Projekt „Rozvoj příhraniční spolupráce vysokých škol v oblasti historické architektury“
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STATIC ANALYSIS OF HANGING TRUSS OF BEAMED FLOOR IN EVANGELICAL CHURCH IN VYSNA BOCA

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ABSTRACT

Evangelical Church in Vysna Boca in 1785 has been studied in this research. Historical truss in Vysna Boca with a height of 7.8 m is collar-beam truss strengthened with longitudinal standing trestle and central king-post. In the space truss is an impressive structure of hanging truss of wooden beamed floor. The hanging truss of ceiling is made of double-beam grating of teeth, a system of three racks with struts in both directions and span pieces. Beam grid was not properly implemented. Toothing is implemented in one direction, not symmetrical, as would be correct. This affects the overall functionality and structure static. Static analysis, it was found that hanging truss beamed floor has low operational effectiveness and burden to the construction of wooden beamed floor, primarily because of its incorrect solution. Hanging truss of ceiling due to its own deflection and deflection of the ceiling, its construction, spacers and bearers negatively affects the entire roof structure. The design of the truss then loaded to the perimeter walls of the church, there is arise a cracks. The analysis shows the impact of the negative primary solutions to the original object as a whole.

1. INTRODUCTION

1.1 Church history

Lutheran Church in Vysna Boca is one of the typical representatives of the classicism. It was built in 1785 as a tolerance church on the site of a native temple from the seventies of the XVI Century (congregation of Lutheran in Vysna Boca was originated in 1540). The original tower was attached to new church in a building renovation in 1819 - the 1825th. The church is now used only sporadically. It has an interesting construction particularly of the king-post of wooden ceiling beams, which is situated under the roof space.

Vysna Boca Village is located southeast of Liptovsky Mikulash, in the Low Tatras in the upper valley of the Bocianka creek. The area of Bocianka creek was royal property since the second half of the XIV century and here originated settlements due to existing mines (older Svatojanska Boca Royal Boca 1522). Municipalities were in the mid-19th century divided into Vysna, Stredna and Nizna Boca. Mining operations gradually declined until mining ceased in 1860. In 1927 the settlements in the lower valley village Nizna Boca and in the upper valley-community Bocianka Vysna Boca were founded.
According to [1] there was a Lutheran church in the village as early as 1540. The first temple was built in the seventies years of the XVI century at the suggestion of mine chambers for the majority German population in the former Royal Boca. On the site of an older temple was built in 1785 a new tolerant church. According to [1] the tower was a remnant of an older church tower, and only from 1819 to 1825 it was linked to the mass of the building. During this reconstruction the wooden bell tower from the 17th century was destroyed.

Fig. 1 Left view in to the nave, the right view of the church.

1.2. Description of the church

The church was built in the Classical style, made of stone. The church was built as a three-nave, the walls are plastered with lime plaster, the floor is of stone plates placed in the compacted clay. The roof of the hall is a saddle, complete with a shield-shaped tower made of bricks. Above the altar the roof passes in arc shape. Symmetrical precursor prismatic tower roof is covered placed on a low bell-shaped pedestal, which is based on distinctly profiled (in the area around the dial) wrapped crown rim. The switch blades are at high skull, over which stands the decorative metal double cross. Roofing is made of metal sheets with a red protective coating.The ceiling over the nave is made of wooden beams with the deck. Beams are placed on the perimeter walls, they are supported at the end sixth of the span; in the middle part they are not supported for the length of 9 m. Wooden beams are supported in the middle span by hanging truss which is located in the roof space. Hanging truss of ceiling is a unique structure not only by length of 21.65 meters, but also by a way of execution.

