovan Cvetković[2]

[1]University of Novi Pazar, Department for Technical and Technological Sciences, Novi Pazar, Serbia
[2]Faculty of Civil Engineering and Architecture, University of Niš, Serbia
[3]Faculty of Civil Engineering, University of Sarajevo, Bosnia and Herzegovina

Abstract. *Timber-concrete composite beams are classified as modern constructions. They are created by connecting a timber and concrete element. They are designed in such a way that the concrete part of the beam is placed in the compressed zone, and the timber part is placed in the tension zone. Different types of fasteners can be used for connecting, from mechanical (screws, nails, perforated plates, parts of steel profiles, etc.) to chemical (various types of glues). In this work, the possibility of active strengthening for this type of beam by external prestressing, is examined. One way for applying an external prestressing force is shown. By experimental testing are determined results for prestressed and beam without prestressing. Obtained results are presented and compared.*

Key words: *timber-concrete composite beams, shear-studs, active reinforcement, external prestressing*

1. INTRODUCTION

In the general case, composite beams are those type of constructions in which two elements of the same or different material, with connecting elements (shear-studs), are connected into one girder. The most commonly used type of composite beams are those created by connecting steel and concrete. This type of beam is widely used in various types of constructions: bridges, buildings, industrial buildings, etc. The idea that guided the designers when they started projecting these beams was to make the best possible use of the mechanical characteristics of constitutive elements. Thus, with steel-concrete girders, the steel element is placed in the tension zone, and the concrete element is placed in the compressed zone. In this way, a safe and economical girder was achieved, because

Received July 4, 2023 / Accepted August 20, 2023
Corresponding author: Emir Maslak, University of Novi Pazar, Department for Technical and Technological Sciences, Novi Pazar, Serbia
e-mail: e_maslak@yahoo.com

when the steel part of the beam is tensioned, unfavorable phenomena that follow pressed steel elements are avoided (buckling, lateral torsional buckling), while with the concrete element, due to the massive cross-section, these problems are absent. The good thing about this construction system is that the mechanical characteristics of individual parts of the beams are used in the right way, because it is known that concrete, compared to tension, has almost 10 times higher compressive strength.

Timber-concrete composite beams were created primarily out of the need to strengthen the existing old floor slabs made from wood, and in times after the great wars, when there was a shortage of steel. By pouring a concrete layer over timber beams, on which connecting elements (nails, screws or profile pieces) were previously installed, a new composite was created, which, in addition to increasing the load capacity, had other significant benefits:

- existing wooden beams partly represent the formwork, which makes easier the installation,
- layer of concrete that was subsequently installed also represents the waterproofing of the timber beams, and by placing the appropriate layers on the concrete deck, it is possible to achieve sound and thermal insulation,
- concrete plate, in the story plane, has sufficient rigidity to equalize the displacements of the columns in that level, which significantly improves the dynamic characteristics of the building as a whole,
- fire resistance of the building is significantly increased,
- from the aspect of aesthetics, due to their warmth and good looks, they fit very easily into the interior of the building. Basic idea of prestressing is to cause deformations in a specific element (or the entire construction) to the structure during the construction phase, and in this way ensure a more favorable behavior in service. This would mean that the service load should "spend" a certain part of the intensity, in order to return the structure to its initial state. The consequence of this is constructions that are able to bridge larger spans, and more economical buildings compared to non-prestressed ones. Prestressing is most often applied to concrete structures, but it is not uncommon to design and construct structures made from steel or timber.

2. Timber-concrete Composite Beams

As a consequence of the increased scope of application for this type of girders, there was a need to better study their behavior in real constructions. Until today, a large number of theoretical and experimental researches have been carried out, which have provided many answers to designers and make possible to design such constructions in different ambient conditions.

2.1. Theory of elastic composite connection

When connecting a concrete slab with the timber beam, three characteristic cases (Figure 1) can occur. Picture 1a shows the deformation and dilatation of a beam with fully composite action. At these beams, there is no relative displacement in the connection plane, because connecting elements are rigid enough to fully accept the shear stresses in that plane. The strain diagram has one neutral axis and their value in the connecting plane is the same. Displacement and strain diagram on the beam, without any composite action, are given in Figure 1c. At these beams, the dilatation diagram has two neutral axes, and when the beam is not loaded with an axial force, these neutral axes are located in the centre of gravity of individual elements. There is no element in the beam that is able to transmit the shearing force in the plane of the connection, so the relative displacement between individual elements of the beam is the greatest.

