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Restoration of Historic Roof Structures on Common Rafters and Tie-Beams with Collars

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ABSTRACT: An almost unique concept regarding the load-bearing structures, which support the roof covering, in continental Europe in the first nine centuries of the second millennium, the historic roof structures on common rafters and tie-beams – of great complexity, able to cover layouts of large sizes – are built of timber according to an empirical-intuitive load-bearing structural conception (without the support of any engineered theory). They are characterised by their resting exclusively on sustaining load-bearing sub-units (load-bearing walls, pillars, columns), without supported by slab load-bearing sub-units. In the case of historic roof structures on collar beams the span of the common rafters is diminished by collar beams placed between the common rafters, the bending of which is reduced due to the compression rigidity of the collar beams. The restoration of roofs allows the return of the load-bearing structural sub-unit to the original concept, using materials and traditional technologies with features similar to the original ones. In this case the original mechanical concept is considered appropriate (the historic roof structure meets the present requirements related to performance). Thus the intervention implies local replacement of materials, whenever these materials are decayed for different reasons. The paper presents the principles applicable to the restoration of historic roof structures on common rafters and tie-beams. These principles are based on comprehensive researches including also the mechanical modelling in 3D on computer. The theoretical principles are illustrated with roof structures restored during the last decade in Transylvania, Romania.

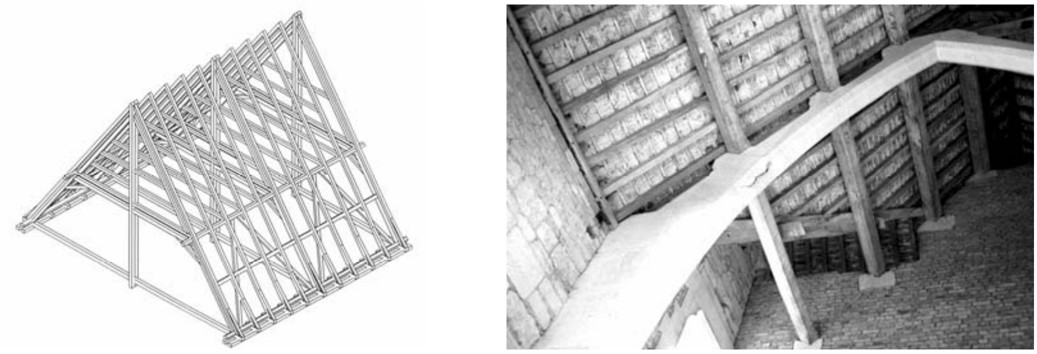
1 INTRODUCTION – ABOUT HISTORIC ROOF STRUCTURES

1.1 Historic roof structure

Load-bearing structural sub-unit built of timber according to an empirical-intuitive load-bearing structure conception (without the support of any engineered theory). They are characterised by their resting exclusively on supporting load-bearing sub-units (load-bearing walls, pillars, columns), usually placed on the exterior of the buildings, without resting on slab load-bearing sub-units. The spatiality of the roof sub-units differs in every case, from the plane roofs (for example: historic roof structures on beams), the spatial roof structures made of frames (historic roof structures on common rafters and tie-beams) to the actual spatial roof structures (of the church towers), the mechanical systems being constructed differently on the southern and western coast of the continent, as well as in continental Europe.

1.2 Historic roof structure on common rafters and tie-beams

Spatial load-bearing sub-unit of great complexity, able to cover layouts of large sizes. Spatial load-bearing structure with thrusts, made up of cross and longitudinal frames (Fig. 1a) The cross frames are made up of elements placed according to triangular outlines [rafter – tie-beam –rafter], the gravity actions being divided into slanted compression components – according to the direction of the common rafter – balanced by the stretching of the tie-beam and the reaction of the wall plates. Historic roof structures on common rafters and tie-beams are – in order of their appearance – Romanesque, Gothic, Baroque, or eclectic, each having several sub-types marked by a different concept. If one takes as a classification criterion the way the bending of the common rafters can be reduced, two large categories result: (historic) roof structures on collar beams and (historic) roof structures on purlins. The structure with collar beams is the oldest one and is characteristic of the Romanesque and Gothic roofs – these having no knowledge of the notion of purlins. Purlins occur in the Baroque roof structures (real purlins: eaves purlins and pseudo-purlins: ridge, intermediate or corner purlins), becoming widely used in the eclectic roof structures.

