F O L I A F O R E S T A L I A P O L O N I C A

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DURABILITY OF CARPENTER'S JOINTS IN HISTORIC TIMBERWORK ON THE EXAMPLE OF ROOF STRUCTURES FROM THE PERIOD OF 13TH-15TH CENTURIES

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SYNOPSIS. The present paper concerns the evaluation of durability of carpenter's joints in historic timberwork. The condition of joints in selected medieval roof structures has been assessed taking into consideration first of all the condition of the material within the joints' area and the correctness of collaboration of surfaces, taking part in carrying the load. In the discussed structures the joints have been preserved in a very good condition, which indicates their high durability and the same time it bears witness to the proper design of the roof constructions. Practical conclusions expressed in the final part of the study should by useful in diagnosing the technical condition of historic buildings and in further conservation procedures.

KEY WORDS: historic carpentry, roof, timber constructions, conservation

INTRODUCTION

Monuments of architecture make an essential part of the cultural heritage and are a valuable document attesting high level of the old times' art of building. Wood as a traditional construction material has been used in historic buildings quite extensively – starting form walls of timbered and half-timbered buildings, through ceilings, floors and stairs to roof structures. From the point of view of the theory and practice of protection of monuments it is important to keep historic buildings in as much original state as possible, which refers not only to their outer form and spatial layout, but also to construction execution as well as the materials used[1]. From the point of view of the conservator's valuation those two last categories are often neglected, which is quite obviously against the guidelines

[1]See: J. Tajchman, Konserwacja zabytków architektury – uwagi o metodzie. In: Ochrona Zabytków, 1995, No 2, p. 150-158.

of the Venice Charter[2], that is a code regulating the activities of conservators of art and architecture.

State of preservation of carpenter's constructions in historic buildings is conditioned by manifold factors[3]. The most significant of them are the exposure of wood to the influence of biological destructive factors (fungi, bacteria and insects) as well as to the mechanical damage caused by overload of structure elements and joints due to improper exploitation or design faults. Apart from that one should also consider the influence of hygro-mechanical phenomena, due to inevitable fluctuations of temperature and humidity in the environment, resulting in swelling and shrinking of the material of wooden elements. More thorough analysis of the problem of durability of carpenter's constructions leads to the conclusion, that the biggest threat to their integrity and proper static performance is the destruction of joints. This is where the material works in conditions of the most complex states of stress, this is also where the cross-sections of the elements are – for technical reasons – smaller, then in their other parts. Rafter framing is usually the most complex wooden structure in building, and in the same time the one submitted to the biggest load, thus it will be the subject of the considerations. In the further course of the present paper the issue of the condition of carpenter's joints in roof constructions dating back to the period of the 13th-15th centuries, preserved up to our times in their original state, will be considered. Those constructions were examined and catalogued by the author in the years 1996-2003 within the confines of a research project conducted in the Institute for the Study, Conservation and Restoration of Cultural Heritage NCU in Toruń[4].

EVALUATION OF THE CONDITION OF CONSTRUCTION JOINTS IN ROOF STRUCTURES OF THE SELECTED CHURCHES OF POMERANIA

Roof structures, the joints of which are to be a subject of the present paper, belong to the two most widespread construction types. They are collar roofs as well as single- or double king post roofs, made of pine wood. In those structures the elements are joined with the use of two types of joints: lap dovetail joint[5] and mortise-and-tenon joints with a central tenon (Fig. 1).

[2]International Charter for the Conservation and Restoration of Monuments and Sites, 1964. For the full text refer to the website: http://www.icomos.org/venice_charter.html.

[3]More on that matter in: M.R. Gogolin, Profilaktyka i interwencja – wybrane problemy konserwatorskie więźb dachowych. In: Zabytkowe budowle drewniane i stolarka architektoniczna wobec współczesnych zagrożeń. Toruń 2005, p. 225-249.

[4]Within the confines of that research project c. 50 rafter frame constructions have been analysed, the paper presents selected examples, representative for the heart of the problem.