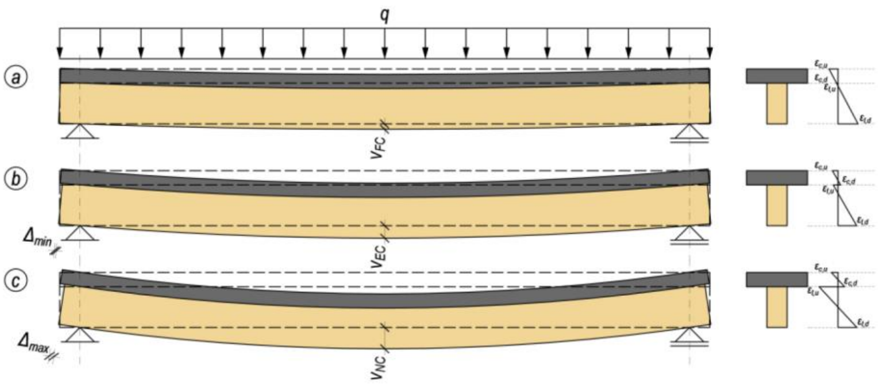

Fig. 1 Deformations of the beams depending on the composite action

Timber-concrete composite beams are located between these two borderline cases (Figure 1b). The strain diagram, for the most commonly used shear-studs, has two neutral axes which, depending on the stiffness of the beam, are at a significantly smaller distance than is the case with the third one girder. Relative movement between elements exists, but is less than with an uncoupled beam. For the first beam, the calculation, based on the elastic theory, consists in calculating of the geometric characteristics for the idealized cross-section, and for such an idealized cross-section, calculating the normal and shear stresses in the edge fibers of the constituent elements. At the third girder, which is rarely used in engineering practice, the procedure is to calculate the stiffness of individual elements of the support and to redistribute the forces in the cross-section in proportion to the stiffness of those elements: the moment is proportional to the bending stiffness EI, the normal force is proportional to the axial stiffness EA, while it can be assumed with sufficient accuracy that the transverse forces accept a rib.

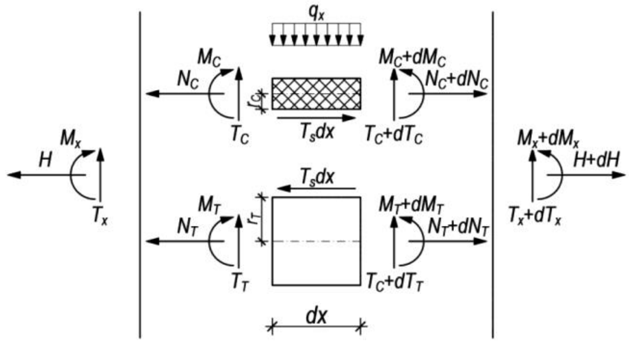

Fig. 2 Composite beam with yielding fasteners. Equilibrium conditions of a differently small part

For the beam in Figure 1b, due to the yieldable nature of connections, the expressions describing the stress-strain state under an arbitrary load are significantly more complicated. The analytical solution for the composite beam with a compliant connection was developed by means of the differential equilibrium equation [1] and [2]. The assumptions introduced during the formation of the equations system:

- linear-elastic behaviour of materials and fasteners,
- assumption of small displacements (first-order theory),
- concrete plate and timber beam during deformation have identical slopes of elastic lines,
- the Bernoulli hypothesis about straight sections is valid,
- it is assumed that the connecting elements are evenly (continuously) distributed throughout the joint,
- the cross-sections are constant in the longitudinal axis of the beam.

For the given conditions, the equilibrium equations of the differentially small part of the beam given in Figure 2 were established. The solution to this problem is obtained in the form of an inhomogeneous differential equation of the fourth degree with constant coefficients, whose form is given by equation 1.

$$w^{IV}(x) - \alpha^2 \cdot w^{II}(x) = \alpha^2 \cdot \frac{M(x)}{EI_\infty} + \frac{q(x)}{EI_0} \tag{1}$$

where is:

$$\alpha^2 = k \cdot \left(\frac{1}{EA_1} + \frac{1}{EA_2} + \frac{a^2}{EI_0} \right) \tag{2}$$

$$EI_0 = E_1 I_1 + E_2 I_2 \tag{3}$$

$$EI_\infty = EI_0 + \frac{E_1 A_1 \cdot E_2 A_2}{E_1 A_1 + E_2 A_2} \cdot a^2 \tag{4}$$

Equation 3 defines the bending stiffness of an uncoupled beam, while equation 4 gives the bending stiffness of a beam with fully composite action. Although this solution describes to a good extent the behavior of these beams under load, it also has certain disadvantages. The first is of a practical nature, because for slightly more complicated load constellations, a solution in a closed form is very difficult to find. The second is reflected in the fact that the equation does not include the rheological phenomena that accompany this carrier during service, and have a great influence on its behavior. Annex B of Eurocode 5 [4] defines the dimensioning of multi-part girders of constant cross-section connected by mechanical connectors. This procedure is based on the theory of elastic composite action, with certain simplifications achieved.

