FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 2, N° 3, 2001, pp. 169 - 184

ANALYSIS OF A COMPOSITE TIMBER-CONCRETE STRUCTURES ACCORDING TO THE LIMIT STATES
Design and Innovative Methods in Coupling of a Timber and Concrete

UDC 624.011.1:624.012.46 (045)

Dragoslav Stojić, Radovan Cvetković*

Faculty of Civil Engineering and Architecture, University of Niš, Serbia and Montenegro,
E-mail: dragoslavstojic@yahoo.com, * radovancvetkovic@yahoo.com

Abstract. *This work deals with composite timber-concrete structures. By means of mechanical fasteners dowels or the other connecting systems, timber and concrete can be connected, namely, coupled in new type of girders characterized by better mechanical and load-baring capacity properties. Here, on the base of theory of elasticity and, it is very important, according to rules and recommendations of new-fashioned concepts for design of timber structures and concrete structures, namely, Eurocode 5 and Eurocode 2, based on the limit states of structures, design procedure is briefly given.*
The structure of footbridge, at the end of the work, is consists of concrete slab and glued-laminated timber beams, connected by steel reinforced fasteners in the composite structure and here is observed the behaviour of this structure according to ultimate limit states and serviceability limit states.

1. INTRODUCTION

As stated, the coupling of a concrete layer on the compression side and of a timber on the tension side of cross section gives the best properties of these materials in terms of strength and stiffness. In this manner, we can have a structurally suitable cross-section which enough rigid and not too much weight in the same time.

If we use this method on an occasion reparation of traditional timber floors, the load bearing capacity can be doubled and its out-of plane rigidity improved three or four times.

Further, the in-plane rigidity becomes so large, that it may be considered infinite. This is important for total stability and rigidity of construction work and its behaviour under an earthquake.

Received March 02, 2001
This work is based on some parts of the masters thesis: BEHAVIOUR OF COMPOSITE TIMBER-CONCRETE STRUCTURES WITH BENDING ACTIONS *by Radovan Cvetkovic. Masters thesis was done at the Department of Reinforced Concrete and Prestressed Concrete Structures, Ruhr University Bochum, Germany. Supervisor was Univ.-Prof. Dr.-Ing. F. Stangenberg.*

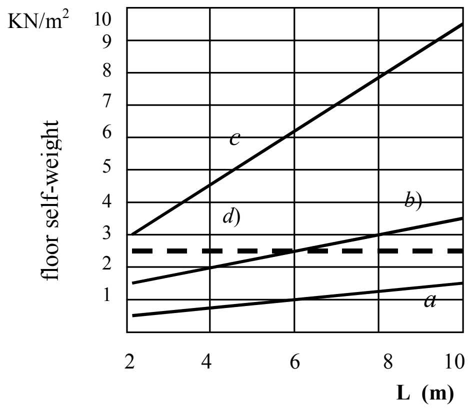

Fig. 1. Correlation between floor self weight versus span *L* for a service load *g* of 2,5 kN/m^2 (line d) in case of a) an all-timber, b) timber-concrete and c) all concrete section-from Natterer (1993).

Sound insulation is improved in this way. On one hand, in case of air transmitted noises, it is improved with respect to an all-timber floor, due to increased mass of the floor (an influence of a concrete) and on the other hand, for impact noises, sound insulation is improved with respect to an all concrete floor due to the higher damping (an influence of a timber).

As follows, we have to have in mind that by using composite timber-concrete systems we can build faster our structure, we need less concrete formwork and less stabilization, because timber elements can partly provide these features themselves.

Further, reduced foundations because of less structural weight, mean better behaviour under an earthquake loading in zones where we expect remarkably action of one.

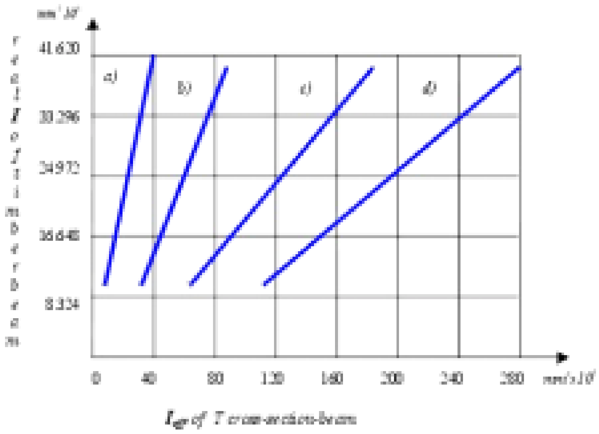

Fig. 2. The increasing moment of inertia of cross section depends on type of coupling a) timber beam, b)composite beam timber-timber, c) semi rigid composite beam timber-concrete, d) rigid composite timber concrete beam. [1]

Figure 2 shows the increase of moment inertia of cross section depending on the type of coupling. The largest magnitude of moment inertia appears for case rigid composite timber concrete beam and consequently the largest load bearing capacity of beam. It is speaks enough on its own.

At the end, composite timber concrete girders have important applying in projecting and engineering of bridges. The concrete layer covers the timber beams and protects them from negative influences of atmosphere. There are to many examples of timber-concrete bridges, mostly in America and in the Pacific region.