[5]The English term "dovetail lap joint" relates to a number of lap joints with laps of various shapes: among others with a symmetrical trapezoid lap – called in Polish "jaskółczy ogon" ("swallowtail") and with a non-symmetrical trapezoid lap – called in Polish "rybi ogon" ("fishtail"). The construction joints discussed here have non-symmetrical laps.

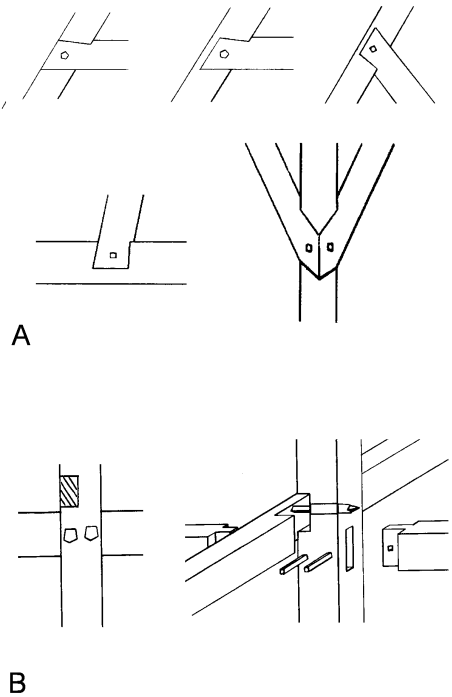

Fig. 1. Basic types of carpenter's joints in medieval roof constructions: a – lap dovetail joint, b – mortise-and-tenon joint

The oldest of the discussed rafter framings, over the church in Lisewo/Liessau, was built in 1282 and is presumably the oldest roof timberwork preserved in Poland. In the nave section there are double king post rafter couples, while in the choir section single king post ones (Fig. 2). The joints used in those rafter couples are lap dovetail joints. They can be encountered where the collar-beams meet the rafters, where the ashlar pieces meet the rafters and tie beams and also where the struts meet the king posts and rafters. In stiffening lengthwise frames the mortise-and-tenon joints have been used where a longitudal timber[6] meets the kings posts and lap dovetail joints have been used in braces stiffening the mortise--and-tenon joints. The material of all the construction elements has been preserved in a very good condition. The wood does not bear any evidence of destruction caused by biological factors (no traces of either feeding of insects' maggots or fungal growth). On the majority of construction elements one can see splits caused by drying of wood. Those splits run close to the axis of the elements and their depth does not exceed 4 cm, that is on the average ca. 15% of the given measure of the

[6]Horizontal beam steadying the post, in Polish called "rygiel", does not have a direct equivalent in English. The term "longitudal timber" applied here has been taken from: C.A. Hewett, English historic carpentry, Phillmore & Co. Ltd, Sussex, England, 1980, p. 244-245 (Fig. 220).

Fig. 2. Roof structure of the church in Lisewo/Liessau

Fig. 3. Construction joints of the roof structure of the church in Lisewo/Liessau

cross-section. The lap dovetail joint connecting braces and struts with the collaborating elements does not have any traces of damage. Despite the lapse of time the fitting of the joints' elements has been preserved – the width of slits between the elements is not bigger than 1.5-2 mm (Fig. 3). The dowels securing the joints are fitted very tightly, one does not notice their loosening in any case, in spite of the fact, that in some cases lengthwise splits of the elements run through the dowel's hole. In king post frames tenon joints are also in a perfect condition. There is no sign of damage to the dowels or loosening of the joints, evidenced by tight fitting and practically no slits between the meeting surfaces of the elements. Measurements of the whole structure allowed for stating that it did not undergo any observable deformations. Particularly, no permanent deflection of the rafts[7] due to the long exposure to the load of heavy ceramic roof tiles has been encountered. One can thus ascertain, that all the timberwork and its elements have been preserved in a perfect condition in spite of over seven hundred years of their history.