To obtain a solution in a closed form, it was assumed that the load along the beam can be defined using a sinusoidal function. In the literature, this calculation method is called the "γ" procedure and consists of calculating the effective bending stiffness of an elastically coupled section. This expression contains all the parameters that are essential for the redistribution of forces within the cross-section of the beam: mechanical characteristics (modulus of elasticity of the beam and plate), geometric characteristics (surface area, moments of inertia of the beam and plate) and stiffness of the connecting elements (sliding modulus). The effective bending stiffness is calculated according to equation 5:

$$(EI)_{eff} = \sum_{i=1}^{n} E_i I_i + \gamma_i E_i A_i a_i^2 \tag{5}$$

Eurocode 5 defines the method of calculation of multi-part elements from non-symmetric (or symmetric) I section. Since in our case the cross-section consists of a plate and a rib (2 elements), the indices that appear in the sum will be 2. Other factors in equation 5 are:

- E_i modulus of elasticity for timber and concrete,
- $I_i = \dfrac{b_i \cdot h_i^3}{12}$ moments of inertia for timber and concrete parts, (6)
- $A_i = b_i \cdot h_i$ cross-sectional areas, (7)
- $\gamma_1 = \left[1 + \dfrac{\pi^2 \cdot E_1 A_1 \cdot s_1}{K_i \cdot l^2}\right]^{-1}$ (8)
- $\gamma_2 = 1$

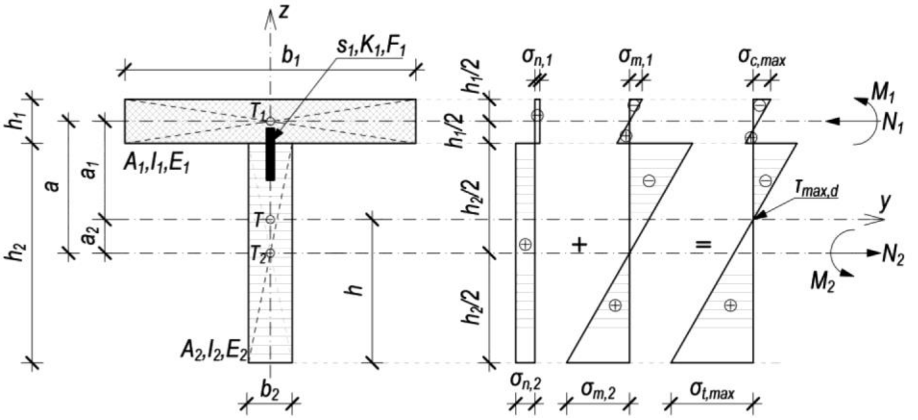

Fig. 3 Stresses in the beam with elastic composite action

In equation 8, apart from the known parameters, the others represent:
- s_1 equivalent distance of the connecting elements used for coupling. In case they are not at the same distance, this value can be calculated:

$$s_{eq} = 0.75 \cdot s_{\min} + 0.25 \cdot s_{\max} \tag{9}$$

$$a_1 = \frac{\gamma_1 \cdot E_1 A_1 \cdot a}{\gamma_1 \cdot E_1 A_1 + E_2 A_2} \tag{10}$$

From Figure 3 it can be seen that $a = \dfrac{h_1}{2} + \dfrac{h_2}{2}$, and therefore $a_2 = a - a_1$.

- K_i represents the sliding modulus for used connecting system, and is obtained experimentally. Often designers are not able to conduct such a test, so in that case, the recommendation given in [4] can be used to determine this parameter.

The non-linearity of this calculation is reflected in the adoption of different values for the sliding modulus for serviceability and ultimate limit state. Those values, according to the proposal [5], are:

$$K_{ser} = \frac{0.40 R_m}{v_{0.40}} \tag{11}$$

$$K_u = \frac{0.60 R_m}{v_{0.60}} \quad \text{or} \quad K_u = \frac{2}{3} K_{ser} \tag{12}$$

With the effective bending stiffness calculated in this way, the redistribution of internal forces and stresses by elements is:

- for concrete plate:

$$N_1 = \frac{M_{Ed}}{(EI)_{eff}} \gamma_1 \cdot a_1 \cdot E_1 \cdot A_1 \text{, and hence } \sigma_{n,1} = \frac{N_1}{A_1}, \tag{14}$$

$$M_1 = \frac{M_{Ed}}{(EI)_{eff}} E_1 \cdot I_1 \text{, and hence } \sigma_{m,1} = \pm \frac{M_1}{I_1} \cdot \frac{h_1}{2}, \tag{15}$$

and finally,

$$\sigma_{c,\max} = \sigma_{n,1} + \sigma_{m,1} \text{, with the condition that it is } \frac{\sigma_{c,\max}}{f_{c,d}} \le 1. \tag{16}$$

- for timber beam:

$$N_2 = \frac{M_{Ed}}{(EI)_{eff}} \gamma_2 \cdot a_2 \cdot E_2 \cdot A_2 \text{, and from there it is } \sigma_{n,2} = \frac{N_2}{A_2}, \tag{17}$$

$$M_1 = \frac{M_{Ed}}{(EI)_{eff}} E_2 \cdot I_2 \text{, and from there it is } \sigma_{m,2} = \pm \frac{M_2}{I_2} \cdot \frac{h_2}{2}, \tag{18}$$

and finally,

$$\sigma_{t,\max} = \sigma_{n,2} + \sigma_{m,2} \text{, with the condition that it is } \frac{\sigma_{n,2}}{f_{t,0,d}} + \frac{\sigma_{m,2}}{f_{m,d}} \le 1. \tag{19}$$

Shear stress control:

- assuming that the entire shear force is assumed by the beam (rib):

$$\tau_2 = \frac{0.50 \cdot V_u \cdot E_2 \cdot h_2^2}{(EI)_{eff}} \text{, with the condition that it is } \frac{\tau_2}{f_{v,d}} \le 1, \tag{20}$$

where M_{Ed} and V_{Ed} are design values obtained by corresponding partial safety factors.

