

REHABILITATION OF A WOODEN ROOF SUPPORTING STRUCTURE

Miloš Milić¹
Nikola Romić²
Stepa Paunović³
Ivan Nešović⁴
Todor Vacev⁵

UDK: 624.011.1:69.059.25

DOI: 10.14415/konferencijaGFS2018.007

Summary: *The structure of the considered wooden roof of the family house, was made correctly from quality monolithic material. However, after one year of exploitation, the beams that transferred load from the wooden pillars to the walls experienced significant deformations. Therefore purlins were lifted with jacks, the deformed beams and pillars were removed and a new roof supporting structure was made. This paper presents the stress analysis with the Finite Element Method (FEM) and the construction process through all the construction stages.*

Keywords: *Wooden roof, rehabilitation, purlin, FEM*

1. INTRODUCTION

The rehabilitation project of a family house included a hipped roof. The object is a ground floor house, with the base dimensions 8×12 m and a porch of 2.45×7.90 m. Above the porch there is a reinforced concrete (RC) slab, while above the rest of rooms there is a wooden joist structure. The old roof spanned the whole house, except the porch. The rehabilitation of the roof was done in the following phases:

- removal of the old roof
- bricking of the parapet wall over the porch
- making of the RC ring beam over the existing and new parapet wall
- construction of the new roof.

On the top side of the RC ring beam several reinforcement bars were left as connectors for the new roof structure. The roof was designed as a strutted purlin roof truss. The roof

¹Miloš Milić, M.Eng., University of Niš, Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, Niš, Serbia, tel: +381 65 426 71 26, e – mail: milos.cicevac@gmail.com

²Nikola Romić, M.Eng., University of Niš, Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, Niš, Serbia, e – mail: romicnikola@yahoo.com

³Stepa Paunović, M.Eng., University of Niš, Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, Niš, Serbia

⁴Ivan Nešović, M.Eng., University of Niš, Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, Niš, Serbia

⁵Todor Vacev, PhD, University of Niš, Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, Niš, Serbia

pitch is 33° . Static analysis of the structure was carried out with *Tower 6* software package, where the following loads were used: structure self-weight, clay tiles weight (M-333) [5] including the tiling batten ($0,50 \text{ kN/m}^2$), and snow ($1,0 \text{ kN/m}^2$). The whole roof structure was made of timber quality class II. Rafters are continuous girders supported on purlins and eaves plates, with 2 cm connection daps and strengthened by E70/210 nails of load capacity of $N_l = 1,45 \text{ kN}$ [1].

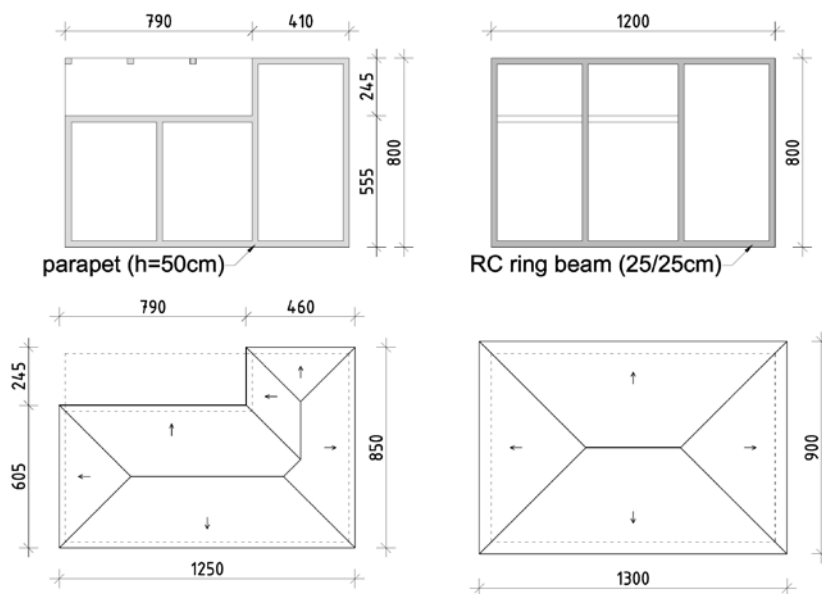


Figure 14. General view of the old roof (left) and the new roof (right)