The next construction is the roof structure over the church in Grzywna/Griffen, dating back to early 14th century. It consists of single king post rafter couples both in the nave and in the choir section (Fig. 4). Similarly to the previous structure lap dovetail joints and mortise-and-tenon joints have been used. The wood of particular elements of the frames has been preserved in a good condition and bears no traces of the influence of biological destructive factors. There are lengthwise splits running close to the axis of longer elements (rafters, king posts, struts and collar-beams) and on some of the braces. They are not deeper than 5 cm (3.5-4.5 cm on the average). Construction joints are preserved in a very good condition. In lap joints between the braces, rafters and tie beams as well as between the struts, rafters and kings posts one can see a perfect fitting of the laps and mortises. The observable slits are not wider then 1 mm, in many joints there are no slits at all (Fig. 5). The fitting of securing dowels in their holes is tight, one does not also notice any traces of crushing of wood on the collaborating surfaces of the joint elements. The mortise-and-tenon joints in the king post frame do not bear any traces of destruction, their fitting is to be recognized as good (the slits not wider then 2 mm). Also the lap joints in that part of timberwork are preserved in a very good condition. The measurements did not reveal any distortions of the whole structure, also no permanent distortions of rafters have been encountered (deflection less than 2 cm). The full planking has been conducive to the good condition of the roof structure. It has additionally protected the timberwork against the leaking rainwater.

The roof over the church in Subkowy/Subkau by Tczew/Dirschau was erected in 14th century. It is a single kings post structure, built in two phases. The choir part dates back probably to the first quarter of 14th century, while the nave part is younger, of the late 14th or even early 15th century (Fig. 6). The construction joints of the rafter framing are the already described lap joints and mortise-and--tenon joints. The condition of wood in most of the elements is faultless. Only at the ends of some few tie beams and at lower ends of ashlar pieces one can notice traces of the presence of pests (feeding of the common Cerembycid *Hylotrupes baiulus* L. maggots). On a large number of elements one can see lengthwise splits

[7]The measured deflection of the rafter did not exceed 15 mm.

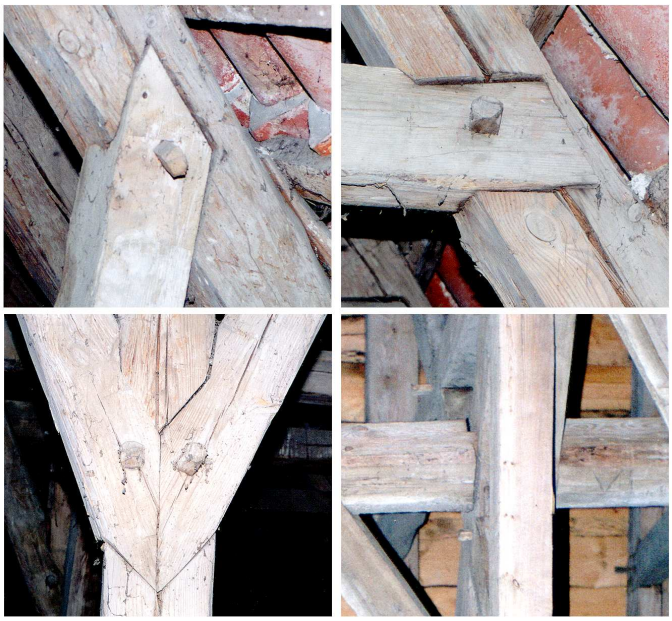

Fig. 4. Roof structure of the church in Grzywna/Griffen

Fig. 5. Construction joints of the roof structure of the church in Grzywna/Griffen