2. TYPES OF CONNECTING SYSTEMS

Connecting systems accept shear forces of interface and provide simultaneous acting of different materials of composite system, under loading. Connecting of elements is possible by adhesion and friction, glue and mechanical fasteners and dowels. Nonflexible fasteners accept shear forces by larger itself area and their plastic deformations may be neglected. Their can be met applying field refers to composite bridges where large shear forces.

In composite timber-concrete connections, mechanical rigid fasteners can not be applied because of the properties of timber. On the other side, flexible fasteners and other connecting systems have wide possibilities of use and, in details on the followin figures shown.

The adequate behaviour of timber-concrete connections can be provided, for example, using split rings and toothed dowels together with bolts or reinforced bars. It is shown on the figure 3.

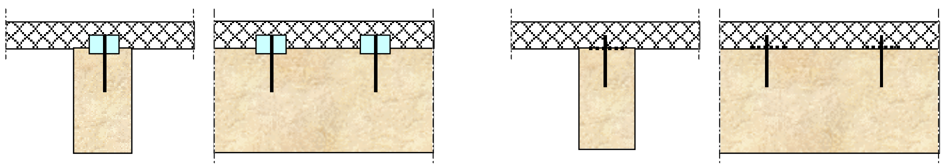

Fig. 3. Timber-concrete connecting systems.

Modern-fashioned methods based on use of steel lattice glued to timber, and steel plate glued to timber shown are on the figure 4.

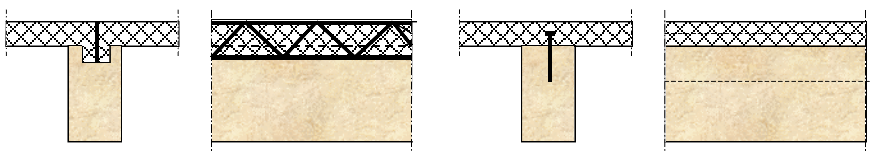

Fig. 4. Modern-fashioned timber-concrete connecting systems

3. New Researches

During the last years of the 20th century, almost in all the research centers of America, Europa and Australia a lot of investigations based on the coupling timber and concrete. There was investigations have given us those new information about new ways of coupling of timber and concrete, about new different types of connectors and its load bearing capacity, about possibilities to applying in real structures that improved methods of making composite elements.

We will now present a short review of new investigations and results in last fivE to eight years with respect to composite timber-concrete elements, connectors.The group of scientist from University of Maine, Bill Davids, Craig Weaver, Habib Dagher, investigate and modulate behaviour of FRP-Glued laminated-Concrete Beams with Partial Composite Action (Figure 5).

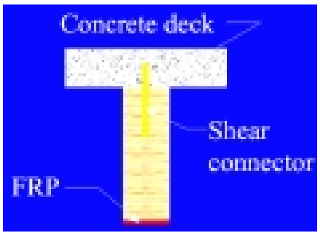

Fig. 5. FRP-glued laminated-concrete composite cross-section

In comparison with usual glued laminated beams or reinforced glued laminated beams by FRP (fiber reinforced plastic), FRP-glued laminated-concrete composite cross section has considerably improved flexural strength and greatly improved stiffness.

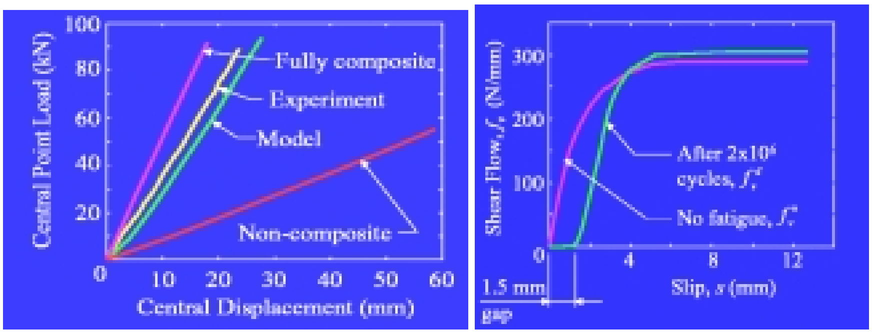

Fig. 6. Shear connector behavior

Diagrams on figure 6 show shear connector behavior during loading. Dowel-type shear connectors are effective, inexpensive and easy to install. From the figure it is obvious that ultimate strength is unaffected by fatigue, and gaps develops due to fatigue damage. The figure 8 shows load-deformation relationship depends on the degree of coupling and very small difference between model prediction and experimental behaviour of beam, load slip relationship, respectively.Therefore, using the newly-developed layered analysis method, numerical solution strategy (Newton's method) and laboratory test of shear connectors and flexural beam test conducted at AEWC, they have got fallowing and conclusions:

- load bearing capacity of beam (strength) increases from 64% to 130% for two tested beams,
- over 200% increase in service-load stiffness,
- numerical model is rational and efficient and there is possibility to capture connector non-linearity and to predict strains and displacements
- composite concrete deck is feasible, structurally efficient, does require shoring during construction and costs will be site-dependent.

