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SLIP MODULUS IN WOOD-CONCRETE COMPOSITES - PRACTICAL ESTIMATION FOR MODELLING

Dragan Manojlović[1]
Tatjana Kočetov Mišulić[2]

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Summary: *Opposite to steel-concrete composite structures that generally consider the rigid connections, the values for "slip" modulus of timber connectors are of essential interest in modeling the wood-concrete composite beams with controlled contact deformations. SRPS regulative doesn't give any recommendation for connector slip characteristics in wood-concrete systems, so the values proposed in EC5 and accompanying studies have to be adopted in practical design using the commercial software. Trough one numerical example and relevant discussion, the paper presents possibilities of practical "slip" modulus estimation for dowel type studs, in cases of existence and non-existence of formwork. The modeling and computational results are discussed in order to show the limitation of EC5 recommendations, as well as possibilities of practical "slip" modulus estimation and it adoption in design using domestic commercial software.*

Keywords: *wood-concrete composite beams, dowel type connectors, slip modulus, EN 1995, SRPS U.C9.200 / 300.*

1. INTRODUCTION

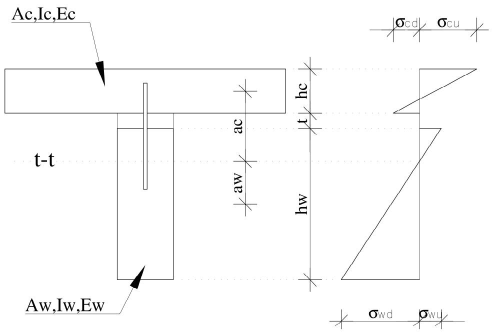
The interest for wood-concrete composite structures is rising worldwide in last few decades because of its structural benefits - improved stiffness and limited deformations of wooden beams. The growing interest is also present in our country, in theory and experiments, as well as in practical issues (Stevanovic [1]), because of possibilities for rehabilitation of ancient buildings and design of new ones, such as wooden floors and bridges with larger loads. The main factor and "measure" of composite action between the wood-concrete members are connectors, whose deformability are mainly determined by excessive experimental and theoretical studies. Several types of connectors have been studied (nails, screws, bolts, punched metal plates ... special connectors...) in many research programs, where the dowel type fasteners (studs) are outlined like particularly suitable for practical purposes due to its easy "in situ" handling. So, the paper is dealing

[1] MSc student, University of Novi Sad, Faculty of Tehnical Sciences, Trg D. Obradovića 6, Novi Sad, Serbia, tel: ++381 21 4852613, e – mail: manojlovicdragan90@gmail.com
[2] PhD, Ass Prof. University of Novi Sad, Faculty of Tehnical Sciences, Trg D. Obradovića 6, Novi Sad, Serbia, tel: ++381 21 4852613, e – mail: tanya@uns.ac.rs

with glulam beams where the concrete slab is collaborating using steel studs, manufactured from smooth steel bars and inserted into calibrated holes.

2. THEORETHICAL BACKGROUND

In wood-concrete composite beam-floor system, the stiffness improvement is the target goal, assuming and including the sufficient bearing capacity and limitation of connector / connection deformability. The EU regulative [2], as well as SRPS [3], [4], considers the so called "γ" i.e. "Mohler" method, developed for wood-to-wood composite structures, Fig. 1, Eqs (1-6), that are also applicable for wood-concrete composite structures.