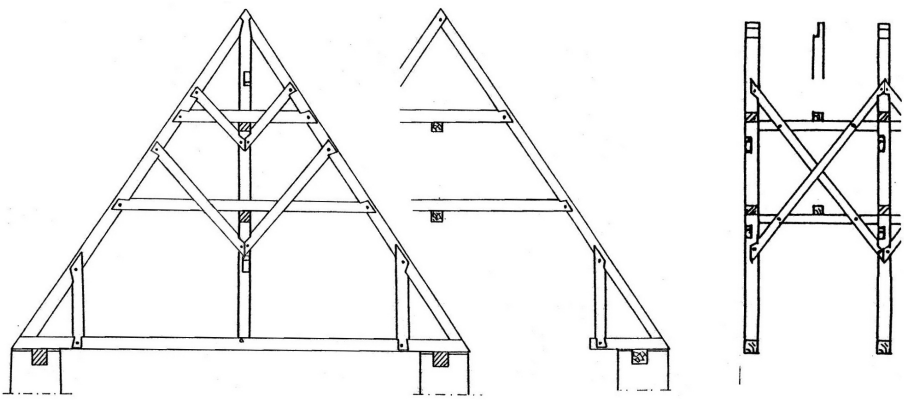

Fig. 6. Roof structure of the church in Subkowy/Subkau

up to 6 cm deep. Construction joints were executed with the same precision as in roof structures described above. In lap joints (both in the rafter couple plane and in lengthwise frame) between the tailpieces of the parts and the edges of mortises there are slits up to 7 mm. Side surfaces are fitted better and there the slits are not wider than 2-3.5 mm. Mortise-and-tenon joints in the king post frame were made correctly, however also not very precisely. One can notice slits up to 9 mm between the king posts' surfaces and the supporting surfaces of longitudal timbers. This may mean that the tailpieces of the neighbouring tenons ram into each other in the mortise or that the axial forces in the joint are shifted by the dowel (Fig. 7).

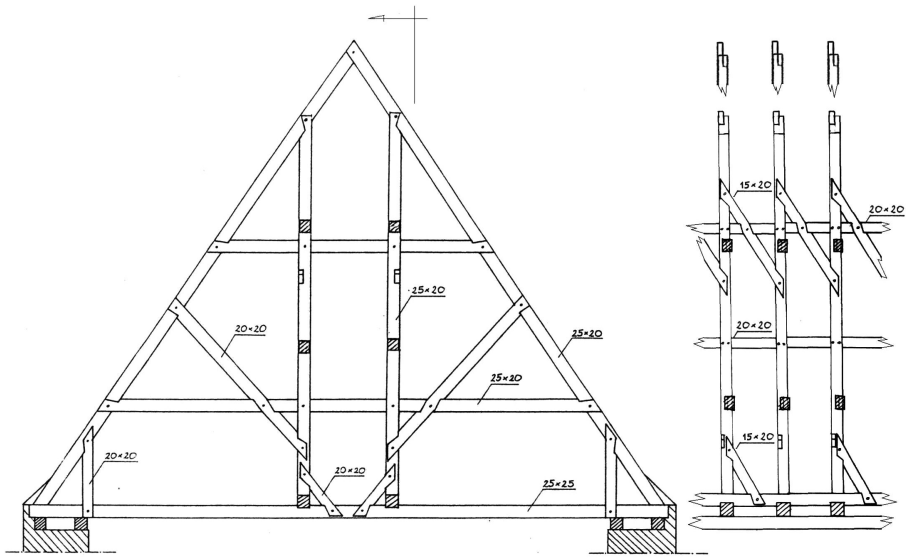

Fig. 7. Construction joints of the roof structure of the church in Subkowy/Subkau

However, despite the discovered shortcomings of the workmanship, the condition of joints is good. No distinct crushing of the wood on the collaborating surfaces of the elements has been noticed, there is also no other evidence of destruction. All the dowels are fitted very tightly, none of them is either cut or deformed. Also no deformation of the whole roof structure has been noticed, that confirms its good technical condition.

The rafter framing over the church in Lubiszewo/Liebschau dates back to mid-14th century (presumably ca. 1350) and belongs to king post roof structures (Fig. 8). The lap joints and mortise-and-tenon joints are applied in a manner

