# REHABILITATION OF A WOODEN FLOOR STRUCTURE BY COMPOSITE JOINT WITH RC SLAB

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***Summary:*** *The paper encompasses rehabilitation of a wooden floor in a residential building constructed about 1930. The strength of the wooden floor was satisfying, but there was a problem of high oscillation amplitudes which caused discomfort for the tenants. The rehabilitation was done by making a composite joint of the existing wooden girders with a cast reinforced concrete slab. The slab is cast over trapezoidal sheet metal, and nails were used as studs. Static and dynamic analysis for all load stages was performed and presented, along with the construction process.*

***Keywords:*** *Rehabilitation, timber structure, RC slab, composite construction, nails*

## 1. INTRODUCTION

In the last few decades there is a great need for rehabilitation of existing structures. Rehabilitation and strengthening are most often performed by adding of reinforced concrete (RC) parts or by welding (at steel structures). One of the structures that should be rehabilitated and strengthened during reconstruction are timber floors. A timber floor structure consists of wooden joists set equidistantly, with covering set over it. Although stands as a technology abandoned long ago, one may also see such systems in nowadays engineering practice. Their strength is mainly satisfactory if the joists were not damaged to the greater extent. However, the problem lies in high oscillation amplitudes and in low natural frequencies which generate discomfort for the users [1]. Because of that, it is necessary to increase the stiffness of the structure during rehabilitation and consequently the natural frequency will increase. The simplest solution for increase of stiffness is in composite action of the existing wooden joists with RC slab.
A RC slab is being laid on a previously set steel profiled sheet, which serves as formwork at the same time. The basic problem in composite construction is selecting of the way of

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joining, that is, the stiffness and the strength, in order to achieve an appropriate composite efficiency. Adding of the RC slab significantly increases the mass of the structure, too. Because of that, composite joining can produce as good, a well as bad results, in case of using shear connectors with insufficient stiffness [2]. For joining of wood and concrete, one may use different elements as connectors: bolts [3], nails [4], reinforcement bars [5], nail plates [6], grooves [7], and other devices. It is not convenient to use all quoted devices for the purpose of rehabilitation because of the limitations of the technological procedures in situ. For that reason, it is suitable to use coach screws or nails. In case of the floor structure investigated in this paper, nails mounted in previously drilled holes have been used.
For design of the composite girders analytical methods are used mostly, with application of the partial interaction theory [8] and the γ-method as its simplification. In this research, the Finite Element Method (FEM) and appropriate software was used as a more accurate procedure.

## 2. SETTING OF THE PROBLEM

Subject of this research was the structure presented in Figure 1. The floor structure was made of wooden joists with cross-section dimensions 18 by 20 cm, set at distance of 80 cm. The static system of the joists were simply supported beams, rested on brick walls 25 cm thick. Wooden planks set over the beams served as floor covering. Rehabilitation of the structure has been done through several stages. First, the plank covering has been removed, so only the wooden joists remained. After that, steel trapezoidal sheet TR60/210 has been mounted over with webs set perpendicularly to the direction of the joists. The sheet has been joined with the joists using nails as shear connectors. Next, a reinforcing mesh Q131 has been laid, and a concrete slab made of concrete class C30/37 has been cast.

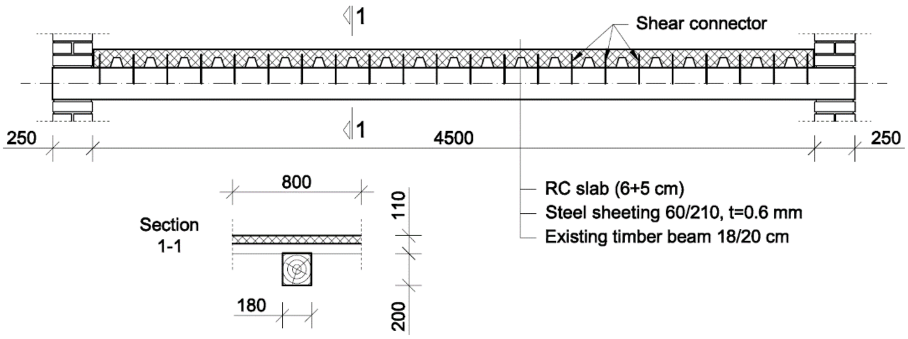


*Figure 1. Analyzed composite floor structure*

## 3. ANALYSIS OF THE MODEL USING FEM

The floor structure has been modelled and analyzed using FEMAP with NX NASTRAN software. Subject of analysis was one joist with adjoining width of the RC slab. The analysis has been conducted by stages given in Table 1.