Figure 15. Rehabilitated house with a new roof structure

In the order for the supports of the roof structure to be constructed properly, there should exist two bearing walls in the direction parallel to the longer edge of the object [3]. The

considered object consists two bearing walls only, and they are both parallel to the shorter side of the structure, so the original design solution was to build two purlins and support the roof structure with them on four supporting points, with transferring the loads through pillars and struts. Thus the roof structure would, in cilling level, rest on eaves plates and four points inside (Fig. 3).

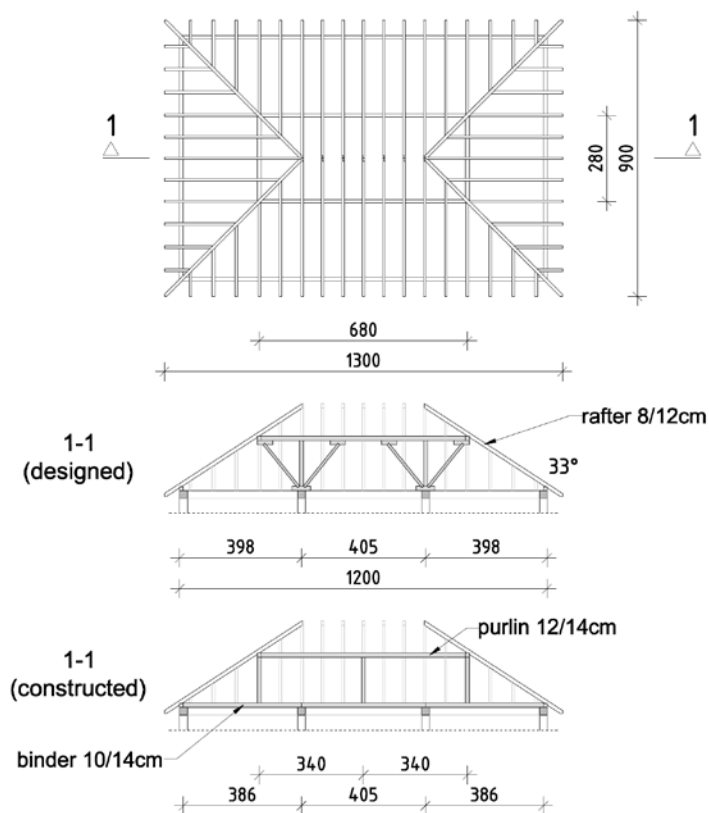


Figure 16 - General view of the roof structure (designed and constructed)

During the roof construction, the bearing structure was changed, so instead of pillars (12/12 cm) and struts (8/12 cm), the roof purlin was supported by six wooden pillars (12/12 cm), three on both sides. This construction solution required that four binders be placed between the newly constructed RC ring beams, because there were no parapet walls beneath some of the pillars. These binders' span is 386 cm and 405 cm. In this way four pillars rest on the binders, while two rest on the parapet wall.

One year after construction, the roof structure was visually assessed. Considerable deflections (up to several centimeters) of the pillar-bearing binders were noticed, which demanded the roof structure rehabilitation.

2. FEM ANALYSIS OF REHABILITATION STAGES

By static analysis it was established that the structure does not satisfy in terms of load capacity. Due to the very low flexural rigidity of binders, the influence of pillars is considerably diminished, and the load is transferred mainly to the eaves plates, which causes large axial forces in rafters and purlins. In the case of a full snow load effect, maximum force per nail in rafter-to-eaves plate joints is 14.56 kN , which is over 10 times higher than the nail load capacity! There was a realistic possibility of nailed joints failure in case of a full load value and the loss of stability of the whole roof structure. The axial force in the straining beam under the same loading condition was 20.49 kN , which also exceeded the load capacity of this element, because the load capacity with the cross-section dimensions of $8/12 \text{ cm}$ equals 17.25 kN [1]. Fortunately, this load state was not realized, because there was no snow during that year.