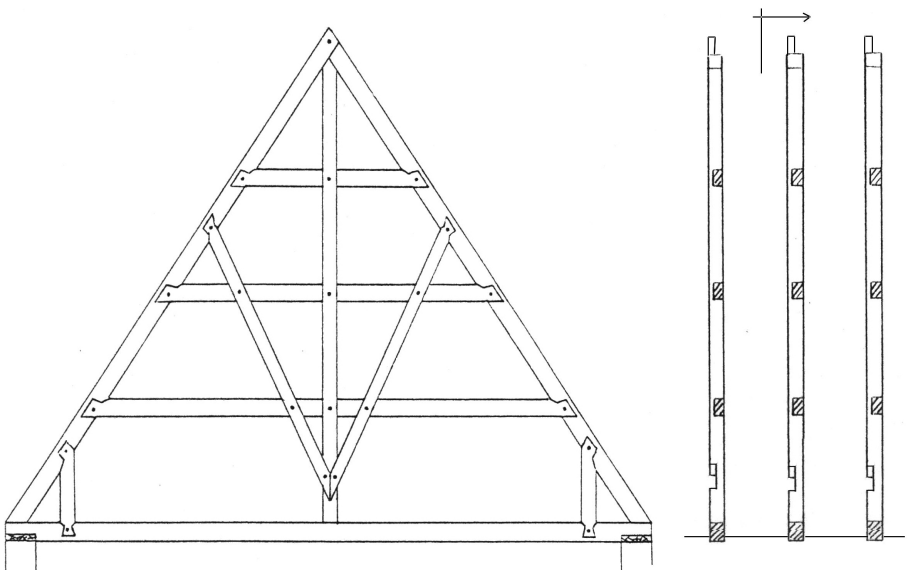

Fig. 8. Roof structure of the church in Lubiszewo/Liebschau

typical for the medieval carpentry. The construction material in most of the elements has been preserved in a good condition. There are lengthwise splits up to 5 cm deep visible, there is no evidence of pest infestation. Only few elements are definitely in much poorer condition. Lengthwise splits are deeper there, reaching up to 8cm, one can also see some alterations of colour being the evidence of fungal growth. The primary cause of that destructive phenomena was probably rainwater leaking through the untight roof covering, that was conducive to fungal growth and caused more extensive cracking of wood due to higromechanical effects connected with intense wetting and drying of the material. One of the elements (king post's strut has been replaced – probably due to the broken lap of the joint (the mortise does not bear traces of more advanced destruction). The condition of construction joints of the roof frame is generally good, however one can notice loosening of some joints caused either by drying of wood or by slapdash making. In the majority of lap joints the fitting of laps and mortises is quite satisfactory (slits up to 1 mm), however, in some of them the width of the slits run up to 10 mm. The mortise-and-tenon joints in the king post frame are in a good condition, with no

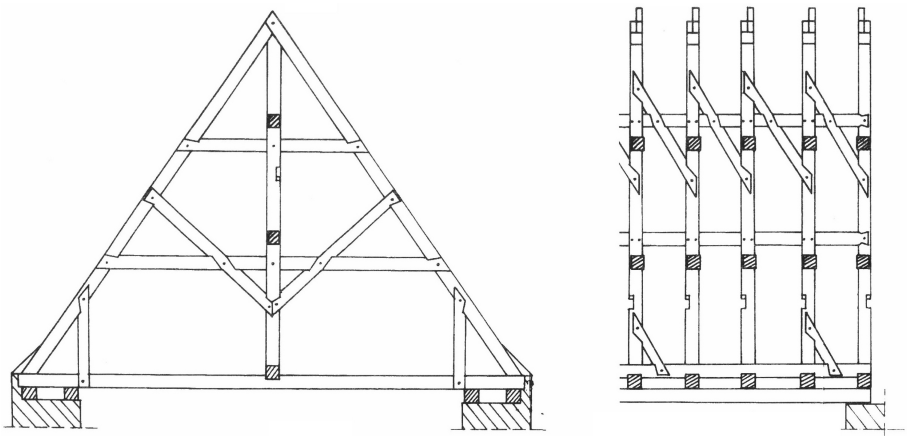

Fig. 9. Construction joints of the roof structure of the church in Lubiszewo/Liebschau

trace of unwanted slits between the collaborating surfaces of the elements (Fig. 9). Dowels in all the joints are fitted correctly, however, some of them have been replaced with new ones (this can be noticed in some of the joints bearing traces of fungal growths and damp). Measurements of the construction have not revealed any significant deformations, only the rafters bearing traces of leaking rainwater and fungal growth have deflection bigger than the others (ca. 5 cm on the average, while the other rafters have the deflection ca. 2 cm).

