

Behavior of Composite Timber-Concrete Beam with CFRP Reinforcement

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Abstract—The paper deals with current issues in research of advanced methods to increase reliability of traditional timber structural elements. It analyses the issue of strengthening of bent timber beams, such as ceiling beams in old (historical) buildings with additional concrete slab in combination with externally bonded fiber-reinforced polymer. The study evaluates deflection of a selected group of timber beams with concrete slab and additional CFRP reinforcement using different calculating methods and observes differences in results from different calculating methods. An elastic (EN 1995) calculation method and evaluation with FEM analysis software were used.

Keywords—Timber-concrete composite, strengthening, fibre-reinforced polymer, theoretical analysis.

I. INTRODUCTION

IN recent years at Institute of Metal and Timber Structures of Brno University of Technology are ongoing full-scale tests of timber beams reinforced with external fiber reinforced polymer. The experimental verification of ultimate and serviceability limit state of these structural elements provided a number of results, basic principles and parameters, which were later used as initial conditions for the study focused on the actual behavior of composite timber-concrete beam adding external carbon FRP reinforcement.

The primary argument for the interest of this type of reinforcement can be found for example for existing timber ceilings in historic buildings. If there is a demand for increased load capacity of ceiling and object is historically preserved, combination of reinforcement with concrete slab and CFRP lamella can be an option. Especially in case when traditional types of reinforcement are insufficient.

In the first part paper briefly summarizes prior research dealing with the bearing capacity of timber beam reinforced with carbon FRP lamella. The following section defines composite timber-concrete beam with FRP reinforcement and introduces different principles of beam analysis. Specific data of ultimate limit state and short-term deflection were evaluated.

II. BEHAVIOR OF TIMBER BEAM WITH CFRP REINFORCEMENT

A. Experimental Tests

Experimental and theoretical analysis of timber beam reinforced with external carbon FRP lamella is proceeding at Institute of Metal and Timber Structures. Bearing capacity and

deflection was evaluated on six profiles 100/120, 100/140, 100/160, 100/180, 100/200 and 100/220mm – with carbon fiber reinforced polymer lamella glued at the bottom surface of beam. Dimensions of lamella were 50x1.2mm, yield strength 3000 MPa and Young's modulus 155 GPa. Six beams with similar dimensions were experimentally tested - three beams with CFRP reinforcement and three beams without reinforcement.

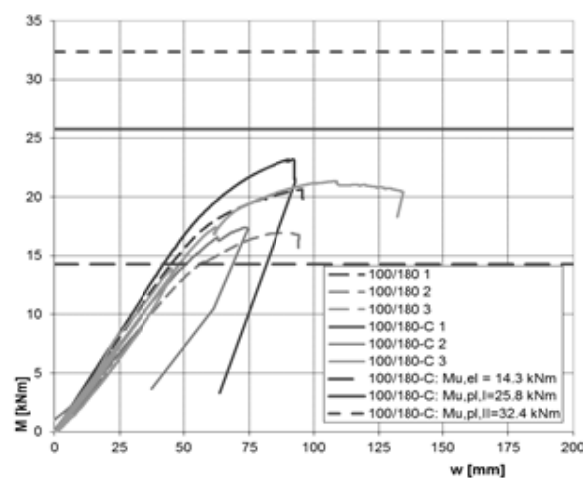


Fig. 1 Relation of bearing capacity “M” and deflection “w” for beam with dimension 100/180 with and without CFRP reinforcement, passed from [1]

B. Comparison of Experimental and Theoretical Bearing Capacity

After experimental tests, one of tests evaluation was comparison of experimental and theoretical bearing capacity. Both plastic and elastic theory was used calculating theoretical values of bearing capacity. Material characteristics of timber beam for theoretical calculation were read from experimental tests of same batch timber beam without CFRP reinforcement. Methodic from [3] and its particular applications in [4] were used.

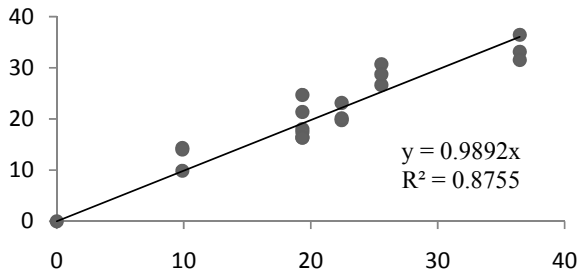


Fig. 2 Comparison of experimental (vertical axis) and theoretical values (horizontal axis) using elastic evaluation

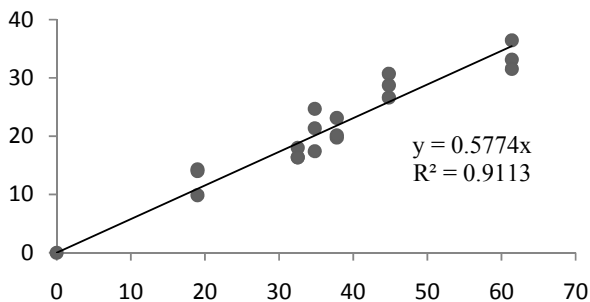


Fig. 3 Comparison of experimental (vertical axis) and theoretical values (horizontal axis) using plastic evaluation

From Figs. 1 and 2, a good equivalence between experimental and theoretical values according to elastic theory is recognizable. Experimental values are lower in comparison with theoretical values trend line by 1.08%. In contrary theoretical bearing capacity using plastic theory is quite overvalued. Experimental values are lower by 42.26% in comparison with theoretical values trend line.