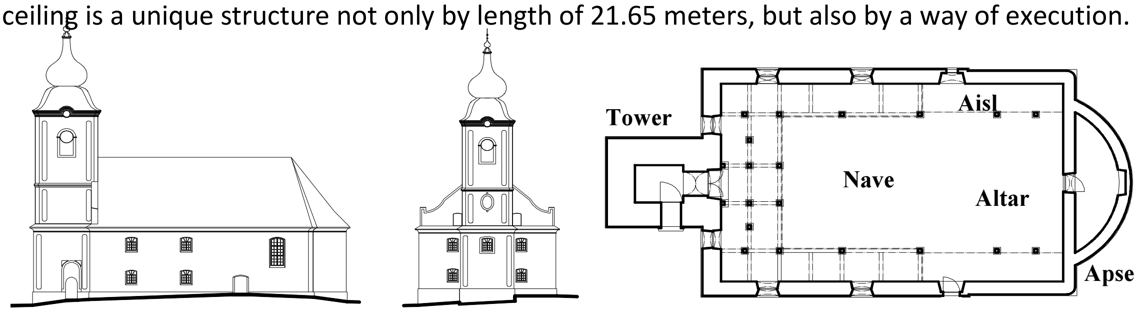

Fig. 2 Church in plan and side views.

2. THE TRUSS OF THE CHURCH

Above the nave and polygonal sanctuary are historical collar-beam trusses with simple bound hanging truss with longitudinal lateral standing trestle. Such beams, from a historical-typological perspective characterized the structure used in the second half of the 18th century, but often also the first half of the 19th century. Investigated truss is original from the time of the construction when the church was built in 1785. The truss consists of three full connections and five frames. Tie beam is supported by truss post in the middle of span, which crosses up to ridge of roof. The column (hanger) is tenoned into the tie beam and gird in the bottom level by steel strap. Lateral standing trestle in the longitudinal direction is provided by straps. (Fig. 3)

Intermediate bonds have a short tie beam tenoned into longitudinal tail trimmer. Collar beams, which are in direct contact with the posting system, as well as ceiling struts are deformed under the pressure. Truss above the polygonal sanctuary consists of a grid with two side tie beam. Prevailing carpenter joints are straight and angled tenon, sloping plating, plating covered dovetail with rectangular jams, cogging, covered front indent on one side, the top pin. Joints are fixed with wooden pegs, in some places, later reinforced by forged nails and tacks. The truss is carved with typical traces of the ax blade. Carpenter signs of cross-linked system use Roman numerals, using an ax chopped counterpoint.

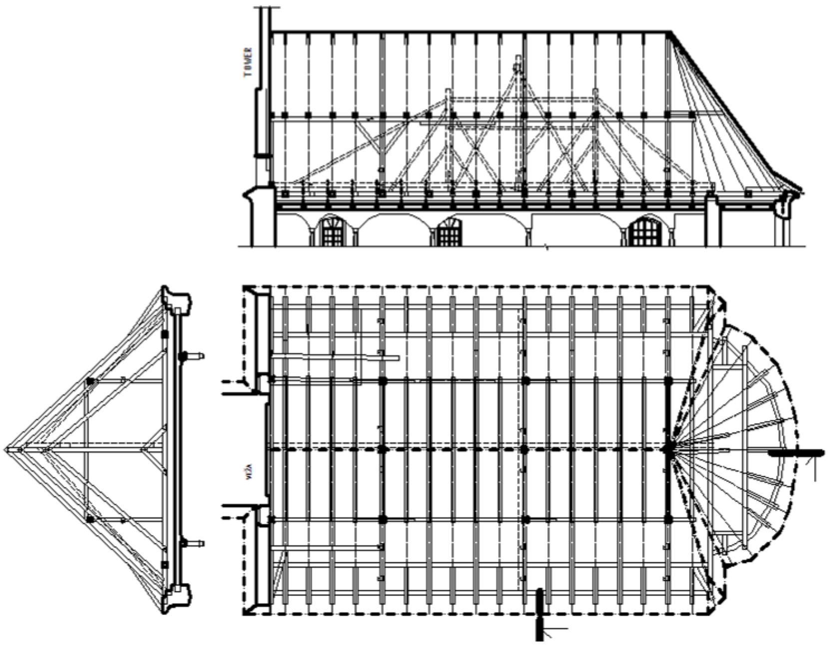

Fig. 3 Plan and sections of the truss above the church, dashed lines indicate hanging trusses.