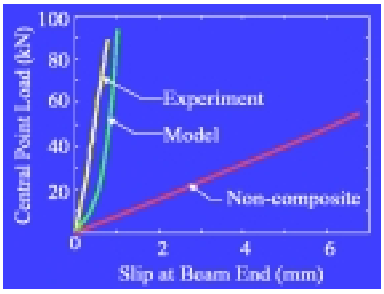

Fig. 8. Beam load-deflection response

In 1996, researchers from the Research and Development Department of the Swiss School of Engineering for the Wood Industry (SWOOD) and from the chemical firm SIKA AG, Zurich, came up with the idea of achieving the connection with glue.

The structural advantages seemed obvious: an adhesive connection distributes the shear forces and avoids the unfavourable concentrated forces which occur when mechanical connectors are used. A glued connection would eliminate the relative movement between timber and concrete: the increased bending stiffness would decrease deflections.

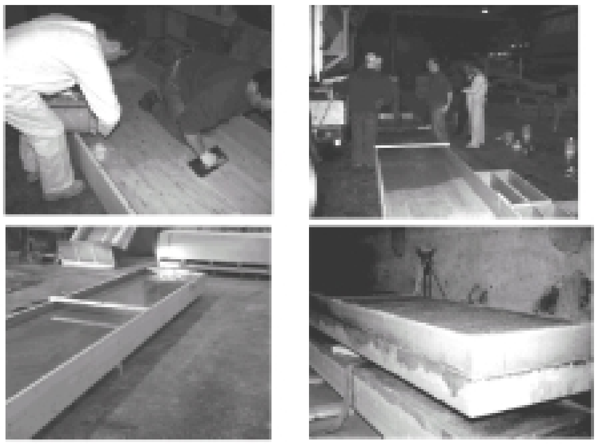

Fig. 9. Production sequences of the test specimens

Thanks to advances in the adhesive industry, the "wet" manufacturing process was envisaged, with the liquid concrete being poured directly on the adhesive applied to the wood surface.The industrial partners decided to prefabricate composite elements with a width of about 1m in the workshop in order to shorten construction time and to avoid water applications on site. Figure 9 shows some phases of the production of the tests specimens. Because of comparison results they made free different cross-section specimens, with classical mechanical connectors and with glue.

Most international codes demand the analysis of the load bearing behaviour at ultimate limit state (ULS) and at serviceability limit state (SLS).

The structural performance was checked with calculation models. The calculation of the structural behaviour was based on the classical theories for composite structures such as steel-concrete composite structures. Zero slippage was assumed: the glue was expected to give 100% bondage. The material properties were partly taken from the values listed in the Swiss code of practice (SIA-Norm). Some of the material properties were determined directly in special tests, or, in the case of the adhesive, from the technical documentation of SIKA AG. The test specimens were all 6,0m long; the span was 5,7m. The deflection of the beams at mid-section was measured (mean of two values), as well as the slippage between the concrete and the timber at both beam end. In all 3 specimens of the test, 8 devices were placed around the beam axis in order to measure the strains in both concrete and in the timber.

The structural performance was checked with calculations and the calculation results agreed quite well with the measured results.

The strain line across the cross section remained linear even with increasing loading.

The tests also confirmed the calculated prediction that failure would be caused by the timber reaching the failure strain of 3,82‰.

They got also a good agreement between the measured and calculated values for the deformation behaviour, because the corresponding force-deflection lines are quite parallel. There is no slippage between concrete and timber when the composite deck is glued together with the proposed adhesive.

According to the Swiss codes of practice, apart from the ultimate load state, the service limit state should also be analysed. For building decks the following condition for long-term deflections is often the most relevant for the design:

$$w_1 + w_2 + w_4 < w_{total} = l/250, \qquad (1)$$

where:

- w_1 super-elevation of structure,
- w_2 long-term deflection under permanent loads,
- w_4 short-term deflection under service loads.

The measured deflections are compared with the values calculated with the test-models and there is quite good agreement.

A continuous wood-concrete-composite system (WCC), investigated by Bathon and Graf, contains steel mesh connecting wooden beams with a concrete slab. The shear connector acts as a rigid but ductile moderator between the materials timber and concrete. The system was tested in both shear and bending conditions to allow a better understanding on the structural behaviour under ultimate loading conditions. In order to allow a prediction of the non-linear behaviour of the specimens a mechanical model was developed.

The comparison between actual test and the mechanical model shows a good correlation and puts trust in the simulation of the innovation. The advantages of this system compared to contemporary WCC-system solutions lay in improved strength, stiffness and manufacturing procedures.

Shear and bending tests results were conducted at the Material Testing Laboratories MPA Wiesbaden which is located on the campus of the FH Wiesbaden–University of Applied Sciences.

The test results then are compared to a mechanical model which was developed in Wiesbaden. The structural elements of the wood-concrete-composite system are shown on the following figure.

