Structural aspects in the reconstruction of historic timber structures

Ján Kanócz

Abstract

This paper describes several important aspects of the design process of reconstruction historic timber roof bearing structures. During this process, two main fields of activities are performed. One is oriented to investigate the wood as a structural material from several points of view. The second is oriented to analyze structural aspects. The primary purpose of these activities is to gain sufficient information and knowledge in order for designers to protect historic timber structures to the maximum extent possible during the process of reconstruction.

Three reconstructed historic roof frame projects that were realized in the historic part of the City of Košice in Slovakia are presented here. It is feasible to modify existing timber roof frames for new uses with minimal loss of the original structural members.

1. Introduction

In Europe, the most common structure for historic building roofs is the timber frame, which was developed during previous centuries. This shape was influenced by specific regional conditions, which vary considerably in different parts of Europe.

Two basic types of historic timber roof frames originated in central Europe. One is called the “Rafter roof system” and the other is called the “Purlin roof system”. Throughout central Europe, there exists a large variety of both systems in complicated forms. The basic difference between these two roof structural systems is their static action. Mainly, the spatial synergic action and transmission of the load action to the supporting masonry system is performed in different ways. In the reconstruction process of historic roof frames, a detailed investigation of each case is required to assess their reliability.

2. Structural characteristic of roof frames

Most central European historic buildings have sloped roofs, which are supported by timber bearing structures. These historic roof structures at first sight often look very complicated. With experience, it is possible to identify the type of bearing system.

2.1 Rafter roof system

In this system, rafters are the main bearing members, which are formed together with the principal beam to the cross frame with triangular shape.
All frames along the roof are similar with equal static parameters. According to the rafter slope and cross frame span, the additional rods – collar beams – are added to the roof system to reduce strain in the main members. Longitudinal stability of this roof system is provided by brace planks connected to rafters (Figure 1). Rafters are normally loaded with permanent load, snow load and wind load. From these loadings, a dominantly bending moment and axial force occur in the rafter. The ratio between stresses from bending and axial forces depends on the slope of roof, as the degree of the roof plane has effect to the size of snow and wind load.

2.2 Purlin roof system

Longitudinal purlins with vertical struts, cross beams, and collets create the main spatial structure called “chear”. This “chear” supports through the purlins the pattern of sloped rafters. The main cross frames, which consist of principal members, vertical struts, cross beams, collets, and rafters, in certain longitudinal distances is shown in Figure 2. In this roof system, rafters and purlins are dominantly stressed by bending moments. Stability of the spatial frame is provided by bracing rods and collets.

3. Basic aspects of structural modification

Global renovation or reconstruction of historic buildings often utilizes the space under the roof for the different purposes. In the design process of these spaces, different requirements are required for the modification of timber roof bearing structures. The modifications that change the overall spatial static action of roof frames, bring new internal forces in the structural members. Therefore, the numerical verification to prove reliability of modified roof frames is required. Conditions of each structural alternation must be analyzed in detail. Before the design process and structural analysis, the following activities on existing roof frames are necessary in order to provide:

- measurement of the global geometry of the structure;
- definition of the dimensions and material properties of individual members (NDT, SDT);
- visual inspection and detection of wood degradations and detail defects.

The absence of any of these activities may lead to inadequate information to provide the correct calculation of historic roof frames. In many cases, incorrect results lead to decisions that harm valuable historic timber structures.

In addition, the design of different modifications of historic roof timber frames may lead to the replacement of most structural members and, in turn, the decreased historic value of the structure. This means that structural modification must be designed during the reconstruction process in order to save the maximum number of the original timber members.

The more frequently modified parts of the roof frames are the members crossing the floor plan. In addition, the rafters are often changed if their quality or dimensions are not sufficient for the new design. If historic rafters with low wood quality are replaced by new members, the new rafters can be designed like an original member but with more function. Besides the supporting function, the bracing function can be added to the structural design. Rafters may also
provide lateral stability of roof frames instead of the adjusted original spurs.

Structural changes in historic roof frames may cause significant increase of internal forces in structural members and in some cases, the tension force may shift to the compression force. For example, structural change can occur in upper collets if the vertical struts with sloping supporting struts are replaced.

Problems with the principal members may result if they are placed higher than the designed floor level. The liquidation or interruption is very complicated because the principal members support struts and bracing rods. If it is not possible to leave them in the original position, their supporting function has to be substituted by an additional structural member, as new floor beams or new individual elements.

A problematic part of the loft is the timber floor system, which has no required load carrying capacity for the new loadings. The solution is either to design the new floor above the existing floor or to strengthen the existing floor creating timber – concrete composite floor system.

Forces acting upon the supporting walls of roof frames are often changed due to the modification of roof frames. These forces may lead to the failure of the historic supporting walls, meaning strengthening is necessary. Strengthening can be attained by adding a reinforced concrete ring to the top of the historic external walls, which can provide additional strength.

Changing forces in roof frame connections due to structural modifications represent a serious danger for historic carpentry connections. To strengthen them, various metal fasteners may be used.

4. Reconstructions of historic roof frames

The principles explained above regarding structural modifications of roof structures are presented in the following examples of reconstruction projects in the historic core of the city of Kosice (Slovakia).

To determine the quality of structural wood, visual inspection and NDT were used to define strength parameters on each roof structure.

4.1 Building on Mäsiarska street

According to the architectural plan, it was necessary to remove the middle part of the principal beam. A new floor structure was also required because of low load carrying capacity of the original timber beam floor.

Above the existing floor, a new floor was designed using steel “I” beams covered with reinforced concrete plate.

Figure 3 Section of original purlin roof

In the Rafter roof frame, vertical struts were replaced by sloped struts, which settled on the new steel floor beams. Horizontal reactions from struts were eliminated in steel floor beams. Except parts of principals and struts, all members of the roof structure that were preserved are shown in Figures 4 through 6.

Figure 4 Section of modified roof frame

Figure 5 View of new sloped strut connection to purlin
4.2 Building on Kovácska street

In this project, the original level of the principal members was higher than the designed floor level. In addition, the rafters, due to wood quality and low load caring capacity, were replaced by new members with larger cross-section dimensions.

Eliminating the principal members to support the existing vertical struts with longitudinal reinforced concrete beams were designed. To substitute the function of the bracing members, rafters were joined to the “chair” by the bolted connection. With this modification, the increase of axial forces in the rafters was evoked. The reinforced concrete ring that was added to strengthen the external brick walls is shown in Figure 9.

4.3 Building on Drevný trh street

This project is an example of how it is possible to save the historic timber roof structure with minimum amount of modifications.

To create a new timber floor system, the existing principal members were involved. In some locations, it was necessary to strengthen them with nailed timber planks. In order to fill the distance between principal members, nailed timber floor beams with an “I” profile were added. In Figure 11 the strengthening method of principal beam is shown. In Figure 12 part of the new nailed “I“ floor beams is shown.
5. Conclusion

There are many possibilities to protect existing historic timber roof structures during the reconstruction process. Considerable professional expertise is required to conduct the detailed analysis to make informed decisions. Therefore, in the design process of reconstruction, highly educated specialists have to be involved, not only in order to provide excellent new design, but also to prevent damage to the historic timber roof structures that are part of our cultural heritage.

References