For control according to the serviceability limit state, it is necessary to calculate the effective bending stiffness with the help of the sliding modulus K_{ser}. With the modulus of displacement calculated in this way, for the case of uniformly distributed load, the deflection of the beam is calculated:

$$v_{\max} = \frac{5}{384} \cdot \frac{q \cdot l^4}{(EI)_{eff,ser}} \text{, with the condition that it is } v_{\max} \le v_{all}. \tag{21}$$

As already mentioned, both concrete and timber are rheological materials, which means that they tend to change their mechanical properties over time. These changes are influenced by various factors, the most important of which are related to the duration of the load, air humidity, temperature, etc. In order to include these phenomena in the calculation, the proof of the bearing capacity of such girder is carried out in two stages. In the first stage, the bearing capacity is checked for short-term loads, with the mechanical characteristics of the materials obtained by already established procedures. In the second stage, the bearing capacity of the carrier with long-term effects is proven [6].

3. POSSIBILITIES FOR STRENGTHENING TIMBER-CONCRETE COMPOSITE GIRDERS

So far, a very few numbers of researchers have dealt with the problem of strengthening such types of girders. The paper [7] presented the possibility of strengthening the TCC beams with carbon fibers (CFRP - carbon fiber reinforced polymers). The idea is to place these fibers along the tensioned edge of the timber beam, as shown in Figure 4. The paper also includes a procedure by which it is possible to perform the calculation for this beam. This procedure is in accordance with the recommendations given in [4]. The only difference is that when calculating all the parameters necessary to obtain the effective bending stiffness (equation 5), the carbon fiber strip with its geometric and mechanical characteristics is also included.

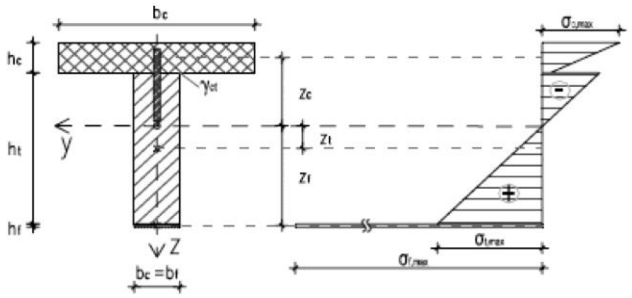

Fig. 4 Model of a beam reinforced with CFRP fibers [7]

By strengthening the tensioned zone of the wooden beam, in addition to the global increase in load capacity, a more ductile girder is obtained, because it is known that brittle failure in timber structures occurs along the tensioned fibers.

The effects of prestressing on semi-prefabricated coupled wood-concrete beams were analyzed by comparing the results obtained by testing beams with a static span of 5.70m [8]. A total of five beams were examined (Figure 5) three with and two without prestressing. Prestressing force was applied with one tendon placed in rectangular notch (24.0mm width and 30.0mm depth). This notch was slotted at the bottom center of the timber beam, along the entire span. The examination showed that the application of 100.0 kN prestressing force can improve ultimate bending capacity of TCC beams up to 110%.

In general, there are two types of reinforcement of this type of girders: passive and active. In passive reinforcement, the elements that are added to the structure are not prestressed. Due to the low bending stiffness, during the assembly phase, a small deflection, at this element, is possible (Figure 6a). For their activation, it is necessary for the structure to receive a certain intensity of the external load and obtain an initial deformation (Figure 6b). In the case of active strengthening, the tension is already applied in the element during the construction phase (Figure 6c).