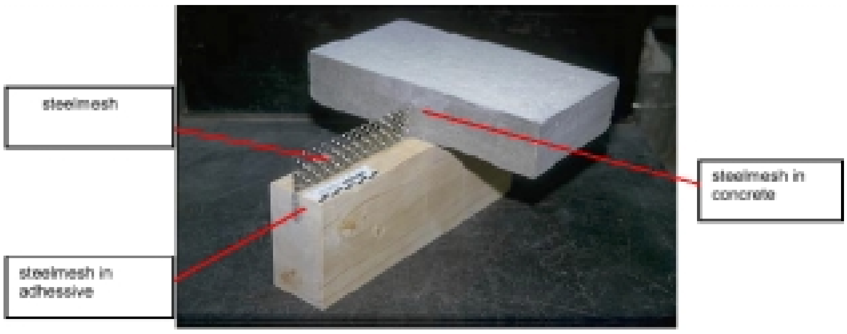

Fig. 10. Structural elements of a shear test specimens

The continuous shear connector- in form of a steel mesh- is inserted into a continuous slot within the wooden beam and connected by adhesive action. The continuous slot in the wooden beam is manufactured through a common circular sew in carpentry. The adhesive used is fire resistant up to approximately 200°C and cures within 30 minutes. The shear connector acts as a support of the reinforcement and is fixed with the hardened concrete.

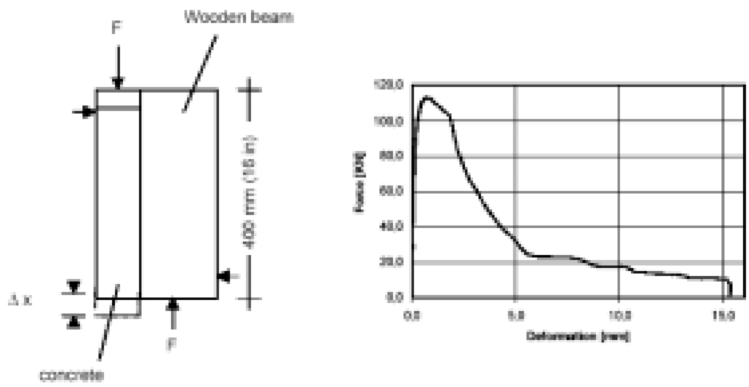

Fig. 11. Test set up of the shear tests and the load-displacement diagram

The load-displacement performance of the WCC-system is shown in the following diagram. The figure shows almost a linear performance up to failure which supports the observation of a wooden fracture.

For a few years some connecting systems appeared in the building practice. In the field of renovating old buildings, the use of lightweight aggregate concrete (LWAC) for composite structures, gives possibility to minimize additional loads for the existing structure, improving the bearing capacity, serviceability, sound protection and fire resistance.

Thorsten Faust and Ricky Selle from Institute for Engineering and Timber-Technology, University of Leipzig, analysed the push-out tests with two connecting systems and the properties of timber-LWAC composite structures.

Both systems are screws set under an angle of 45° into the beam and embedded in concrete. Screws type A are set in pairs with one screw in the direction of shear and one against it (figure 12). Screws type B are set all together in the direction of shear (figure 13).

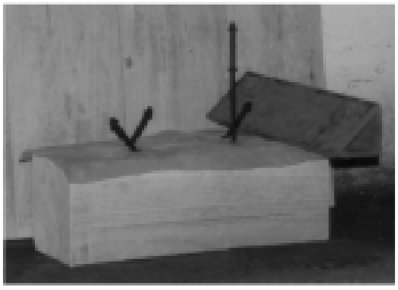
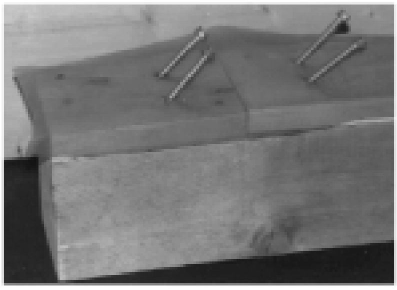

Fig. 12. Screws type A Figure 13: Screws type B

The loading was chosen in accordance with DIN EN 26891. This code regulates the determination of the so-called initial stiffness which is the characteristic value for the calculation of composite structures. The initial stiffness is the quotient of the load at 40 percent of the estimated ultimate load to the accompanying slip v_{04}.

On the base special testing procedure it can be concluded that timber-LWAC composite structures are characterized by the specific properties of the LWAC. In the same strength class as NWC (normal weight concrete) the lower modulus of elasticity leads to a more yielding compound and therefore to a lower stiffness of the composite beam.

The shear bearing capacity is as lower as is the dry density of the used LWAC.The use of LWAC is especially favourable in renovating timber floors in old buildings. By using LWAC for the composite structures the additional load from the renovating including usual floors can be reduced from 2,1 kN/m² to 1,3 kN/m².

The economical advantages of LWAC concerning its lower dead weight have to be faced with its higher production costs, which results from a higher price of the lightweight aggregates and the higher supervision costs.

The lower dead weight is not the only difference between LWAC and normal weight concrete (NWC). For the calculation of the composite structures the lower modulus of elasticity of LWAC and its lower tensile strength at the same compressive strength level as NWC have to be taken into account.