*Table 1. Stages of analysis review*

| Stage | Description | Cross-section | Load description | Total load [*kN/m*] |
|---|---|---|---|---|
| **1** | *initial state* | *timber, 18/20 cm* | *wooden joist, plank covering, live load* | *2.13* |
| **2** | *load remove* | *timber, 18/20 cm* | *wooden joist* | *0.22* |
| **3** | *slab casting* | *timber, 18/20 cm* | *wooden beam, RC slab* | *2.14* |
| **4** | *service state (t=0)* | *composite* | *stage 3, plank covering, live load* | *4.54* |
| **5** | *service state (t=∞)* | *composite* | *stage 4, concrete shrinkage, creep* | *4.54* |

Different models regarding relevant stages have been created. Since the analysis domain was linear static analysis, forces and stresses have been obtained by superposition. The joist and the RC slab have been modelled by FE elements of BEAM type. The slab has been cast over the trapezoidal sheet, so it had no constant depth along the span. It was adopted that that system line of the slab FE lied at the half of the depth of the thinner part of the slab ($d_1$=50 mm). In order to keep the top edge of the girder as straight line, the thicker part of the slab ($d_2$=110 mm) has been modelled with eccentricity. The slab reinforcement has not been taken into account. The boundary conditions were as follows: at one end of the wooden joist the Y and Z direction displacements have been restrained; at the opposite end only Z direction displacements have been restrained; all nodes have been restrained in X direction.

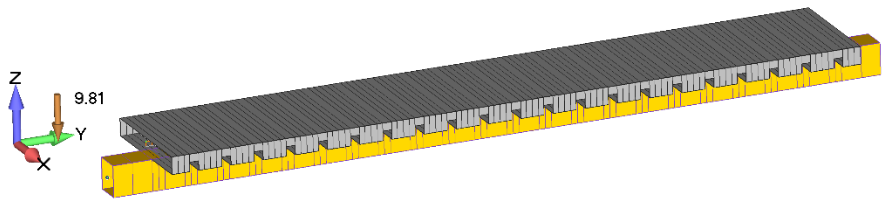


*Figure 2. 3D Model of the structure*

Connection of the wooden joist and the RC slab webs has been modelled using FE of ROD type, set in the connection plane, and oriented in the girder direction (Figure 3). The axial stiffness of the those elements was equal to the shear stiffness of a nail group in one web. The strength and the stiffness of the nails have been determined according to the recommendations given in Eurocode [9]. The used nails had diameter of 8 mm, and length of 200 mm, of which 120 mm was in wood, and 80 mm in concrete. Based on the previous data and assumed timber class, C24 [10], the strength of the nails has been determined as $F_v = 8110$ N, and stiffness $K_{ser} = 5990$ N/mm.

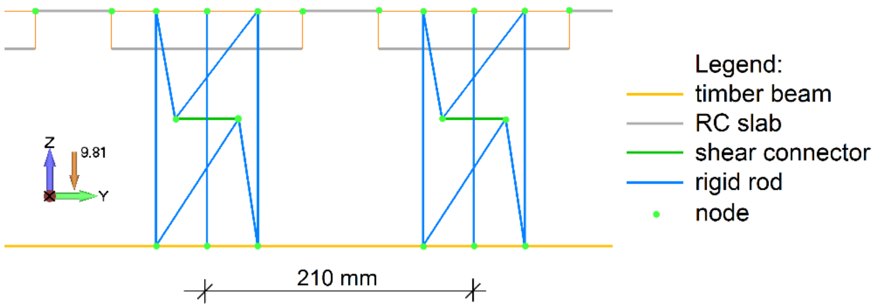


*Figure 3. Model of the structure, line elements; detail*

The connection of the nodes of the shear connector FE element, wooden joist, and the RC slab has been realized by ROD FE, which possess noticeably higher stiffness than other FE. The connection between the wooden beam FE and the RC slab FE has been made using three elements with the same characteristics. They provide a constant distance between the correspondent elements of the beam and the slab, and their equal curvature.
The load of the structure had gravitational character. Load values given in Table 1 have been modelled as nonstructural mass attached to the wooden joist, while the remained elements have been modelled without it. Creep of material has been introduced applying the effective modulus of elasticity [11], and the shrinkage of the concrete has been modelled as cooling of the RC slab.