"γ / Mohler" method

$$n = \frac{E_c}{E_w} \tag{1}$$

$$\gamma = \frac{1}{1+k} \tag{2}$$

$$k = \frac{\pi^2 \cdot E_c \cdot A_c \cdot s}{L^2 \cdot K_s} \tag{3}$$

$$a_c = \frac{1}{2}\frac{A_w(h_c + h_w + 2 \cdot t)}{\gamma \cdot n \cdot A_c + A_w} \tag{4}$$

$$a_w = \left(\frac{h_c + h_w}{2}\right) - a_c + t \tag{5}$$

$$I_{ef} = n \cdot I_c + \gamma \cdot n \cdot A_c \cdot a_c^2 + I_w + A_w \cdot a_w^2 \tag{6}$$

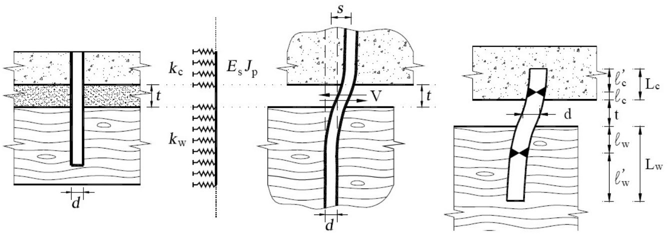
Figure 1. Cross-section and basic equations of "γ" i.e."Mohler" method [2], [3]

The dominant factor in eqs. 1-6 is **"Ks"**, or according to EC5 **"Kser"** coefficient, which is the so called "slip modulus for connections" - the target value of numerous experimental and theoretical verification. According to EC5 [2], the **"Kser"** value is established as a function of connector's type, it's diameter and specific mass weight of wood. Equations (7) represent values for dowels.

$$K_{ser} = \rho_m{}^{1.5}\frac{d}{23} \tag{7}$$

$$K_u = \frac{2}{3}K_{ser} \tag{8}$$

The proposed values EC5 do not include the presence of formwork in cross-section. For the Ultimate Limit State (ULS), the connection slip modulus has to be adopted according eq (8), while for **"Kser"** in wood-concrete composites this value has to multiplied by 2. Additional research about this issue (Gelfi & atl. [5]) gives the theoretical background and experimental results for stud connectors with existing formwork (with depth of planks in range t=0-5cm, and stud diameter from 12 to 20mm). The minimum embedding stud lengths, both in concrete and wood, theoretically and experimentally derived for minimum collapse approach, are given in Fig. 2, [5].



$$K_s = \frac{V}{s} = \frac{12 E_s I_s}{l^*} \quad (9)$$

$$K_s = \frac{124000 \cdot d}{(4.34 + \frac{t}{d})^3} \quad (10)$$

$$L_w = 6d \quad (11)$$

$$L_c = 3d \quad (12)$$

$$L_{w,tot} \geq L_w + d \quad (13)$$

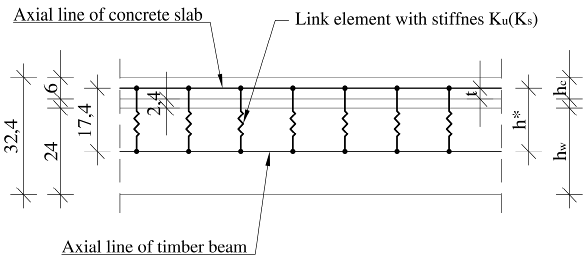
$$L_{c,tot} \geq L_c + d \quad (14)$$

$$l^* \cong 17.3 - 0.000572 \cdot k_c - 0.00894 \cdot k_w + 0.880 \cdot t + 4.34 \cdot d \quad (15)$$

Figure 2. Stud connection modeling, Ks and stud lengths according Gelfi & alt [5]

3. MODELLING OF COMPOSITE BEAM WITH INTER-LAYER SLIP

For practical engineering purposes, the plenty of commercial software are available. The software package "Radimpex" Tower 7, based on SRPS regulative, was used. In this particular study, structural analysis is made using 1st order theory, and model was made using beam elements. Connector studs/connections were modeled with beam elements that link central lines of concrete slab and wooden beam, Fig.3, [6], [7]. The length of such "link" element was adopted as h* (eq 16). Slip modulus was introduced trough stiffness of "link" element, recalculating Young's modulus Es (eq 17) for adopted stud length (h*) and dowel diameter (d) , [8], [9].



$$h^* = \left(\frac{h_c + h_w}{2}\right) + t \quad (16)$$

$$E_s = \frac{K \cdot h^{*3}}{12 \cdot I_s} \quad (17)$$

Figure 3. Modeling of Wood-Concrete composite beam

4. NUMERICAL EXAMPLE

In order to compare the results obtained by EC5 and Gelfi, the design example (disposition of elements, dimensions) shown at Fig. 4 was adopted for computation, representing the real floor structure. The characteristics of applied materials are selected according the Table 1.