Richard M. Gutkowski, Kevin Brown, Patrick Etournaud and Wayne Thompson from Colorado State University, investigated the concept of combining wood and concrete in layered composite bridge deck. A shear key-anchor detail shown on the figure 14 was adapted for this study.

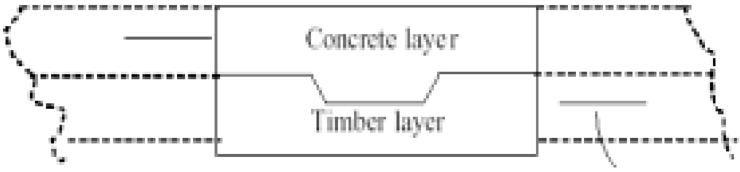

Fig. 14. A shear key-anchor detail

This connection detail provides the interlayer shear transfer between the layers. Laboratory testing included anchor pull-out tests, interlayer slip tests on various key/anchor details, preliminary load tests of full-scale rectangular layered beam specimens and pilot tests of two full-size layered deck specimens. The deck specimens were realistic for short span right and skewed longitudinal deck bridges, respectively. An analytical model successfully predicted the beam behavior.

Results show that under static loading, a high degree of composite action was achieved in the beam specimens, as compared to use of ordinary mechanical connectors. An initial analysis shows extremely high efficiency for the deck specimens, but is overestimated in the model.

The objective of this investigation was to make a notched shear key-anchor detail for a composite wood-concrete bridge deck. The goal was to achieve a high degree of systems behavior to result in a viable short span bridge concept and possible strengthening method.

One approach to strengthening a wood bridge deck is to add a concrete deck layer and interconnects it to the wood deck. Principally, shrinkage of the concrete and wood during hydration of the concrete resulted in a loss of bond with the mechanical connectors used to join the layers. Because of that the system essentially non-composite in a structural behavior sense and the intended strengthening was not achieved.

In Europe, a notched shear key with a steel dowel tension anchor is used to join the layers.

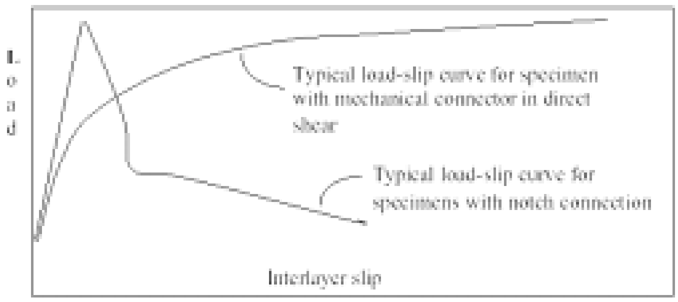

Fig. 15. Typical load-slip curves.

Therefore, deficiencies of the past approaches have been overcome. This method produces a high degree of composite action, exceeding 80 percent.

Furthermore, these group researchers, according to special laboratory investigation procedure which details not be noted here because of volume, conducted tests and have got fallowing result, compared the layered wood-concrete T-beams interconnected by mechanical connectors, to beams with notched shear key anchor detail:

- Computed efficiency of the composite action of the beam specimens ranged from 54,9 percent to 77,0;
- Computed efficiency of the composite action of the skewed and rectangular deck specimens was 81,1 percent and 92,2 percent, respectively;
- Lateral load sharing of the bare wood decks was dramatically improved by addition of the concrete layer;
- Layered beam failures were almost characterized by tensile failure in the wood.

4. DESIGN OF LOAD BEARING CAPACITY OF COMPOSITE TIMBER-CONCRETE T-CROSS-SECTION BEAM

The analysis of composite timber-concrete beam demands knowledge of the relationship between stress and deformations for all three components, timber, concrete and shear connectors.

Complexity of problems concerns determining this relationship and demands the introduction of large number of parameters, which complicates calculations. For practical calculations, we can make certain simplifications, certain assumptions that enable us to reach the solution relatively easily.

The design of the composite beams is regulated in the appendix B of the Eurocode 5. The stress calculation for timber and concrete and the calculation of the connectors is to be performed in accordance with the theory of the elastic compound.

According to recommendations from the appendix B of the Eurocode 5, consistently with what has been said, for cross section shown by figure 16, geometrical properties, stresses, and characteristics of connection we can calculate according to next steps:

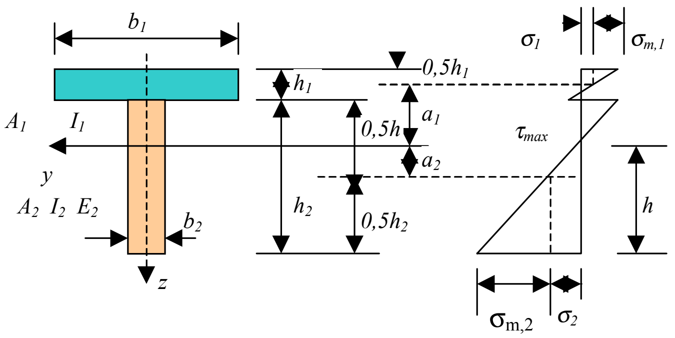

Fig. 16. Cross section timber concrete beam

The effective bending stiffness $(EI)ef$ will be calculate as follows:

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

$$A_i = b_i h_i \,,\; I_i = b_i h_i^3 / 12 \,,\; \gamma_2 = 1 \,, \tag{3}$$

$$\gamma_i = [1 + \pi^2 E_i A_i s_i /(K_i \ell^2)]^{-1} \text{ for } i = 1 \text{ and } i = 3, \tag{4}$$

$$a_2 = \frac{\gamma_1 E_1 A_1 (h_1 + h_2) - \gamma_3 E_3 A_3 (h_2 + h_3)}{2\sum_{i=1}^{3} \gamma_i E_i A_i}, \tag{5}$$

for T-cross sections, $h_3 = 0$.