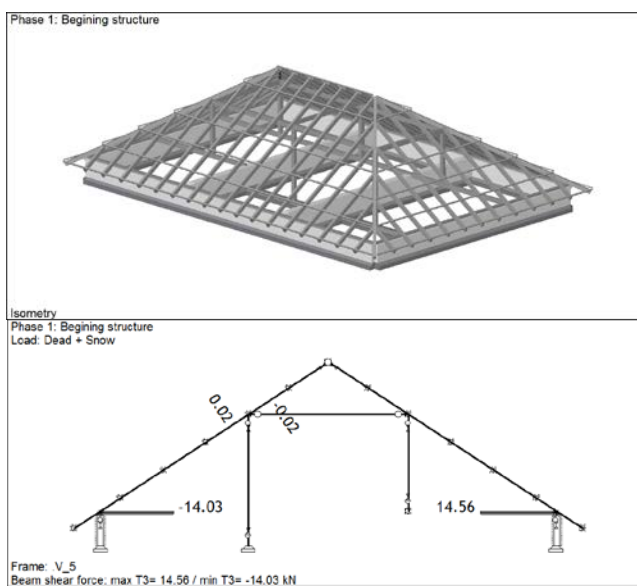


Figure 17. Spatial model and shear forces in nails in connections (14.56 kN) (Tower 6)

The main reason for roof rehabilitation was the exceeding of the nail load capacity. It was necessary to construct the purlin supporting structure that would safely transfer the loads to the bearing walls, i.e. to build the roof supporting structure that was originally designed.

3. SCAFFOLDING STRUCTURE

In the order to remove binders and pillars and assemble the new supporting structure of pillars and struts, the present structure elements needed to be relieved from the roof load first. This meant certain uplifting of the purlins by hydraulic jacks, as it is commonly done with composite structure elements [2]. The most suitable position for the jacks

would be on the verticals going through the new RC ring beam and purlins. However, since the new wooden pillars should be put at these positions, it was decided to move the jacks closer to one another for 20 cm, and support them with an additional wood scaffolding (Fig. 5). This structure consisted of two beams (1) (10/14 cm) of 300 cm length connecting the purlins, two short beams (needles) (2) (10/14 cm) 60 cm long that run under the main beams, and two dead shores (3) (8/12 cm) under which are the hydraulic jacks located. Beams (1) are at 40 cm distance from each other. Element disposition like this enables acting on purlin without interfering with assembling of the new pillars. In order to obtain the required purlin lifting value, the statical analysis was done with respect to the construction stages. Original intention was to lift the purlins for 10 mm. During the statical analysis, the lifting values were varied between 5 mm and 10 mm, and it was concluded that there is no need to lift the purlin for more than 5 mm.

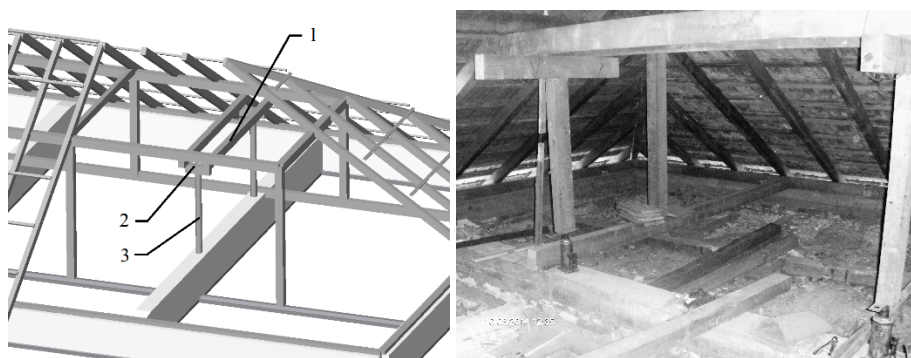


Figure 18. Scaffolding structure, left: model, right: structure „in situ“

(1. beam 10/14 cm, 2. needle 10/14 cm, 3. dead shore 8/12 cm)