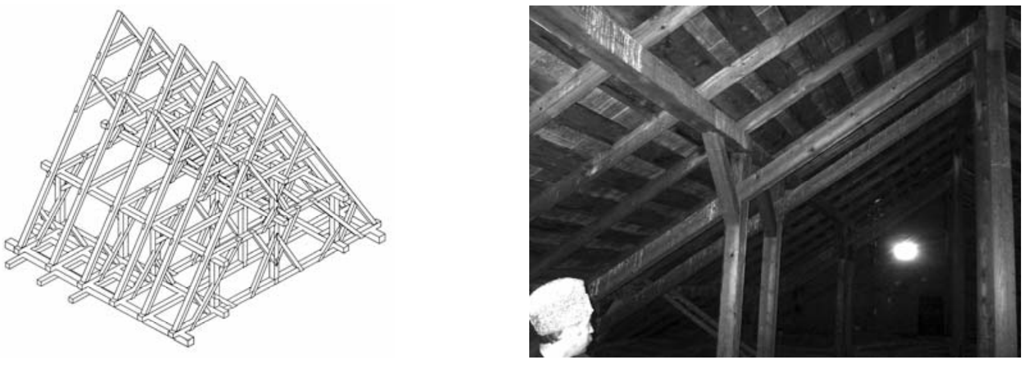


(a) (b)

Figure 1 : Historic roof structures (a) on common rafters and tie-beams and (b) on beams

1.3 Historic roof structure on beams

Load-bearing sub-unit of low complexity, supporting half-pitched or pitched roofs; made up of main beams placed perpendicularly to the direction of the pitch of the roof, resting on supporting load-bearing sub-units, the latter being conformed so as to allow the main beams to ensure both the pitch and the ridge of the roof (Fig. 1b). The supporting load-bearing sub-units are made of masonry walls, timber frames, and masonry. The main beams can support secondary load-bearing elements placed on the direction of the roof pitch. This system works through the bending of the main and secondary elements.



(a) (b)

Figure 2 : Historic roof structures on common rafters and tie-beams with (a) purlins or (b) collar beams

1.4 Historic roof structure on purlins

Historic roof structure on common rafters and tie-beams, which ensures the reduction of the bending in the common rafters through intermediate supports ensured by purlins, which, being rigid to bending, transmit the actions from the common rafters to the straining trusses or straining-hanging trusses (Fig. 2a). The secondary trusses without tie-beams (their self-balancing not being possible) discharge on the main trusses, including through purlins. This system is favored in coastal-type roof structures, including in continental eclectic roof structures.

1.5 Historic roof structure on collar beams

Historic roof structure on common rafters and tie-beams, in which the distance between two marginal supports of the common rafters is diminished by collar beams placed between the common rafters, the bending of which is reduced due to the compression rigidity of the collar beams. The secondary trusses, usually having tie-beams, can self-balance themselves (especially under dead loads), and thus the two common rafters can balance each other, without discharging on the main trusses. This system is favored in continental Romanesque, Gothic and Baroque roof structures.

1.6 Historic roof structure on principal rafters and tie-beams

Historic roof structure from ancient times, less complex spatial load-bearing sub-unit, being able to cover layouts of large sizes (Fig. 3a). Spatial load-bearing structure with thrusts, characterized by trusses, having elements placed according to triangular outlines (principal rafter – tie-beam – principal rafter), taking over and passing to the supports the actions of the roof covering transmitted through the common rafters to the purlins, which are supported by the principals. The main elements of the trusses are the tie-beams, which balance the horizontal components transmitted through the principal rafters to the hanging or straining trusses, as well as the elements, which increase the bending rigidity of the principals, reducing their span with the placing of some vertical elements, which in their turn lean against the tie-beam or the hanging trusses placed in the vertical symmetry axis of the trusses.