In the equations above, the signs have the following meanings:

i number of elements consisting composite cross section.
In case of T- cross section, that is 2,

E the average value of modulus of elasticity for concrete and timber, respectively,

γ_i slip modulus of the mechanical fastener,

Ki the equivalent slip modulus in the joint.

The normal stresses are given by equations:

$$\sigma_i = \gamma_i E_i a_i M /(EI)_{ef} \,,\; \sigma_{m,i} = 0{,}5 E_i h_i M /(EI)_{ef} \tag{6}$$

Maximum shear stress at certain point along the high of timber element of cross section should be calculated according to expression:

$$\tau_{2,\max} = (\gamma_3 E_3 A_3 a_3 + 0{,}5 E_2 b_2 h^2) V /(b_2 (EI)_{ef}) \,. \tag{7}$$

Load of the fastener should be calculated according to expression

$$F_i = \gamma_i E_i A_i a_i s_i V /(EI)_{ef} \tag{8}$$

with $i = 1$ and 3, where $s_i = s_i(x)$ distance between fasteners determined in B1.3 and $V = V(x)$.

The "effective width" ($b_{1,eff}$) is defined as the length parallel to the supports which is structurally active in resisting a load acting on a floor decking or concrete slab of composite element. It is very important term in calculation of composite structures and it is based on the assumptions of the theory of elasticity.

However, assumptions about displacements due to shear deformations are not valid for behaviour of composite girder subjected to bending load, because of discontinuity of normal stresses over the width of concrete slab .

It is a consequence of influences of shear stresses on the bending of the beam. Those stresses, by means of shear forces at zone of contact between timber and concrete act on the concrete slab and on the distribution of normal stresses.

The active width of concrete slab, $b_{1,eff}$, can be determined according to the equation:

$$b_{1,eff} \cdot \max \sigma_x = 2 \int_0^{b/2} \sigma_x dy \tag{9}$$

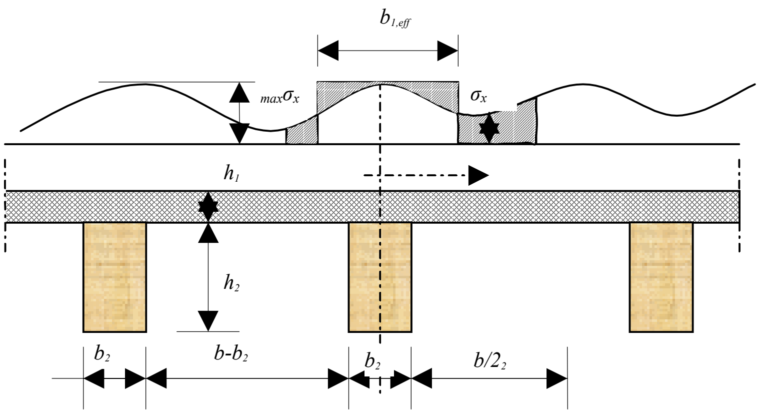

Fig. 17. Distribution of normal comprehensive stresses over the width of slab

The active width of concrete slab depends on:

- relationship between total width of slab and length of girder;
- type of loading (uniform load, concentrated load, position of load)
- type of statical system of girder (the "effective width" or active width is different for fixed, continuous and simply supported deckings);
- type of coupling between elements of composite structure;

Considerable influence on the active width of slab has a relationship between total width of slab and length of girder, the other factors have a less important role. According to theoretical-experimental investigations, we can find different equations which determine the design of active width of slab, but with certain safety, we can use theoretical results by Natterer and Hoeft, given as follows:

for uniform loading:

$$b_{1,eff} = b\,[1 - 1{,}4(b/l)^2] \tag{10}$$

for concentrated load:

$$b_{1,eff} = b\,[1 - 1{,}4(b/l)^2 - 0{,}8(b/l)] \tag{11}$$

where, *b* is the distance of timber girders and *l,* length of the girder.

According to recommendations of the American Institute for Timber Engineering (AITE), the active width of concrete slab in case composite timber-concrete structures can be calculated as least value from values calculating on the base fallows three equations:

$$b_{1,eff} \le \frac{1}{4} l\,; \quad b_{1,eff} \le 12d\,; \quad b_{1,eff} \le b\,; \tag{12}$$

The signs have the following meanings:

b distance of timber girders,
l length of girder,
d at least thickness of concrete slab.

Solutions given in Eurocode 5 and German Codes DIN 1052 are valid for panel systems and take in consideration only characteristics and properties of timber as material.