4. CONSTRUCTION PROCESS AND RESULTS

The structure design process was carried out in *Tower 6.0* software [4] with the following construction stages considered:

1. Original roof structure loaded by self-weight and snow
2. Original roof structure loaded only by self-weight, without snow
3. Scaffolding assembly on the eastern side of the structure
4. Lifting of the eastern side of the structure
- 5, 6. Dismantling of the existing structure and assembling of new pillars and struts
- 7, 8. Dismantling of the scaffolding from the eastern side of the structure
9. Scaffolding assembly on the western side of the structure
10. Lifting of the western side of the structure
- 11, 12. Dismantling of the existing structure and assembling of new pillars and struts
- 13, 14. Dismantling of the scaffolding from the western side of the structure
15. Rehabilitated roof structure loaded by self-weight and snow

The structure is stable through all construction stages. As a proof, the representative static values through construction stages are presented. Shear forces in nails in raft-to-

eaves plate joint, axial force in the straining beam, bending moments in purlin and a force in the hydraulic jack were considered. The straining beam was removed from the model in stages 10 to 15, because in these stages it is in tension, and its end joints are realized so as to convey only the compression forces. Some of stages are grouped in Table 1 because corresponding static values are equal or they differ only slightly.

Table 2. Internal forces in some elements by stages

Stage	Max nail shear force [kN]	Straining beam axial force [kN]	Max purlin bending moment [kNm]	Hydraulic jack force [kN]
1	14.56	20.49	3.62	/
2, 3	5.69	7.98	1.36	/
4, 5, 6	4.04	5.38	1.53	7.47
7, 8, 9	3.96	5.27	1.76	/
10, 11, 12	0.49	0.	1.85	7.23
13, 14	0.48	0.	1.85	/
15	1.13	0.	2.30	/
Element load capacity	1.45	17.25	3.92	50.0

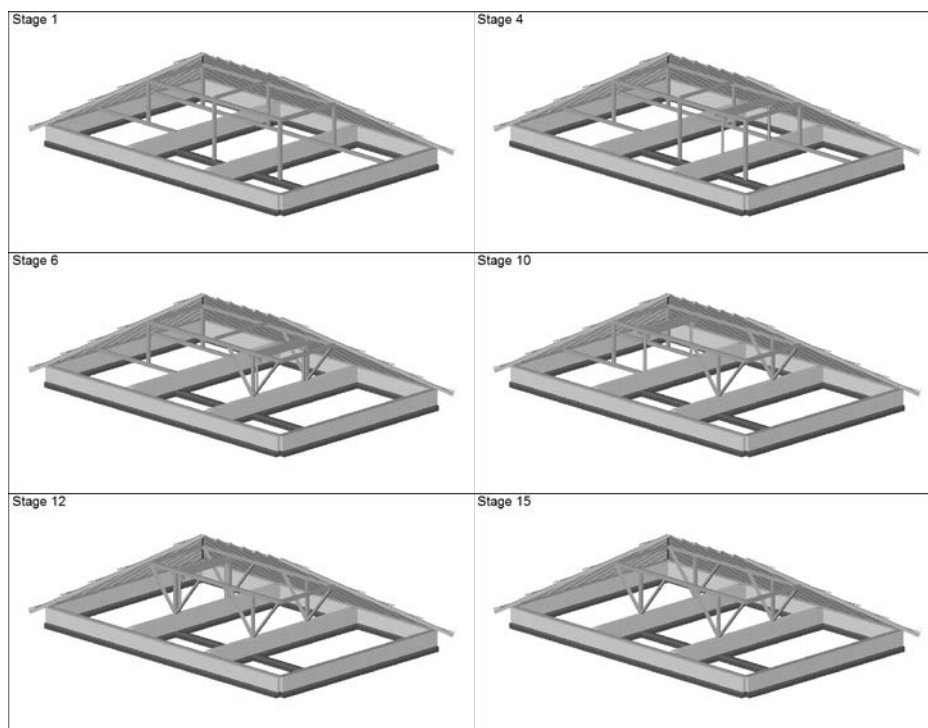


Figure 19. Some of construction stages

From Table 1 it can be observed that the force required for purlins lifting is 7.5 kN . There were two hydraulic jacks for vehicle lifting, each providing a maximum force of 50 kN . The lifting of purlins was measured by rulers, with precision of 1 mm .