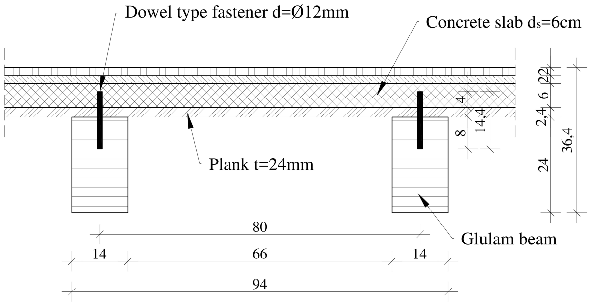


Table 1: material characteristics			
	Class SRPS	E [GPa]	ρ [kN/m³]
Concrete	MB30	31.5	25.0
Plank	MD II klasa	10	5.00
Glulam	LLD II klasa	11	5.00
Dowel	GA240/360	210	78.50

Figure 4. Design example and relevant material cross-section characteristics

In order to establish differences between proposed values for Ks (Ku), plank thickness **"t"** was changed in the range of 0 to 5 cm, that represent the possible formwork depth during construction works. The relevant stresses for plank thickness t = 0; 2.4cm and 4.8cm respectively, as well as stresses for two opposite cases (no inter-layer slip and non-composite action), are shown at Fig.5.

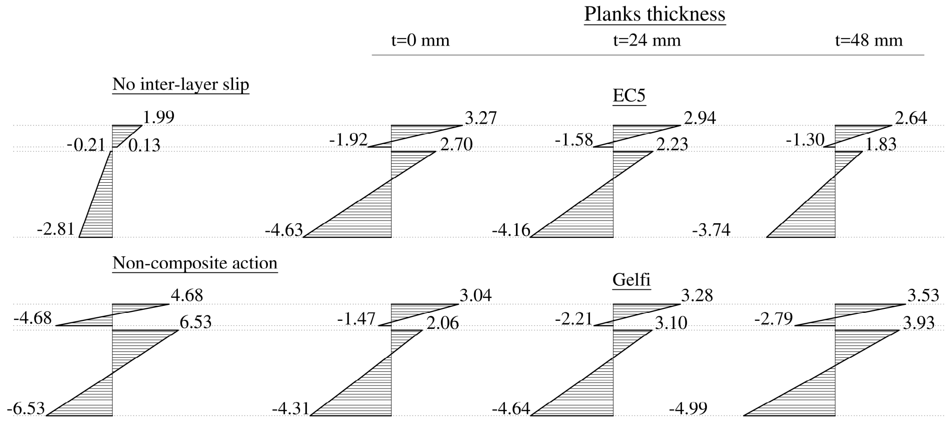


Figure 5. Stresses according EC5 and Gelfi for analyzed structure

5. DISCUSSION OF RESULTS

Trough the performed analysis, several conclusions are made. EC gives the constant value for slip modulus, while model proposed by Gelfi & alt. introduce the variable value of slip modulus, depending on planks thickness. Results obtained by EC5 show the decrease of cross-sectional stresses in cases when plank depth increase, that do not correspond to real situation. Gelfi's model for Ks gives more realistic description for stress distribution related to applied plank thickness, Fig. 5.

Performed stress analysis imposed the question of more detailed consideration of mutual matching of two proposed slip modulus' values.