3. HANGING TRUSS

Hanging truss of ceiling is designed as a distinct structure, namely as hanging trusses combination in the two directions. Hanging truss beam (girder grillage) length is 21.65 m, height of the queen post is 4.59 m, the central king post is 6.23 m high. The hanging truss of ceiling structure is unique, innovative solution of posting joists for several reasons. First, it is not made in accordance with the general principles contained in the literature. Hanging truss span is 21.65 m, when the recommendations suggest for such a span four hangers for easy scheme. Construction of hanging truss of ceiling is formed by a massive beam 200/410 mm with teeth (girder grillage). The girder grillage is composed of two massive wooden beams, size 200/200 mm. The separate beams are connected with scarfed joint at about half the length of beam by steel strips in places of connection

(Fig. 4).The beam is supported on one side by placed in the towers walls and on the other side it is placed on the wall separating the nave from the sacristy. The beam is at the point of laying on the wall deflected to the side (Fig. 5). The total deflection of the beam is large, visible to the naked eye, about 300 mm.

Toothing and connecting prisms are not implemented according to the principles published in original literature, which had already determined the principles of the axially symmetric solution for toothing a method for bonding a greater length of the girder. Also, we do not lock joints connected in realized ideal solution according to the rules of carpentry joints.

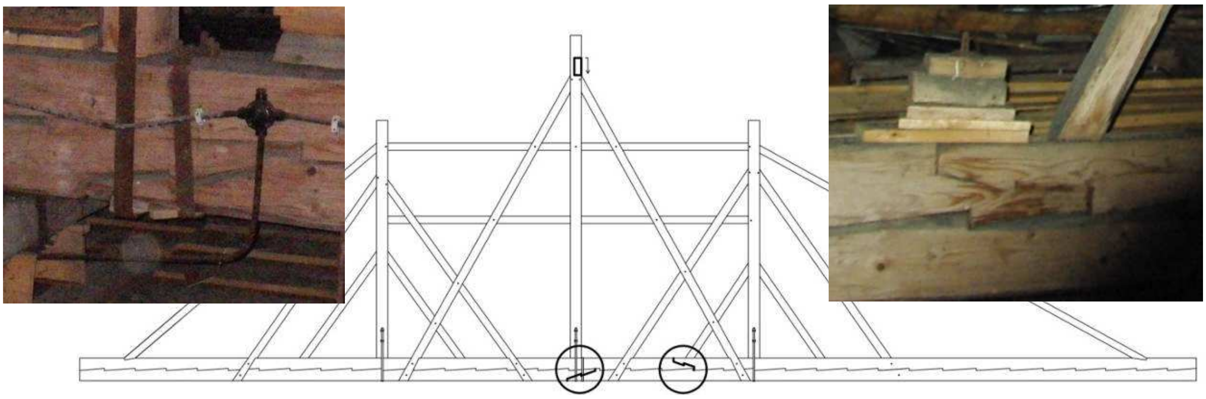

Fig. 4 Structure of hanging truss with connection of the upper and bottom beam left; connection of the lower beam, in the middle; right: way to lock the joint [5], beams of the upper left connection of girder.