## 4. RESULTS AND DISCUSSION

The basic goal of rehabilitation of the floor structure was increase of its natural frequency, so that its value surpass 8 Hz. For that reason, the dynamic behaviour of the initial (wooden) and new (composite) girder has been analyzed. Different number of studs has been modelled by defining of the area of the stud element, wherewith its axial stiffness has been altered, too. The case with 10000 nails per connection is not feasible physically, but that way has been realized full composite action, and the theoretical upper frequency limit of the composite girder has been determined. At cases labelled as 2-1-2 and 4-2-4 the applied nail pattern was such that the support third of the girder length had twice as much nails in one connection than in the middle third. The mass of the structure has been determined as sum of the masses of the wooden joist, the RC slab, the covering, and half of the live load. Table 2 presents the results of the dynamic analysis depending on the number and the pattern of the nails in the connection.
For further analysis the nail pattern 4-2-4 has been adopted. In that case the frequency of the first mode of oscillation was higher than requested, and a saving in nails needed regarded the model with four nails in all connections has been achieved, and their frequencies were very close. In Table 2 are presented superimposed results of the static analysis by stages, and in Figure 4 the contour presentation of the results.

*Table 2. Natural frequencies depending on the number & pattern of nails in connection*

| Stage | Mass [*kg/m*] | Number of nails per connection | Natural frequency [*Hz*] |
|---|---|---|---|
| **1** | *153* | */* | ***6.15*** |
| **4** | *394* | *1* | *6.62* |
| | | *2* | *7.59* |
| | | *3* | *8.23* |
| | | *4* | *8.69* |
| | | *10000 (→∞)* | *11.49* |
| | | *2-1-2* | *7.54* |
| | | *4-2-4* | ***8.63*** |

*Table 3. Stresses and forces in elements by stages*

| Stage | Timber stress (max) [MPa] | Timber stress (min) [MPa] | Concrete stress (max) [MPa] | Concrete stress (min) [MPa] | Connectors shear force [*N*] | Deflection [mm] |
|---|---|---|---|---|---|---|
| **1** | *4.89* | *-4.89* | *0.00* | *0.00* | *0* | *11.5* |
| **2** | *0.51* | *-0.51* | *0.00* | *0.00* | *0* | *1.2* |
| **3** | *4.92* | *-4.92* | *0.00* | *0.00* | *0* | *11.6* |
| **4** | *6.72* | *-5.50* | *1.40* | *-2.64* | *4164* | *14.2* |
| **5** | *7.31* | *-6.37* | *2.34* | *-3.26* | *2376* | *18.0* |
| **Load capacity** | *10.0* | *10.0* | *3.0* | *12.0* | *8110* | */* |

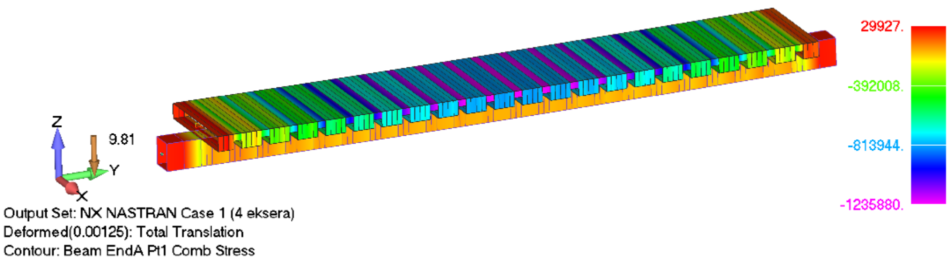


*Figure 4. Results; max. stress in the RC slab in case of 4 nails per connection*

## 5. CONCLUSION

Based on the created models and the most convenient pattern of nails as shear connectors determined, one may draw several conclusions:

- stress utilization in the wooden joist before rehabilitation was relatively low, which permitted additional loading of the girder during slab casting;
- rehabilitation of timber floor structures by composite joining with RC slab cast over a steel trapezoidal sheet is a good and applicable solution. Installation of the sheet and the shear connectors (nails) is simple and fast;

- during the design process of such structure, one must bear in mind the shear stiffnes of the connecting devices; in case of using nails, the analytical calculation of the girder assuming a full composite action does not give good results; it is necessary to conduct an analysis based on partial interaction.

This research has been performed with assumption of linear behaviour of material and with application of service load. Further investigations could include non-linear behaviour, giving possibility of examining of behaviour of composite girders in non-linear domain, up to failure.

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# САНАЦИЈА ДРВЕНЕ МЕЂУСПРАТНЕ КОНСТРУКЦИЈЕ СПРЕЗАЊЕМ СА АБ ПЛОЧОМ

***Резиме:*** *Радом је обухваћена санација дрвене међуспратне конструкције стамбеног објекта саграђеног тридесетих година прошлог века. Носивост дрвене конструкције је била задовољавајућа, али је постојао проблем великих амплитуда при осциловању, што је стварало неугодност код корисника. Санација је урађена спрезањем постојећих дрвених носача са армиранобетонском плочом. Плоча је изливена преко трапезних лимова, а као мождваници су коришћени ексери. Дат је статички и динамички прорачун по фазама применом МКЕ и приказ извођења.*

***Кључне речи:*** *Санација, дрвена конструкција, АБ плоча, спрезање, ексери*