After the rehabilitation, the following improvements were achieved:

- The maximum nail shear force in raft-to-eaves plate joint nails is reduced (the most important improvement) from 14.56 kN to 1.13 kN . Relative reduction equals:

$$(14.56 - 1.13)/14.56 = 92.2 \% \quad (1)$$

- The compression force in the straining beam is completely eliminated. This removes the additional stresses from rafters in level with the straining beam, and purlins now rest on new pillars and struts.
- The maximum bending moment in purlin is reduced from 3.62 to 2.30 kN , which represents a relative reduction of:

$$(3.62 - 2.30)/3.62 = 36.5 \% \quad (2)$$

Although the purlin was subjected to unusual bending during the rehabilitation process, final purlin internal forces are lower than original. The reason for this is that now both purlins rest on 12 supports (4 pillars $12/12 \text{ cm}$ and 8 struts $8/12 \text{ cm}$), instead of original 6 pillars $12/12 \text{ cm}$.

- Better load distribution to supports is achieved. In the original structure, most of the roof load (223.6 kN) was supported with exterior walls of the house (214.7 kN), while the internal walls were supported only the small part of the load (8.9 kN):

$$8.9/223.6 = 4.0 \% \quad (3)$$

The load distribution in the rehabilitated roof is improved, so now exterior walls is supporting 143.8 kN , while internal is supporting 79.8 kN , that is:

$$79.8/223.6 = 35.7 \% \quad (4)$$

5. CONCLUSION

The application of the purlin lifting procedure in structure rehabilitation processes is very important. The value of lifting should be chosen carefully, because it directly influences the required lifting force value, internal forces during the rehabilitation process, and the behavior of structure in further exploitation. Recommendation is to use the minimum lifting sufficient to relax the existing structure from residual stresses.

In this paper the linear elastic structure analysis was used, because it is the most convenient design method. The behavior of timber, especially in joints and connection regions, is nonlinear, so the nonlinear analysis should be used in order to obtain static values with more precision during the rehabilitation process. However, this would require much more modeling and design time, so it is unsuitable for application in engineering practice.

REFERENCES

- [1] Gojković, M.: *Drvene konstrukcije*, Naučna knjiga, Beograd, **1983**.
- [2] Pržulj, M.: *Spregnute konstrukcije*, Građevinska knjiga, Beograd, **1989**.
- [3] Schunch, E., Jochen Oster, H., Barthel, R., Kießl, K.: *Atlas krovnih konstrukcija – kosi krovovi*, Građevinska knjiga, Beograd, **2009**.
- [4] *Tower 6, uputstvo za rad sa programom*, Radimpex, Beograd
- [5] <http://toza.co.rs/asortiman/gruba-keramika/>, download 26.02.2018.

САНАЦИЈА НОСЕЋЕ КОНСТРУКЦИЈЕ ДРВЕНОГ КРОВА

Резиме: Конструкција разматраног дрвеног крова породичне куће, израђена је правилно и од квалитетне монолитне грађе. Међутим, након годину дана од израде, греде које су прихватале оптерећење са дрвених стубова и преносиле га на зидове доживеле су знатне деформације. Због тога је извршено подизање рожњаче дизалицама, уклањање деформисаних греда и стубова и израда нове конструкције. У раду је приказана анализа напона по фазама уз помоћ МКЕ и приказ извођења.

Кључне речи: Дрвени кров, санација, рожњача, МКЕ