1.7 Continental roof structures

These structures are built on the European continent – a part from France, Germany, the Czech Republic, Slovakia, Hungary, Romania (Transylvania) – and are mainly roof structures on beams and roofs on common rafters and tie-beams. The great majority of the roof structures from the Carpathian basin are of the continental type – the few exceptions are always in connection with the Italian engineers, in the service of the Habsburg Empire (army, churches etc.).

(a) (b)

Figure 3 : Coastal roof structures (a) on principal rafters and tie-beams or (b) on Crucks

1.8 Coastal roof structures

These are present on the southern and western coasts of Europe are characteristically roof structures on beams, on principal rafters and tie-beams or roof structures on crucks (Fig. 3b) (Harris 1992). The roofs on beams have already been used both in the continental and coastal structures since ancient times (Ginouves 1992), the roofs on common rafters and tie-beams are characteristic of the continental structures and those on principal rafters and tie-beams belong to the coastal structures.

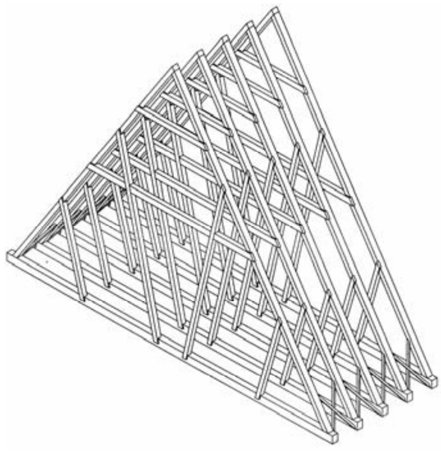
2 ROOFS ON COMMON RAFTERS AND TIE-BEAMS WITH COLLAR

2.1 History

The roof structures on common rafters and tie-beams with collar beams are used in continental Europe; the oldest examples (of a Romanesque character) dating – to our knowledge – to the 11th century (Froidevaux 1985.). From the 13th century the Gothic roof structures begin to appear, these having been built in Transylvania – Romania until the 18th century. The collar beams also appear in the Baroque roof structures (mainly in secondary trusses) – representing the passing from the roof structures with collar beams to the ones with purlins. The characteristics of the roof structures are connected with (1) geometric and mechanical conformation of the elements and frames; (2) mostly used materials and with (3) the construction technology.

2.2 Geometric and mechanic conformation of the elements and frames

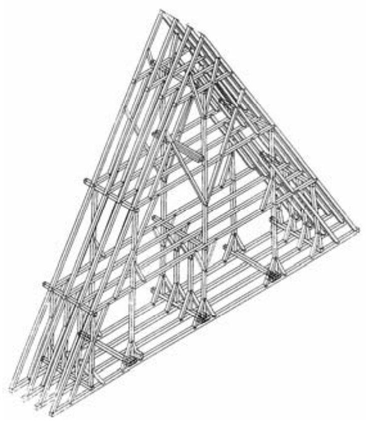
The geometric-mechanical conformation is usually characterized by: (1) the shape of the supported roof – the common rafter pitch; (2) the main cross frames/ trusses; (3) the secondary cross frames/ trusses; (4) the longitudinal bracing frames; (5) the co-working between frames – the spatiality of the roof structures; (6) taking over and transmitting actions at sub-unit level. The Romanesque roof structures make an exception, where – due to the lack of spatiality – the characterization is much briefer. In the case of the Romanesque roof structures (1) the common rafter pitch usually does not exceed 45°; (2) they are built only of main trusses, which have common rafters, tie-beams, collar beams, upper collars, angle braces and counterbraces; (3) there are no longitudinal bracing frames, the longitudinal bracing was ensured through the elements supporting the roof covering; (4) the actions are transmitted to the founding ground mainly through wall plates – usually double or triple – placed on longitudinal load-bearing walls; the longitudinal actions can be partially transmitted to the gables and transverse load-bearing walls (Fig. 4).