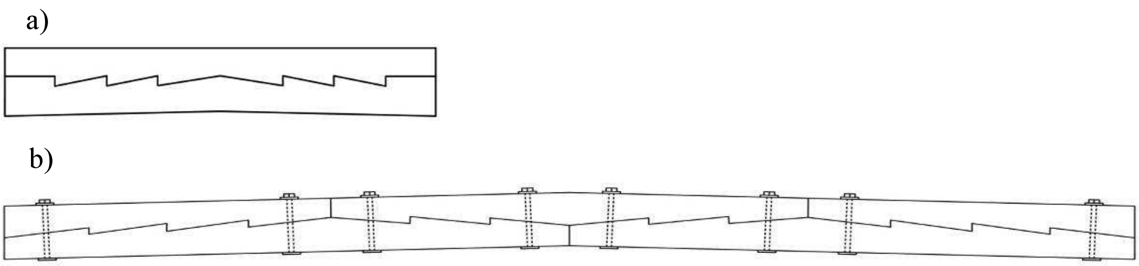

Fig. 5 Right way of girder grillage. a)toothing [6], b) composed of several parts according to the contemporary literature. [5]

Linkage of the beam is realized with teeth that is improperly oriented. The length of one tooth is 580 mm in height 40 mm, the bringing together is also by a steel rod passing through each joist with the possibility of tightening. Distance at centre joists is 1.2 m. Teeth from the middle part are not compressed but oriented in the direction of deflection. Hanging truss of ceiling is a combination of queen post truss and king post in a direction perpendicular to the double (in space). The two queen posts are double hanging truss struts and spreads among them. Hanger is the column with a cross-section 200/220 mm tenoned the beam, connected by steel strips.

Struts and spreads with sizes 140/130 mm are in regards to their length undersized. Struts are connected to a simple beam plugging. Spacer is tenoned to the hanger (pole) and fixed with wooden peg. The outside hangers are also supported by struts of approximately 2.0 m and they carry two elements to reduce the girder grillage deflection. The pulled elements are connected with girder grillage by shoulder-dovetail halving joint, the queen-post is tonened into girder grillage, fixed by wooden peg. In the middle of the girder is the king-post - central. Struts of this hanger with dimensions 150/150 mm is compressed into wall plate. The central king-post in the perpendicular direction pulls girder grilage with two beam elements that are connected to girder grillage by shoulder-dovetail halving joint and with horizontal straining sill.

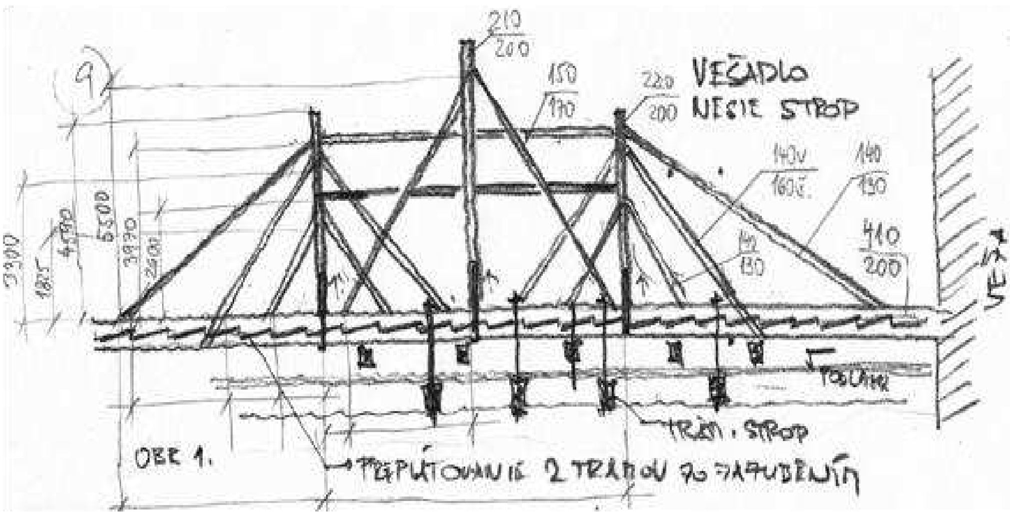

Fig. 6 Sketch of hanging truss of investigated ceiling (Lubor Suchy)

Fig. 7 Left girder anchor beam to the tower walls, right the girder placed on the wall with a visible deflection and tilt to one side.