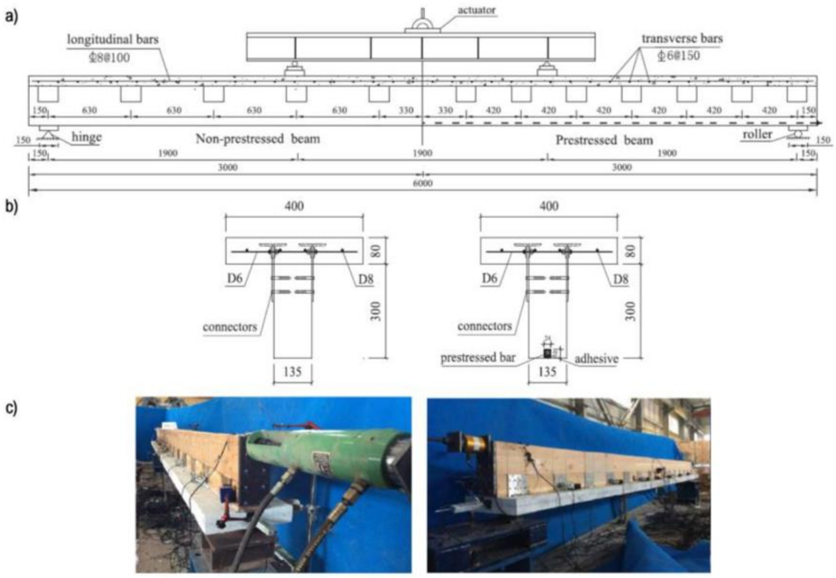

Fig. 5 Beam strengthened with steel tendon [**8**]

As a consequence, the additional elements, not only immediately become active parts of the structure (under-deck tendon), but the girder receives an initial deflection, which is in the opposite direction from one that occurs in service. For this reason, the external load must spend a part of its intensity to return the structure to the initial state (Figure 6d).

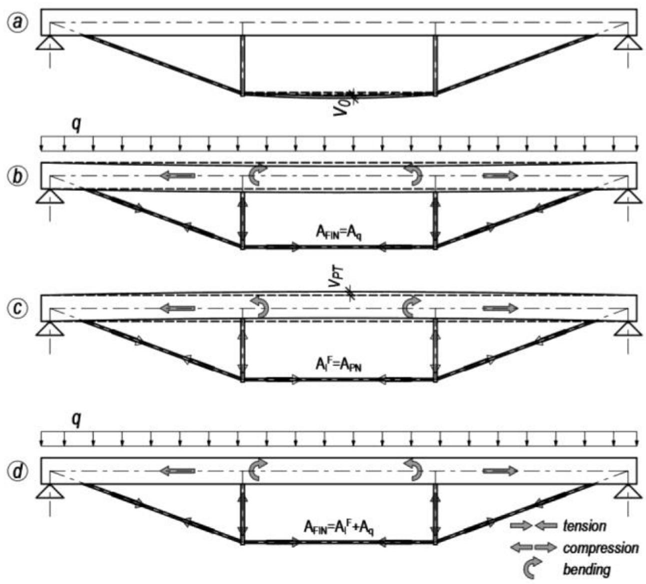

Fig. 6 Active and passive strengthening of the girders

4. VARIANTS FOR PRESTRESSING OF TCC BEAMS

The subject of research presented in this paper is the case of active prestressing. In order to determine the degree of improvement achieved, 10 beams with a 3.0m static span were tested. Five beams were prestressed, while five beams were without prestressing.

Special problem during the construction this type of beam is connected with the fact that wood has a relatively low resistance to pressure around the shell of hole. Before the test was conducted, three variants, for solving this problem, were considered. Figure 7, variant 1, shows the possibility of strengthening the TCC beams with the 2 cables.

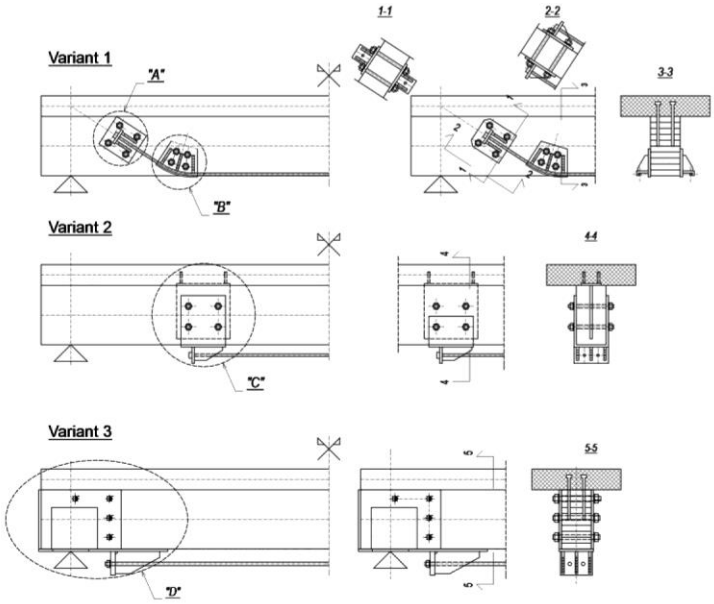

Fig. 7 Variants for strengthening of TCC beams

The method of anchoring the tension is shown in detail 1, while the structural design of the deviator is shown in detail 2 of the mentioned picture. The good side of this method is reflected in the fact that the screws at the anchor points are equally loaded. Disadvantageous about this variant is the way of applying the prestressing force. If it is assumed that the anchors are active on one side of the girder, the prestressing force must pass through two deviators. By increasing the force in the clamps, the turning force in those places increases. As the deflection force increases, the frictional force on the contact between the cable and the deviator increases, which makes its applying much more difficult. If it is assumed that the prestressing force is introduced from both sides of the beam, then this force must pass through one deviator, but now there are problems with synchronization, because the force is applied in four places. There is certainly a possibility of prestressing by removing the supports, but even in that case there is a problem with the construction of the supports due to the occurrence of negative reactions.