(a) (b)

Figure 4 : Romanesque roof structure on common rafters and tie-beams with collar beams – Crasna (a) axonometric projection (b) view

In the case of the Gothic roof structures (1) the common rafter pitch varies between 50° and 75°; (2) the quality of the main truss manifests mainly at non-gravity actions, there being a difference in rigidity between the two kinds of trusses; main trusses have: common rafters, tie-beam, collar beams (on one or two levels), upper collar, angle braces [bracing the joists formed by common rafters – tie-beams, or common rafters – collar beams], king/queen posts, slanted struts, and eventually counter-braces; (3) the secondary trusses have some common characteristics with the main ones [both are self-bearing, have common rafters, tie-beam, collar beams, upper collar, angle braces and maybe counter-braces], resting on main trusses especially at non-gravity actions; (4) the longitudinal bracing frames are well-defined, being positioned, depending on the roof structure span, in the vertical symmetry axis, or – symmetrically to this axis – always in vertical pairs of planes, on one or several levels; they have plates, and between the upper and lower plates there are wedged king/queen posts, braced by angle braces and (maybe) counter-braces, which sometimes intersect each other; the upper and lower plates of the longitudinal frames are placed on tie-beams or collar-beams [upper collars] without joints, or simply notched; (5) the distribution of the main and secondary trusses varies; typically, the row of trusses starts with and ends in a main truss (M), and every second truss is secondary (S), thus: M–S–M; a more rare type is the one having only main trusses: M–M–M, or the one in which between two successive main trusses there are two secondary ones: M–S–S–M; the connection between trusses and longitudinal bracing frames is achieved by common king/queen posts; (6) the actions are transmitted to the founding ground usually according to a transversal direction, mainly through wall plates – usually double or triple – situated on the longitudinal load-bearing wall; the longitudinal actions can partly be taken over by gables or by the transverse load-bearing wall (Fig. 5).


(a)


(b)

Figure 5 : Gothic roof structure on common rafters and tie-beams with collar beams – Sighisoara (a) axonometric view (b) view

2.3 The materials mainly used

The material mainly used is hardwood (oak, evergreen oak etc. – having a durability of 500-1000 years inside the building, in a dry environment), fit for constructing thin elements.

2.4 Construction technologies

The construction technology implies processing by trimming and the forming of joists achieved by the typical dovetail half-lap joints, reinforced by cylindrical fibrous oak pegs; the pegs are capable of taking over the shearing strain, preventing the elements from detaching from each other at the joists; dovetail lap joints contribute to taking over axial and bending stresses, achieving thus more strongly fixed joints.

3 INTERVENTION WORKS ON ROOFS ON COMMON RAFTERS AND TIE-BEAMS WITH COLLAR

3.1 Research on the roof structures on common rafters and tie-beams with collar beams

The research on the historic roofs is carried out in seven phases, which are grouped in the diagnostics and the therapeutics of the roofs (Szabo 2005b). Diagnostics implies (1) surveying, (2) identification of the shortcomings of the load-bearing structure, (3) testing its load-bearing capacity and (4) specifying the causes of the shortcomings of the roofs. Therapeutics consists in (5) the elimination of the causes of the shortcomings, (6) ensuring the necessary load-bearing capacity and (7) maintaining the load-bearing capacity in time – the durability of the interventions carried out on roof structures.

(1) The surveying consists in the identification of the roof structure. One has to determine the geometrical and mechanical coordinates, including the age of the timber used, as well as the rheological features. One has to take into consideration the possible re-use of the elements of an earlier roof, as well as the consolidation works from earlier periods. (2) The insufficiencies of the load-bearing structure are connected to the mechanical and biological degradation of the timber, to displacement (relative movements) or to the elimination of load-bearing elements (Fig. 6). (3) The testing of the load-bearing capacity – through the spatial modelling of the roof – takes into consideration the effective mechanical parameters, evaluating at the same time at least two work hypotheses: the modelling of the current situation and of the situation after the restoration works. From this results the quality of the initial mechanical concept, which meets or doesn't meet the current performance requirements. (4) The determination of the causes of the load-bearing structural shortcomings closes the diagnostics of the load-bearing sub-unit, being the phase of special importance in the long-lasting rehabilitation of historic buildings.