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Fig. 6 Visible deflection of ceiling, right view into the under roof space (hanging truss)

4. CEILING

Ceiling above the nave is made up of wooden beams of dimensions 240/210 mm. The wooden beams are coated by spruce wood boards from the interior and from under the roof space. Ceiling beams are stuck in the walls. At present, the wooden beams are also supported at the outer sixth of the span. The total light beam span is 13.28 m. The support is a wooden purlin (girder) 2.05 m from the perimeter. Deflection of the lower edge of the ceiling is visible to the naked eye. (Fig. 6)

5. PROBLEMS OF HANGING TRUSS

Due to the large visible deflection of girder grillage and visible sag in the ceiling structure, viewed from below (from the aisle of the church), we developed a static analysis scheme of hanging truss and ceiling wooden beams in the form of case study. Girder grillage is realized with teeth, but the linkage is broken due to the fact that toothing along the entire length of the beam is carried out incorrectly. The orientation of the teeth is the same throughout the length of the lower band, and the cross section can not be considered as coupled.In the case study we have chosen two basic alternatives in terms of explanations of visible sagging of the ceiling structure. Alternative "A1" is based on the assumption that the ceiling beams are placed on the wall, and that are supported at mid-span by hanging truss. Joist span is 13.28 m. Alternative "A2" in addition considers the carpentered joists in the outside sixth, that is 2.03 meters from the perimeter (mean field span is 9.19 m).

In each of the alternatives, we verified the behavior of structures in the so-called, ideal case "P", when we are considering the alternative with the total and unweakened cross section (excluding the incorrect toothing) and in case with weakening the "O" section of the lower beam of girder-truss, which reflects the wrong toothing. In these alternatives, we further investigated the effect of the central queen-post. In those alternatives, that means fully functional "VK", since its effectiveness is limited by lateral brace rods resistance "VO", and that "VF" is functionless.To describe the impact of individual elements of the outer queen-posts, we consider in each variant with condition of ideal case 'I', a status which is reflecting way of joining the lower beam and the real resistance of the elements "O", and reflecting the state of the joining method to the lower beam, but excluding the outer brace rods of two queen-posts "H".

6. STATIC ANALYSIS OF THE HANGING TRUSS OF CEILING

Analysis of ceiling girder-truss construction and ceiling was focused to the visible ceiling deflection, biggest deflection of girder-truss and approximation of construction phases evolution. From analysis of the girder-truss structure results that ceiling beams were not supported in the outer sixth portion of the span. When ceiling beams were realized as three-partion beams with a central portion span of 9.2 m with load transfering via double decking, the deflection of the beams would be only 36% of the deflection limit (9200/300 = 30.6 mm) and without any posting ceiling in the central part of the span. Primary ceiling was comprised of ceiling beams placed to enclosure wall and in central part posted up with girder-truss located in the roof space. Primary girder-truss have significantly undersized outer brace rods and queen-posts were not secured against buckling perpendicular to its axis. The bad implementation toothing of the lower beam, caused moment of bending inertia to decline for 18.8% unlike from the correctly toothing of the lower beam. Failure in original project caused that girder-truss could have up to 4.1 times higher deflection than deflection of the ceiling beams. (14200/300 = 47.3 mm) / A1-O-HF-O /. Probably this is why the strengthening was made by the two queen-posts girder truss with addition of central queen-post with collar beams to the wall beams and supported in the sixth parts of span. / A1-O-IN-O /. The residual deformation suggests that the ceiling structure was not strengthen on time strengthening was adequately or was not additionally supported. Strengthening the girder truss, with three queen-posts, should have carried the load of the ceiling and used to raise ceiling structure. The central queen-post was placed across strutting into the wall beams (stored in enclosure wall), without tie-beam or pulling rod. Applying of horizontal forces introduced by the central queen-post, caused walls disturbing (cracks in the window lintel), and, at the same time central queen-post lost its function and the double queen-post lost its stiffness. Ceiling beams, supported on the sixth parts of span, had a greater stiffness than all the girder truss and with rectification of the ceiling beams at girder truss, the deflection of ceiling beams did not decrease, but the beam deflection of the girder truss had increased.