According to this comparison it is recommended to use theoretical evaluation of ideal timber beam with CFRP reinforcement using elastic theory. Slippage of carbon FRP lamella didn't have noticeable influence. The same result was found also in [2]. Elastic theory was also used for consequential timber-concrete beam with GFRP and CFRP reinforcement evaluation.

III. METHODS OF COMPOSITE TIMBER-CONCRETE BEAM WITH CFRP REINFORCEMENT THEORETICAL ANALYSIS

For following theoretical research of composite timber-concrete beam with carbon FRP reinforcement the same types and dimensions of timber beam as well as carbon FRP lamella were used as in Chapter II. Additionally the concrete slab on the top of the timber beam was considered. Dimensions of concrete slab are 1000x50mm and material is considered as C25/30. Concrete slab is joint to timber beam with dowel type fasteners. The rigidity of joint, based on profile and quantity of fasteners, was included in both theoretical and numerical analysis. The value of spring constant was calculated using method in [3], Appendix B.

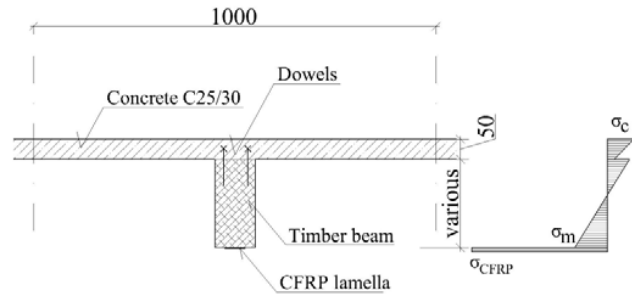


Fig. 4 Schema of composite timber-concrete beam with CFRP reinforcement

For analysis of actual behavior of composite beam two theoretical methods were used.

The method in [3], Appendix B is conservative general method for calculation of composite timber-concrete or timber-timber beam bearing capacity and deflection. With conclusions from beam with CFRP reinforcement analysis [2], method from [3] was used in combination with elastic theory for CFRP lamella. Maximal bearing capacity and equivalent deflection was found for three different beams, with dimensions 100/180, 100/200 and 100/220mm. Dimension of carbon FRP lamella and concrete slab remains the same for all beams. Quantity of dowel type fasteners is variable, providing full bearing capacity of composite beam without limitation of joint bearing capacity. This method was also used in [6].

The numerical evaluation, using FEM model, is the second used method. The most accurate FEM model was tuned using comparison of experimental deflection values from prior research [2] and calculated deflection of numeric model, using also [5] for modeling timber-concrete joint. After comparison, 2D FEM model was used calculated with modified Newton-Raphson method for large deformations. Joint between carbon FRP lamella and timber beam is considered as fully solid. Joint between concrete slab and timber beam is considered as elastic friction with limitation.

IV. COMPARISON OF COMPOSITE BEAM DEFLECTION

Three composite timber-concrete beams with carbon FRP lamella were compared.

TABLE I
COMPOSITE BEAM BEARING CAPACITY AND DEFLECTION

Timber beam [mm]	Maximum bearing capacity [kNm]	Theoretical value of deflection [mm]	Numerical value of deflection [mm]
100/180	41.85	41.14	58.70
100/200	47.83	36.68	54.02
100/220	57.80	34.93	50.89

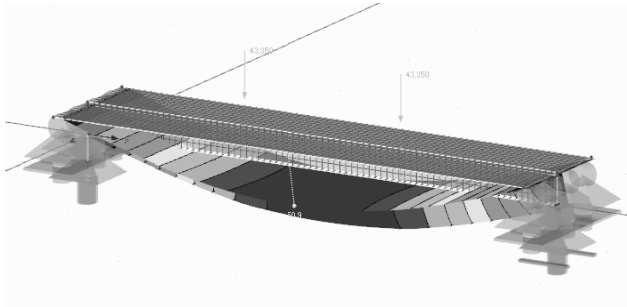


Fig. 5 Results of numerical model of composite beam

At Table I is calculated deflections for all three timber profiles. The values significantly differentiate, and are depending on calculation method used.

V. CONCLUSION

In the article are presented two different methods for analysis of composite timber-concrete beam with external carbon FRP reinforcement. Results from these methods are significantly different, so this means that one or both methods are inaccurate for composite beam analysis. Only experimental research, which will follow at Institute of Metal and Timber Structures, will confirm theoretical values. Method using [3] seems to be inadvisable for composite timber-beam with CFRP reinforcement.

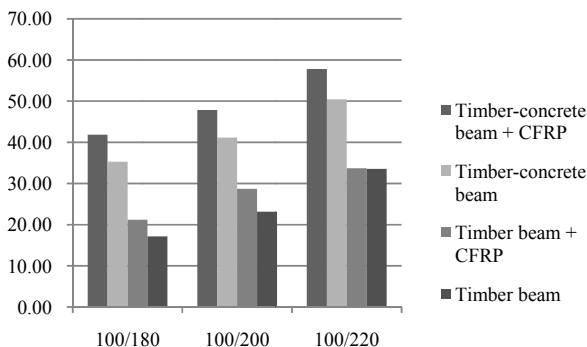


Fig. 6 Comparison of beam bearing capacity with different types of reinforcement

On Fig. 6 are compared bearing capacities of timber beams, reinforced with CFRP lamella, with concrete slab and with concrete slab together with CFRP lamella. For these profiles, CFRP reinforcement increases bearing capacity by 14 - 18%. If well designed, FRP reinforcement can significantly increase bearing capacity of concrete-timber composite beam especially at shorter spans and it has also benefit for lowering ceiling deformation. Nevertheless it is necessary to reflect an economical aspect of reinforcing with FRP in comparison of influence on ceiling load capacity.

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