With the second variant, problems with deviators and turning forces are eliminated because the tendon is rectilinear, so the method of applying the prestressing force is much simpler. The problem that is present in wooden constructions, and concerns the pressure on the shell of the hole, is avoided here by placing a steel plate inside the wooden beam.

This plate is anchored to the concrete slab with the help of the anchor and accepts the forces from the screws. The disadvantage of this variant is only the placement of the steel plate inside the wooden support, because this operation requires precision both when placing the plate and when drilling the holes. Another disadvantage concerns the redistribution of shear force in the joint plane. It is clear that the shear-studs attached to the steel plate, due to their rigidity, will absorb most of that force.

Third variant consists in the formation of a steel element at the end of the beam in the form of a box. This element, in the process of prestressing and during service, stresses the front side of the wooden beam to eccentric pressure. The screws also have a function in force transmission, but their main function is to keep the geometry, in such way , that the front plate of the box rests on the front of the wooden beam with as much surface as possible. The disadvantages of this procedure are reflected, first of all, in the complications related to the execution when it is necessary to strengthen the existing supports.

Third variant was selected for testing.

5. Experimental Examination of Girders

The examination of the beams, which are the subject of research in this work, was carried out in the laboratory of the Institute for Materials and Structures (IMK), Faculty of Civil Engineering and Architecture, University of Sarajevo. Five coupled and five coupled-prestressed timber-concrete beams were tested. The tested beams have a static span of 300.0 cm and are loaded with two symmetrical concentrated forces at a distance of 100.0 cm. This load setting is known as the "four point bending test" (Figure 8). For common elements (wooden beam and concrete slab), the arrangement of measuring points on the beam without pretension are the same.

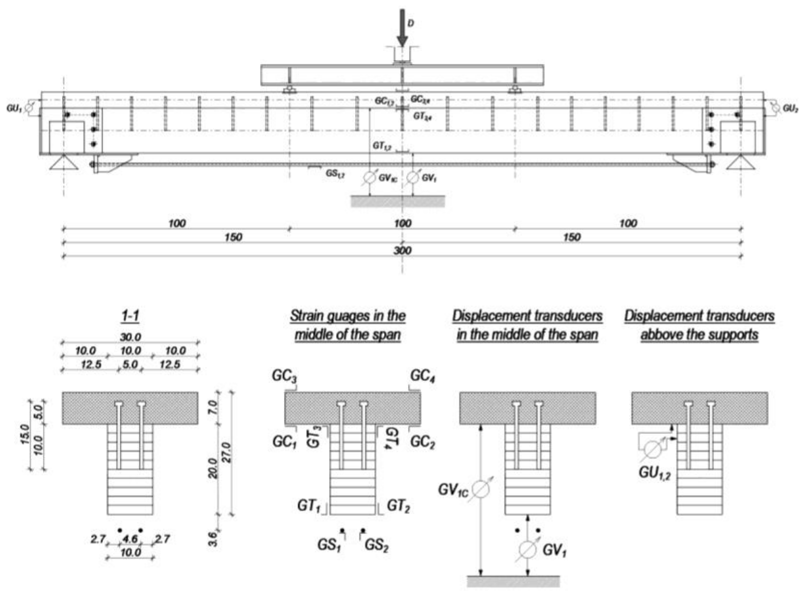

Fig. 8 Dimensions of the cross-section and the measuring points on the beams

Prepared beams for testing are shown in Figure 9.

Fig. 9 Girders prepared for testing

Applying force to the girders was done with the help of a hydraulic crane that lifted the platform on which the support was placed. The second part of the platform, the height of which can be adjusted before the start of the test, is immovable during the test and the force measuring device (dynameter) is pointed at it, which transmits its reaction to the rigid steel I-profile. The profile is supported at the points of force input - a concrete slab. This procedure was carried out in accordance with the recommendations of EN 26981. According to this procedure, first about 40.0% of the determined ultimate force is applied for 2 minutes. Then that load level is maintained for half a minute, then the structure is unloaded by 10.0% of the force, then the load is kept at that level for half a minute, and then the load is applied until failure. The reason for this relief is because it is assumed that up to a load level of 40.0%, the adhesion between wood and concrete will be canceled and that in the continuation of the test, most of the shearing force at the joint of wood and concrete will be accepted by the shear-studs.