A2-O-O-VK - indicates alternative with support on the peripheral walls and at the edge of sixth partions of span and posting on girder truss, with a weakened cross-section of the lower beam with queen-posts, with a fully functional cross shoring of central queen-post, with action of the outer queen-posts elements into account form of joint and endurance of elements. Table 1 describes the impact of weakening on deflection of the lower beam of girder truss, reaction on the left side of the lower beam and the normal force at the shoring of the central queen-post. The impact of weakening of the lower beam of girder grillage with three queen-posts is shown in Table 2.

A1	deflection of the lower band [mm]	deflection of wooden beams [mm]	RL [kN]	NV [kN]
A1-O-VK-O	26,1	26,1	6,34	86,8
A1-O-VO-O	113,4	113,4	16,69	29,33
A1-O-VF-O	194,3	170,6	22,34	0
A2	deflection of the lower band [mm]	deflection of wooden beams [mm]	RL [kN]	NV [kN]
A2-O-VK-O	8,5	8,5	6,26	29,87
A2-O-VO-O	8,5	8,5	6,31	29,2
A2-O-VF-O	36,3	11,1	9,22	0

Tab.1 Deflections of the lower beam, ceiling beams, reaction to the left side of the girder truss RL and normal strength in the shoring of central queen-post NV

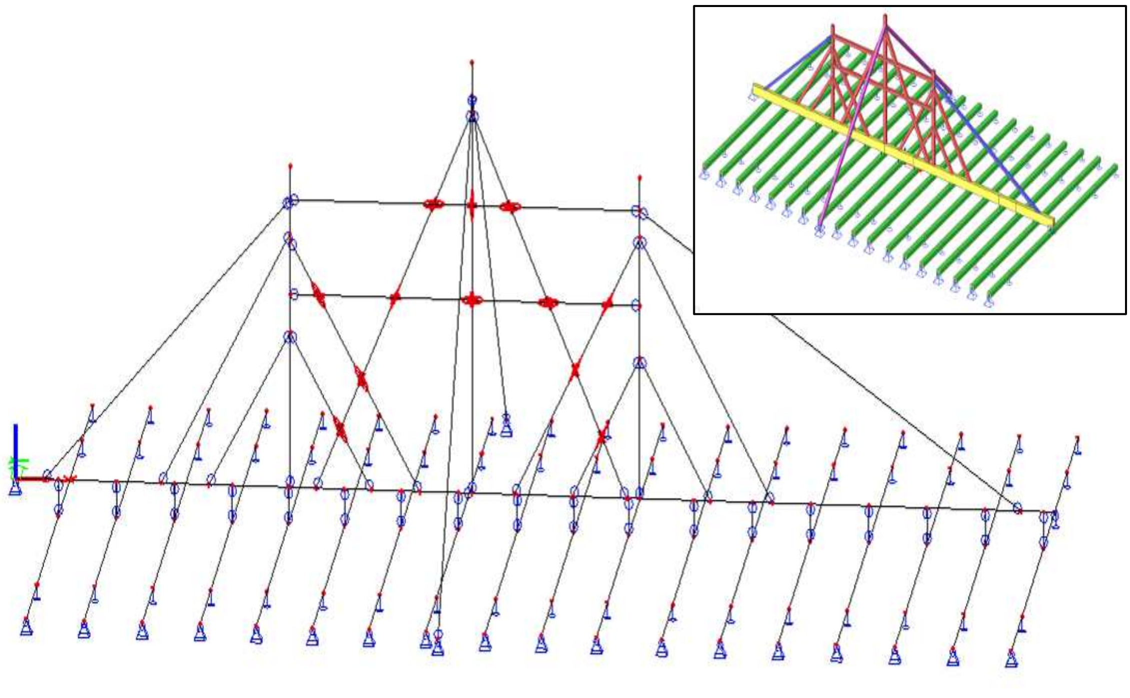

Fig. 7 Static scheme of hanging truss

Table 3 shows the influence of the central queen-post on the maximum deflection of the lower beam of girder grillage with queen-posts in separate alternatives. Influence of outer queen-posts elements can be see in table 4. The way of realizing elements of edge queen-posts reflects the way of joining and resistance of elements.