(a) (b)

Figure 6 : Insufficiencies of the load-bearing structure:(a) displacement of load-bearing elements, (b) biological decay of the timber

(5) The elimination of the causes of the load-bearing structural shortcomings can usually be done in full measure, because all the materials and protection technologies of the historic roof structures are mastered. (6) The intervention works need to be conceived in such a way, that – apart from ensuring the resistance and stability of the historic roof structure – the heritage values of the load-bearing structural sub-unit get to be protected to the maximum; values that are stored in the empirical-intuitive concept, the historic materials and the traditional technologies. Thus the protection of the roof structures with an initially wrong mechanical concept is also recommended, which includes necessary consolidation elements in the load-bearing structure, which allow the full maintenance of the historic variant. (7) The conceptual, material and technological compatibility leads to the durability of the interventions.

3.2 The restoration of the roof structures on common rafters and tie-beams with collar beams

The intervention works on historic roofs require several categories in connection with the proportions of the interventions: preservation, restoration, consolidation and re-construction. The restoration of the roofs allows the sub-unit of the load-bearing structure to return to the initial concept, using materials, which are close in quality to the original ones and using traditional technologies similar to the initial ones. At this intervention category, the initial mechanical concept is correct (the historic roof meets the present performance requirements), in the case of which the intervention means the local replacement of materials, every time these materials got damaged because of biological attacks or local overloading or extraordinary actions (such as fires, explosions etc.). This is illustrated through two restoration works from Transylvania – Romania: the Unitarian Church from Maiad (Kirizsan 2005) and the home for the elderly from Sibiu.

The phases of the intervention are: (i) the preparation of the building site with the construction of an exterior and interior scaffolding, the opening of the roof covering and the temporary protection of the uncovered surface, (ii) the opening of the sections, which need to be replaced, (iii) measures to restore the roof to its initial geometrical state, if it's possible, even the introduction of some «counter-rises», so that the elements can immediately start functioning after their fitting (propping up, bringing closer through tie bars etc.), (iv) biological treatment of the historic roof structure – the treatment of the section of the roof, which will be treated with fungicide and against fire, (v) completion and replacement of elements and parts of elements with new material by using – when possible – the same kind of timber as that of the existing element, without any rheological deformities and which meets the quality requirements, (vi) the elimination of the temporary tools, (vii) the loading of the roof with the re-fitting of the non-bearing structures (floors – if needed - , necessary access for the maintenance of the roof covering, the covering and its accessories for carrying rainwater and snow etc.), (viii) monitoring the consolidation joints and carrying out necessary repairs in time.

Restoration includes the completion of elements, the replacement of elements or parts of elements (the replacement of entire frames is rarely necessary). Replacements often affect the joints, which connect the elements.

(a) (b)

Figure 7 : The restoration of the roof structure of the Unitarian church in Maiad – Mures: (a) element partially eliminated during previous consolidation works and (b) completed element

Completions are done whenever an element or part of element is missing from a certain motif (Fig. 7). Usually one type of element or part of element that is to be completed can also be found in other sub-units, if not, then the historic dimensions are determined through analogies (Fig. 8).

(a) (b)

Figure 8 : The restoration of the roof structure of the Unitarian church in Maiad – Mures: (a) completion of missing element (b) overall view of the restored roof

The replacement of parts of elements is very often used, eliminating only the deteriorated part of the element (Figs. 9a, 9b). Usually it is the joint that is affected, and the adjacent parts of elements. The replacement of the elements is carried out whenever the joints are well-preserved and only the element is decayed for some reason (Figs. 9c, 9d).

(a)

(b)

(c)

(d)

Figure 9 : Replacement of parts or all of the elements from the roof of the home for the elderly in Sibiu (a) end of the tie-beam, (b) upper parts at the common rafters; replaced (c) upper collar, (d) angle brace.

4 CONCLUSIONS

Whenever the initial empirical-intuitive concept of the load-bearing structure is correct and meets the present requirements regarding resistance and stability – this concerns the vast majority of the historic roof structures on common rafters and tie-beams with collar beams -, restoration is recommended in order to eliminate the shortcomings, which hinder the normal use of the load-bearing sub-unit. By means of adequate calculation methods we can determine the correct load-bearing structural concept and by means of adequate technologies and materials we can carry out sustainable interventions.

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