Eurocod 2 gives following approximated solutions for active width of slab,

for a symmetric T-beam section:

$$b_{1,eff} = b_2 + \frac{1}{5} l_0 \leq b_1 , \tag{13}$$

for a one-sided T-beam section:

$$b_{1,eff} = b_2 + \frac{1}{10} l_0 \leq b_1 , \tag{14}$$

where, l_0 is the distance of the points of zero-moments in the field;

5. FOOTBRIDGE, STRUCTURAL DETAILS AND DESIGN

As an example for application of design according to ultimate and serviceability limit states, the design of some elements of a footbridge structure is taken. Here, only a description of the structure, geometrical properties of the elements and the calculated nominal loading according Eurocode 1 is given.

The length of a footbridge is 12,0m and distance between two main composite timber-concrete girders is 1,80m. The different materials consisting cross-section, by steel headed bars, along the interface with calculated spacing, are connected. Thanks to concrete slab, the structure will have the high horizontal plane stiffness, but regardless of that, the main composite girders at the certain points of the length, by means of lateral secondary girders are connected. These connections realised by bolts and steel plates. The static system of a structure is simple supported beam. The supporting points, made from steel plates, have to provide "work" of a structure according to structural analysis rules. Except for loading from humans, wind and snow, the structure will be considered for a possibility of accidental loads, induced by traffic load from cars weighted less than 100kN. The concrete slab will be covered with a certain thickness of asphaltic concrete.

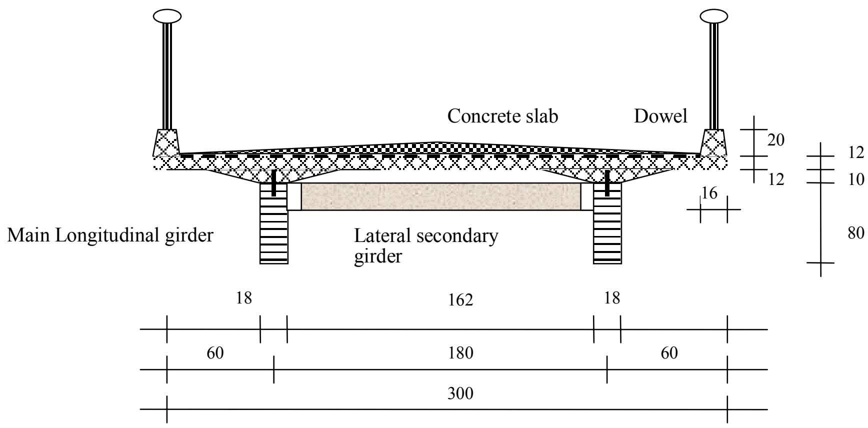

Fig. 18. Characteristic lateral cross-section of a footbridge structure

Characteristic value of permanent load per beam: g_k = 9,0 kN/m.
Characteristic value of variable load per beam: q_k = 8,925 kN/m.
Characteristic value of variable load (wind) per beam: $F_{wx} = -0{,}195 kN/m'$.
Characteristic value of accidental load per beam, max M_k = 110,5 kNm.
Design values of the internal forces for load combination (permanent load + variable loads):
$M_{d,I} = (1{,}35 g_k + 135 q_k) l^2 / 8 = 435{,}60 kNm$, $V_{d,I} = (1{,}35 g_k + 1{,}35 q_k) l / 2 = 145{,}20 kN$.

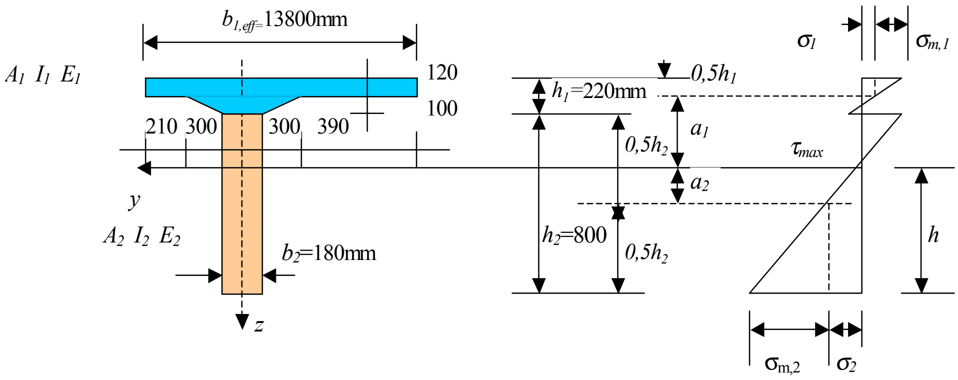

Fig. 19. Cross section of characteristic girder of the footbridge

Mechanical properties of elements of the composite timber-concrete connection:

Top slab: concrete strength class C25/30, according to ENV 206:
$f_{ck,cube}$= 30 N/mm^2, f_{ctm}=2,6 /mm^2 E_{cm}=30000 N/mm^2;
for C25/30, RH = 80% and $2Ac/u$ ≈200: $\varphi_{28,\infty} = 2{,}12$ and $\varphi_{3year,\infty} = 1{,}10$.