	deflection of the lower band [mm]	RL [kN]	NV [kN]		deflection of the lower band [mm]	RL [kN]	NV [kN]
A1	O/P	O/P	O/P	A2	O/P	O/P	O/P
VK-I	1,905	0,376	1,231	VK-I	1,700	0,608	1,043
VO-I	2,500	0,894	0,999	VO-I	1,700	0,611	1,015
VF-I	2,350	0,916	-	VF-I	1,525	0,735	-
VK-O	2,023	0,738	1,290	VK-O	1,604	0,729	0,974
VO-O	1,541	0,660	1,003	VO-O	1,545	0,718	1,000
VF-O	1,582	0,597	-	VF-O	1,962	0,697	-
VK-H	2,045	0,684	1,004	VK-H	1,421	0,671	0,947
VO-H	1,516	0,526	0,998	VO-H	1,200	0,609	1,003
VF-H	1,734	0,495	-	VF-H	3,747	0,639	-

Tab. 2 The impact of weakening of the lower beam of girder grillage with three queen-posts

	P	O		P	O
A1	Vx/VK-I	Vx/VK-I	A2	Vx/VK-I	Vx/VK-I
VK-I	1	1	VK-I	1	1
VO-I	1,182482	1,551724138	VO-I	1	1
VF-I	1,627737	2,007662835	VF-I	1,6	1,435294
	P	O		P	O
A1	Vx/VK-O	Vx/VK-O	A2	Vx/VK-O	Vx/VK-O
VK-O	1	1	VK-O	1	1
VO-O	5,705426	4,344827586	VO-O	1,037736	1
VF-O	9,51938	7,444444444	VF-O	3,490566	4,270588
	P	O		P	O
A1	Vx/VK-H	Vx/VK-H	A2	Vx/VK-H	Vx/VK-H
VK-H	1	1,206896552	VK-H	1	1
VO-H	5,474026	4,896551724	VO-H	1,22807	1,037037
VF-H	8,675325	8,877394636	VF-H	6,385965	16,83951

Tab. 3 Influence of king-post to the maximum deflection of the girder grillage.

1	VK	VO	VF
	x/l	x/l	x/l
I	1	1	1
O	1	2,8	3,708015
H	1,206897	3,155556	4,421756
A2	VK	VO	VF
	x/l	x/l	x/l
I	1	1	1
O	1	1	2,97541
H	0,952941	0,988235	11,18033

Tab. 4 Effect of outer shorings of two queen-posts to the maximum deflection.

Fig. 8 Left - joint the king-post with a beam grill and extension the lower beam of girder grillage. Right - view to the truss-post ceiling.

7. CONCLUSION

Church in Vysna Boca is interesting with unique solution of its hanging truss ceiling structure. The design of the posting ceiling in the original ideas does not interfere with the roof construction, contrary, its primary function was to reduce the joist ceiling span. However, improper design solution of truss-post ceiling has influenced not only the roof construction, but also the whole object. Hanging truss with its construction posts additional load to roof construction, with hanging braces presssing the wall beams and causes destruction of the church walls. Ceiling construction of the wooden ceiling beams is sufficiently dimensioned to fulfill its function even without construction for posting of the ceiling. Excessive deflection of truss-post ceiling, which initiated analysis of this structure is not statical significant. Deformation of hanging truss ceiling is stabilized and does not affect the construction of the ceiling.

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