ASSESSMENT OF THE DURABILITY OF CARPENTER'S JOINTS AND PRACTICAL CONCLUSIONS

Analysis of the condition of carpenter's joints in medieval roof structures allows for the statement, that their durability is very high, providing that the wood was well protected against the destructive factors, particularly against a direct influence of rainwater and pests. It is important, that lengthwise splitting of construction elements, inevitable in the fact of a prolonged influence of changing climate conditions on the structure, either does not have any observable negative impact on the static performance of the rafter framing as a whole, or does it cause any destructive phenomena in the joints themselves – when the splits are located in the joint area. What needs to be considered here, is the way the loads are being carried by the particular, neighbouring surfaces within the joint. The problem can be examined twofold. According to the first theory properly designed and executed carpenter's joints carry the load though the mutual pressure of the collaborating surfaces of the lap or tenon and mortise[8]. Thus the dowels should not make ele-

[8]The analysis of this problem – see: M.R. Gogolin, Dawne konstrukcje ciesielskie a współczesna statyka. Roczniki Akademii Rolniczej w Poznaniu 2004, 362, p. 37-46.

ments taking an active part in the work of the joint. In such case the proper functioning of the joint would be due to the condition of the surfaces of laps or tenons and their mortises, the proper fitting of the elements and the lack of traces of destruction of wood in joint area being the decisive factor. Another attitude is presented by Jasieńko, Engel and Gospodarek[9], who – by conducting elastooptical research and numerical simulations have reached the opposite conclusions proving, that in a lap dovetail joint as well as in a mortise-and-tenon joint the role of dowels in carrying the load is an essential one. In the light of that research the durability of carpenter's joints is also conditioned by the state of dowels and their proper fitting in the holes of the collaborating elements. However supporting that theory needs further verification, since the tests run by Jasieńko and his team did not take into consideration the anisotropic properties of wood, and because of that the obtained results can not be recognised as conclusive.

In conservation practice, while evaluating the technical condition of timberwork in the aspect the carpenter's joints, in the light of the present state of research, one should consider the condition of dowels and their fitting as an element of a secondary meaning. Since from the practical point of view the extreme condition the joint can reach, is depriving it of its securing dowel. Admittedly, in the examined roof structures it did not occur, but the analysis of conservation reports revealed, that such situations are probable and sometimes (however rarely) encountered. The same sources proved, that despite the lack of dowels the joints continued to fulfil their constructional role with no severe side-effects. Of course this can hardly be considered a proper condition, but proves, that from the point of view of the statics alone, the dowel is not an indispensable element of the joint.

What it means for the evaluation of the condition of the joints is that a proper collaboration of the working surfaces is more important, and it needs a particular attention in the process of diagnosis. Securing the joints with dowels provides a permanently correct positioning of the joint elements in the plane, and this aspect is of an essential significance, since it guarantees proper collaboration of the elements of the structure.

Creating the conservation program for the historic timberwork should comprise the above discussed conclusions regarding the durability of carpenter's joints. First of all one should avoid introducing unnecessary reinforcements or replacing the elements in cases, where the only observable alterations of the material are the lengthwise splits due to drying of the wood - even those reaching the joints between the elements. This phenomenon occurs in almost all the preserved timberwork constructions and does not create any significant danger. The interference in the structure is justified only when there are symptoms of an advanced destruction of the material by pests or observable evidence of exceeding the durability limits of wood – crushing, transversal splits cutting the grain or even broken laps or tenons – in the joints' area. In preventive procedures one should control the proper fitting of dowels in the joints' holes, adjusting them or replacing when necessary. Following the above guidelines will allow for preserving historic carpenter's

[9] J. Jasieńko, L.J. Engel, T. Gospodarek, Badania elastooptyczne i numeryczne wybranych drewnianych połączeń w drewnianych konstrukcjach zabytkowych. Materiały 6 Polsko-Niemieckiej Konferencji „Architektura ryglowa – wspólne dziedzictwo". Szczecin, 2005, p. 195-205.

constructions in their original state and will assure their further performance as integral compounds of architectural monuments.

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