Beam: glued laminated timber class BS16(h), according to prEN 338:
$f_{m,k} = 32$ N/mm^2 $f_{t,0,k} = 22{,}5$ N/mm^2 $f_{v,k} = 3{,}8$ N/mm^2
$\rho_{0,k} = 410$ kg/m^3 $f_{h,0,k} = 26{,}09$ N/mm^2 $E_{0,mean} = 13700$ N/mm^2
$f_{c,0,k} = 29$ N/mm^2 $f_{c,90,k} = 3{,}3$ N/mm^2.
Service class 1: k_{mod}= 0,8 (medium term load combination),
k_{def} = 0,6 (for permanent load), k_{def} = 0,25 (for medium term load).

Fasteners: Steel headed bars, according to EN10080, Service class 1, d = 20 mm.
Including all parameters of the composite structure, ordered above, in the design according to limit states it has got adequate results related to the defined criteria. More details of the calculation can be found in the chapter 5 of the original work [9].

6. CONCLUSION

This paper has a review character and it is based on the investigations in the field of composite timber-concrete structures during the last years of the 20th century. This paper provides details of the calculation procedures of timber-concrete cross sections based on the theory of elasticity. New Euro-code-design concept is applied in the calculation of some elements of the footbridge structure.

By combining timber and concrete in a new type of composite material and using the best properties of both materials, the high tensile strength of timber and the high compressive strength of concrete, depending on different building conditions, we can find a lot of reasons for decision to apply this type of structure in comparison to concrete or steel structure.

As stated, advantages of composite timber-concrete structures can be found in facts that the load bearing capacity of, for example, floors can be doubled and its out-of plane stiffness improved more times, serviceability conditions are better satisfied, sound insulation is improved, fire resistance too, vibrational effect in the buildings thanks to concrete decreases and the self-weight of the whole structure is less than self-weight concrete type structure or steel type structure for the same constructional work.

Generally speaking, composite timber-concrete structures have some advantages in comparison to concrete and steel structures, especially, in comparison to classical timber structures. In some cases of structure or structural details depend on its properties, firstly, on the length of a structure and environmental conditions, timber-concrete structures indicate better behavior. In the base all comparisons is the economical moment and in regards of that, for precision recommendations, experimental work is needed.

REFERENCES

1. A. Ceccotti, Timber-concrete composite structures,
2. Structural Timber Engineering Proceedings 2 (STEP 2), lecture E13, 1995; H. J. Blaß und M. Schlager, Trag-und Verformungsverhalten von Holz-Beton-Verbundkonstruktionen-Teil 1, Bauen mit Holz 5/96, pages: 392-399, 1996;
3. H. J. Blaß, M. van der Linden und M. Schlager, Trag- und Verformungsverhalten von Holz-Beton-Verbundkonstruktionen-Teil 2, Bauen mit Holz 6/96, pages: 472-477, 1996;
4. ENV 1995-1-1.Eurocode 5: Design of timber structures, Part 1.1: General rules and rules for building, European Committee for Standardisation, 1993;
5. ENV 1994-1-1.Eurocode 4: Design of composite steel and concrete structures, Part 1.1: General rules and rules for building, European Committee for Standardisation, 1992;
6. ENV 1993-1-1.Eurocode 3: Design of steel structures,Part 1.1: General rules and rules for building, European Committee for Standardisation 1992;
7. ENV 1992-1-1.Eurocode 2: Design of concrete structures, Part 1.1: General rules and rules for building, European Committee for Standardisation 1993;
8. ENV 1991.Eurocode 1:Basis of Design and Actions on Structures;
9. R. Cvetković, Behaviour of Composite Timber-Concrete Structures with Bending Actions. Masters thesis, Department of Reinforced Concrete and Prestressed Concrete Structures, Ruhr University Bochum, Germany, 2002.
10. B. Stevanovic, Ponašanje spregnutih nosača tipa drvo-beton izvedenih mehaničkim spojnim sredstvima pri eksploatacionom i graničnom opterećenju, Doctoral thesis, Faculty of Civil Engineering, Belgrade, 2003;

ANALIZA SPREGNUTIH KONSTRUKCIJA DRVO-BETON PREMA GRANIČNIM STANJIMA

Dragoslav Stojić, Radovan Cvetković

U radu je data analiza spregnutih konstrukcija tipa drvo-beton. Pomoću mehaničkih spojnih sredstava, moždanika ili nekih drugih sistema za spajanje, drvo i beton mogu biti povezani, odnosno spregnuti u novi tip nosača koji se karakteriše boljim mehaničkim svojstvima. Proračun prema teoriji elastičnosti, posebno prema pravilima i preporukama modernih concepata za proračun drvenih i betonskih konstrukcija datih u Evrokodu 2 i Evrokodu 5 i zasnovanih na graničnim stanjima nosivosti u upotrebljivosti, dat je ukratko.

Ponašanje konstrukcije spregnutog pešačkog mosta, sastavljene od armirano-betonske ploče koja jesa lepljenim lameliranim gredama povezana mehaničkim štapastim spojnim sredstvima analizirano je prema graničnim stanjima.