The global deformations of the beams (deflections) were measured with inductive displacement transducers (LVDT - linear variable displacement transducers) W100 and W50. Similar devices (deflectometers) were used to measure the relative displacements between the wooden beam and the concrete slab. The intensity of the applied force on the beams was measured with an electronic dynamometer. Local deformations (dilations) were measured with the help of strain gauges. On steel, guages TML, Tokyo Sokki Kenkyujo Co., Ltd, type FLA-6-11, length 6.0mm and resistance 120±0.30Ω, on a concrete slab of the same guages, only type PL-60-11, length 60.0mm. On the wooden beams, the same gauges as on the concrete slab were used in the tension zone, while KYOWA guages, type KFG-30-120-C1-11, resistance 119.80±0.20Ω were used in the compressed zone. The SPIDER 8 multi-channel measuring system was used to record the results. The results were recorded for every 5.0 kN of applied load.

6. Test Results

During load application, changes on the girders were recorded electronically and monitored visually. The idea was to apply the test load on both types of supports until failure. In the case of TCC beams without prestressing force, on all beams the failure occurred in the end tensioned fibers. Before the fracture of the wooden elements, cracks would appear in the tensioned zone of the RC plate. As is usual with such type of failure, the break was instantaneous with a loud bang. At that moment, the application of the load would be stopped, and the unloading would be started. When the entire applied load was removed, the permanent deformation on the beams was measured. This deformation resulted from the plasticization of the end fibers of the wooden elements.

Fig. 10 Tested TCC beams with and without prestressing force

In the case of the composite beam with prestressing force, only one beam (PSG3) experienced a failure along the end fiber of the wooden element, while in the other beams, the final value of the load was obtained in 2 ways. The first is the force at which the wooden beam would have such a deflection, to achieve contact with tendons (beams PSG2 and PSG5). Another way is the moment when the range of the crane on the platform (beams PSG1 and PSG4) was exhausted. Figure 10 shows typical failure cases of the tested girders. Figure 11 shows the force-deflection relationship on the examined coupled and coupled-prestressed beams.

7. Discussion of the Obtained Results

The main goal of this test was to compare the characteristics of these two types of beams, when they are exposed to a test, short-term static load. By analyzing the test results, it can be concluded that the mechanical characteristics can be significantly improved by applying system with the external prestressing force. First of all, the load capacity of strengthened composite girders was significantly increased. If we take the mean values of the maximum measured forces on the tested beams, it is obtained that the strengthening of approximately 75% was achieved. It should be noted here that, except for beam PSG2, none of the strengthened beams experienced fracture, but the test was stopped at the moment when the lower edge of the wooden beam made contact with the tendon. There is another improvement for this type of construction. All composite beams, without prestressing experienced a brittle failure at a deflection of about 3.0 cm. On the other hand, strengthened beams would not experience this kind of failure even with larger deflections.

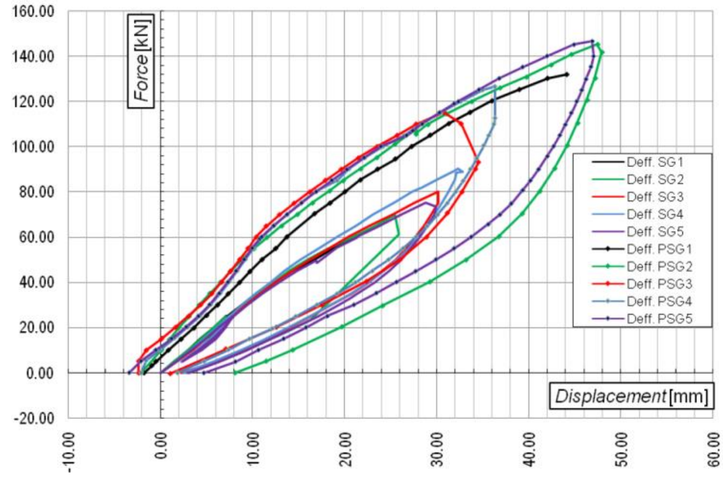

Fig. 11 Diagram of deflections on tested beams

This can be connected to increase of the axial pressure force in the coupled part of the beam. Brittle failure in wooden beams occurs in tensioned elements, so the pressure force postpones this phenomenon to a certain extent. Another favorable effect of the increase in compressive force is reflected in the later appearance of cracks in the tensioned zone of the concrete slab, than is the case with beams without prestressing force. The adverse effect of increasing the pressure force in the coupled beam is related to the increase in deflection due to second-order effects. Residual deformations in strengthened beams are relatively small. If beam PSG2 is excluded, which experienced a fracture, the residual deformation of the other beams was of the order of 2.0 to 4.0 mm. This, to the greatest extent, can be attributed to the tendon. Examining the mechanical characteristics of the used tendons, showed that the elastic modulus was about 186.0 GPa, while the conventional yield strength is about 620.0 MPa. Since it is a high tensile strength steel, these tendons did not experience any plastic deformation at any time and were able to return the beam to a state with little permanent deformation. And finally, the financial requirements compared to the achieved effects, at least, are at a satisfactory level.