Exactly the same results could be reached only in certain points, i.e. to different dowel diameters correspond different plank thickness where the matching is achieved. The intersection of straight lines (EC5) and curves (Gelfi &alt) in Fig. 6, define the exact plank thickness that give the same K values and consequently stress distribution.

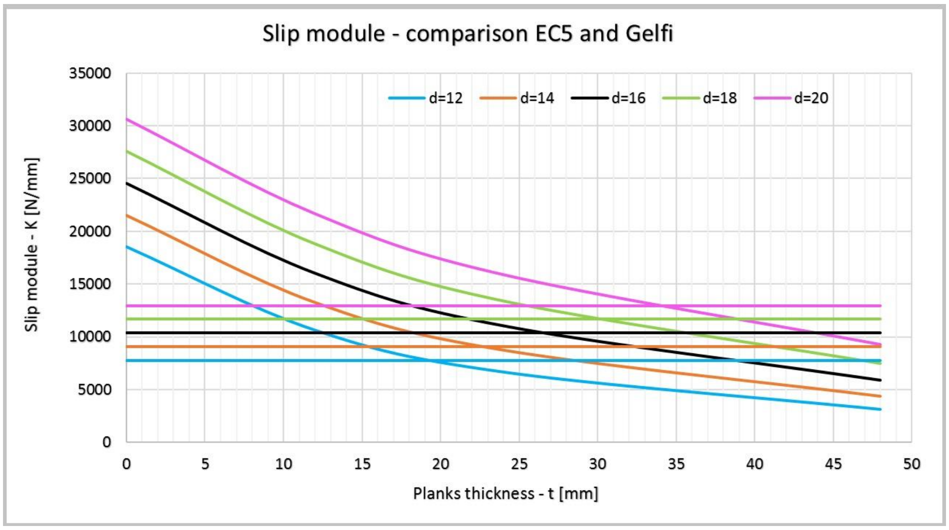


Figure 6. Slip modulus diagram according EC5 and Gelfi for different stud diameters

6. CONCLUSION

Although the Tower 7 software package do not include particular option for input of slip modulus for composite action with inter-layer slip, this engineering problem is possible to solve with relatively simple modeling. In cases where the dowel type fasteners are used for coupling, together with formwork for casting the concrete slab, the recommendation is to use the Gelfi model instead of EC5 values, because it gives the realistic wood-concrete composite structure behavior, and on the safe side. Estimation of "slip" modulus in different composite systems (concrete and timber classes, type, diameter and shape of connectors) is generally the question of experimental and theoretical research. Eurocode 5 tried to bridge the gap and lack of information in everyday practice unifying and simplifying the problem, but proposed solution seems to be more useful for timber-to-timber composite systems.

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МОДУЛ ПОМЕРЉИВОСТИ У СИСТЕМУ ДРВО-БЕТОН : ПРОЦЕНА ЗА ПОТРЕБЕ МОДЕЛИРАЊА

Резиме: *Насупрот спрегнутим челичним конструкцијама које се сматрају круто спрегнуте, вредности модула померљивости спојних средстава су од суштинског значаја у моделирању спрегнутог система дрво-бетон са контролисаним контактним деформацијама. СРПС стандард не даје никакву препоруку за модул померљивости у систему дрво-бетон, тако да предложене вредности у ЕЦ5 и пратећим истраживањима треба усвојити за потребе пројектовања приликом коришћења комерцијалних програмских пакета. Кроз нумерички пример и релевантну дискусију, рад приказује могућност практичне процене модула померљивости за челичне трнове, у случајевима постојања или непостојања оплате. Моделирање и прорачунски резултати су дискутовани како би се указало на ограничење препорука према ЕЦ5, као и могућности за практичну процену модула померљивости и његово усвајање у пројектовању приликом коришћења домаћих софтверских пакета.*

Кључне речи: *дрво-бетон, спрегнути системи, трнови, модул померљивости, EN 1995, SRPS U.C9.200 / 300.*