8. Conclusion

Research has shown that this type of girders can find an adequate application in construction, whether it is the strengthening of existing ones, or the design of new structures. What should be emphasized is that the testing of the beams is limited to short-term loading, with mechanical characteristics of the materials used without rheological effects. For more mass use of these carriers, they need to be studied and researched in more detail. In this paper, only some of the results obtained from the examination are attached. Further research of these carriers can go in several directions:

- The most sensitive part of the structure is the system for strengthening and applying the prestressing force. The paper presents some of the possible variants, their advantages and disadvantages. In order to determine the system that works best, it is necessary to investigate several variants and compare them with each other.

- When applying the prestressing force, it is determined from the condition that the tensile stresses in the end fibers of the concrete slab do not exceed the permitted values. The steel tendons had a nut on their ends, so the preload force was applied with the help of a torque wrench. Something like this was possible because strain guages were placed on the beams, so the size of dilatations in all characteristic places was monitored in real time. It is impossible to expect something like this in real constructions. For this reason, it is important to determine a clear way of introducing the prestressing force. As a starting point, the knowledge gained for the application of the prestressing force of high-value screws in the direction of their axis (at friction joints) could serve as a starting point. The research should cover different types of reinforcement and prestressing systems and define the value of torque in the wrench required to introduce the required value of prestressing in the tendons.
- If the influence of connecting elements is ignored, the behavior of TCC beams under long-term load and different ambient conditions is determined by the characteristics of wood and concrete. Material models that incorporate all these effects are very complex and, for everyday engineering use, they are greatly simplified. When steel is added to these two materials, the problem becomes even more complicated. It is necessary to examine the rheological effects and their influence on this type of carrier.
- In case of prestressed concrete structures, there is a loss of prestressing force. The final prestressing force is obtained when all the losses, that come as a result of cable anchoring, elastic deformation of the beams, friction and time losses are subtracted from the initial force. Certainly, the loss of prestressing force will be present with these supports, so it is necessary to determine their size.
- For every carrier used in practice, there is a calculation procedure that proves its load capacity and reliability. The calculation of composite beams, with elastic composite action, is complicated in itself. Such a procedure should be developed for this type of carrier as well. As a starting point, the calculation procedures of the girders shown in Figure 6, which are successfully used to prove their load-bearing capacity, could serve as a starting point. The test showed that the geometry of such a girder is variable, because the distance between the center of gravity of the elastically coupled beam and the tendon axis is reduced. Therefore, it is not possible to use the procedure shown in [6]. It is recommended to use software based on the finite element method.

REFERENCES

1. Stevanović, B., "Analysis of Composite Timber-Concrete Structures", Doctoral Thesis, Faculty of Civil Engineering, Belgrade, 2003.
2. Möhler, K., "Über das Tragverhalten von Biergerträgern und Druckstäben mit zusammengezetztgen Querschnitten und nachgiebigen Verbindungsmitteln,Habilitation", Technische Universität Karlsruhe, Germany, 1956.
3. Moar, F, "Prefabricated timber-concrete composite system", Master Thesis, Lunds Universitet, 2012.
4. EN 1995-1-1, Design of timber structures, Part 1-1: General - Common rules and rules for buildings, European Committee for Standardization, Brussels, Belgium, 2004.
5. Ceccotti, A., "Timber-Concrete Composite Structures", In: Blass HJ et al. (ed) *Timber Engineering, Step 2*, 1995 1st edn. Centrum Hout, The Netherlands.
6. Čizmar, D., Vrančić, M., "Proraču spregnutih nosača drvo-beton", Građevinar, Volume 71, Issue 7, pp 533-608, 2006.

7. Tajnik, M., Dobrila, P., Premrov, M., "Analysis of composite T beam composed of timber, concrete and carbon strip", WSEAS TRANSACTIONS on APPLIED and THEORETICAL MECHANICS, Volume 2, Issue 9, pp 177-186, 2007.
8. Shi, B., Zhu, W., Yang, H., Liu, W., Tao, H., Ling, Z., "Experimental and theoretical investigation of prefabricated timber-concrete composite beams with and without prestress", Engineering Structures, Volume 204, pp 1-16, 2020.

PRIMENA VANJSKOG PREDNAPREZANJA NA SPREGNUTE NOSAČE DRVO-BETON

Spregnuti nosači drvo-beton svrstavaju se u red savremenih konstrukcija. Nastaju spezanjem drvenog i betonskog nosača. Projektuju se na taj način da se betonski deo nosača postavlja u pritisnutoj zoni, a deo nosača od drveta u zategnutoj zoni. Za sprezanje se mogu koristiti različiti tipovi moždanika, od mehaničkih (zavrtnjevi, ekseri, perforirane ploče, delovi čeličnih profila i dr.), do hemijskih (razne vrste lepkova). U ovom radu je ispitanja mogućnost aktivnog ojačanja ovakvog nosača vanjskim prednaprezanjem. Prikazan je jedan način apliciranja vanjske sile prednaprezanja. Priloženi su određeni rezultati ispitivanja prednapregnutih nosača i upoređeni sa istim takvim nosačima, ali bez ojačanja.

Ključne reči: *spregnuti nosači drvo-beton, moždanici, aktivno ojačanje, vanjsko prednaprezanje*