Design of fire- and impact-resistant ceilings in a medieval castle

Design of Fire- and Impact-Resistant Ceilings in a Medieval Castle

Conception de plafonds résistant aux chocs et à l'incendie, dans un château médiéval

Entwurf von stoss- und brandsicheren Decken in einem mittelalterlichen Schloss

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1. Introduction

Karlštejn Castle is a quite exceptional example not only among Czech castles but in the whole of Middle Europe at all. It was built in the 14th century by Charles IVth, Czech king and since the year 1346 the Emperor of the Roman - German Empire, one of the greatest rulers of his time. The Castle /Fig. 1/ was erected to be not only a place of private retreat for the monarch, but also a noble shrine for a large collection of relics of saints which was enlarged in the year 1350 with crown - jewels of the Roman - German Empire. The most costly part of the treasure was, however, the crown of Charles the Great, a symbol of sovereign power over the whole Middle Europe.

Fig. 1 Karlštejn Castle

Important parts of the Castle are the Emperor's residence adjoined directly with the neighbouring Chapel of Virgin Mary by means of a wooden passage.

This church in the second floor of the tower - building was covered with an ornamental beam - ceiling. On three walls mural paintings from the Apokalypse are preserved together with three other scenes concerning directly important events leading to the foundation of the Castle. They are of extraordinary importance in the Gothic painting being ones of the first realistic portraits, especially those of Charles IVth. The Church of Virgin Mary had a direct connection with a donjon, which was the most solid and most important building of the whole Castle. The central room of this donjon and at the same time of the whole Castle is the Chapel of the Holy Cross on the second floor, characterised by Gothic windows, glassed partly with finely cut semiprecious stones. In a special niche behind the altar a treasure of greatest importance for the State - the crown jewels of the Roman - German Empire - was hidden. However, the greatest treasure for us now is a large medieval set of 128 Gothic tablets, representing saints and saintesses in half - figures in rare completeness /Fig. 2/.

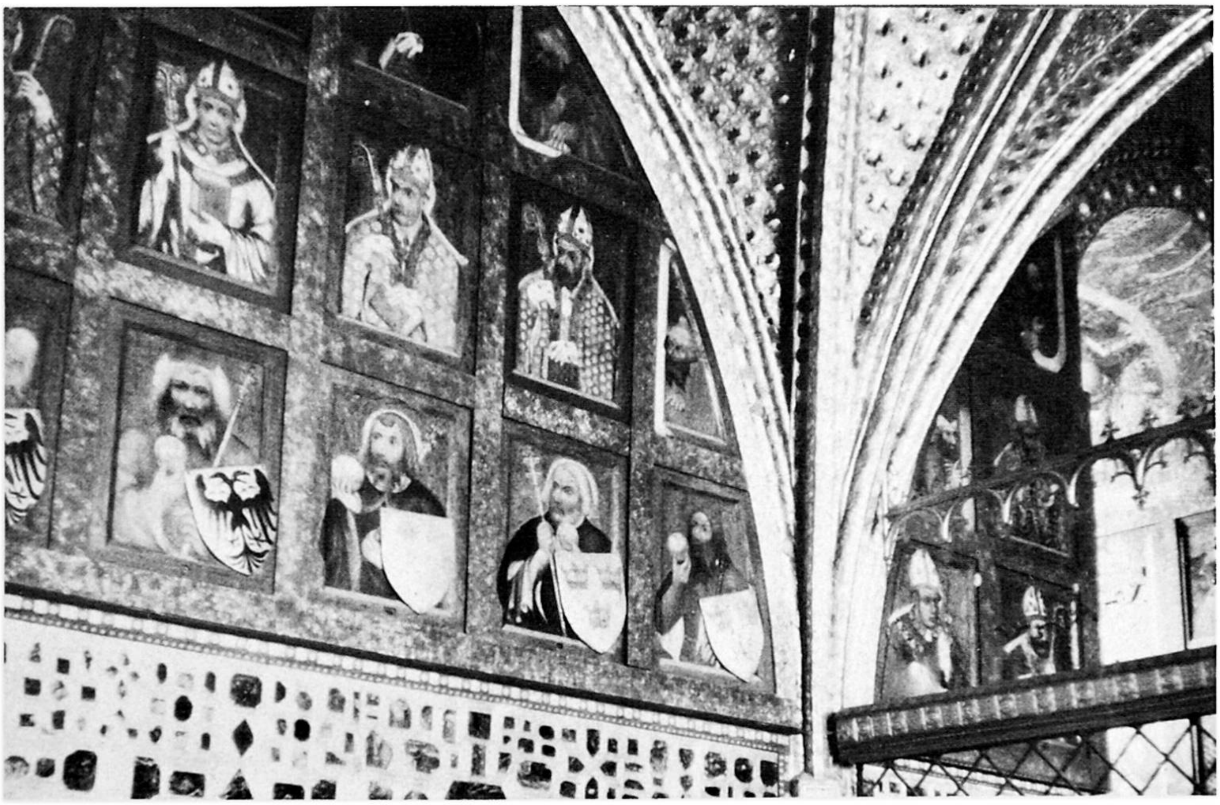

Fig. 2 Interior of the Chapel of the Holy Cross

The restoration of the Castle, carried out in the years 1888 - 1904 removed almost all traces of later renovations, made toward the end of the 16th century. The ancient and venerable Castle, the real memorial of Bohemian national history was deprived during the restoration of the traces of its later rich life. It was artifically clothed into the garment of the 19th century but its interiors with costly paintings have remained mostly intact and represent thus the largest treasure of Gothic religious paintings in the whole world.

Lately it was decided to protect these paintings against the danger of fire and collapse of the 18 meters high roof trusses erected during the last reconstruction at the end of 19th century. Design of fire- and impact- resistant ceilings, prepared by the author together with Mr. J. Bělohlávek, M.Sc., C.E., will be briefly shown in this paper.

2. Purpose and Construction of the Fire- and Impact- Resistant Ceilings

The organisations of state care of historical monuments of Czechoslovac Socialist Republic decided that two fire- and impact- resistant ceilings have to be build on Karlštejn, protecting the Chapel of the Holy Cross and the Chapel of Virgin Mary from fire and collapse of roof trusses. Both these ceilings are designed in the loft level /Fig. 3/, having three main purposes:

- to protect the lower floors under loft from fire which could possibly be caused by a thunder-bolt or other reason
- to shield the ceilings in lower floors from destroying caused by collapse of the burning wooden roof trusses
- and to prevent the lower floors from drenching through with liquids used to extinguish the fire.

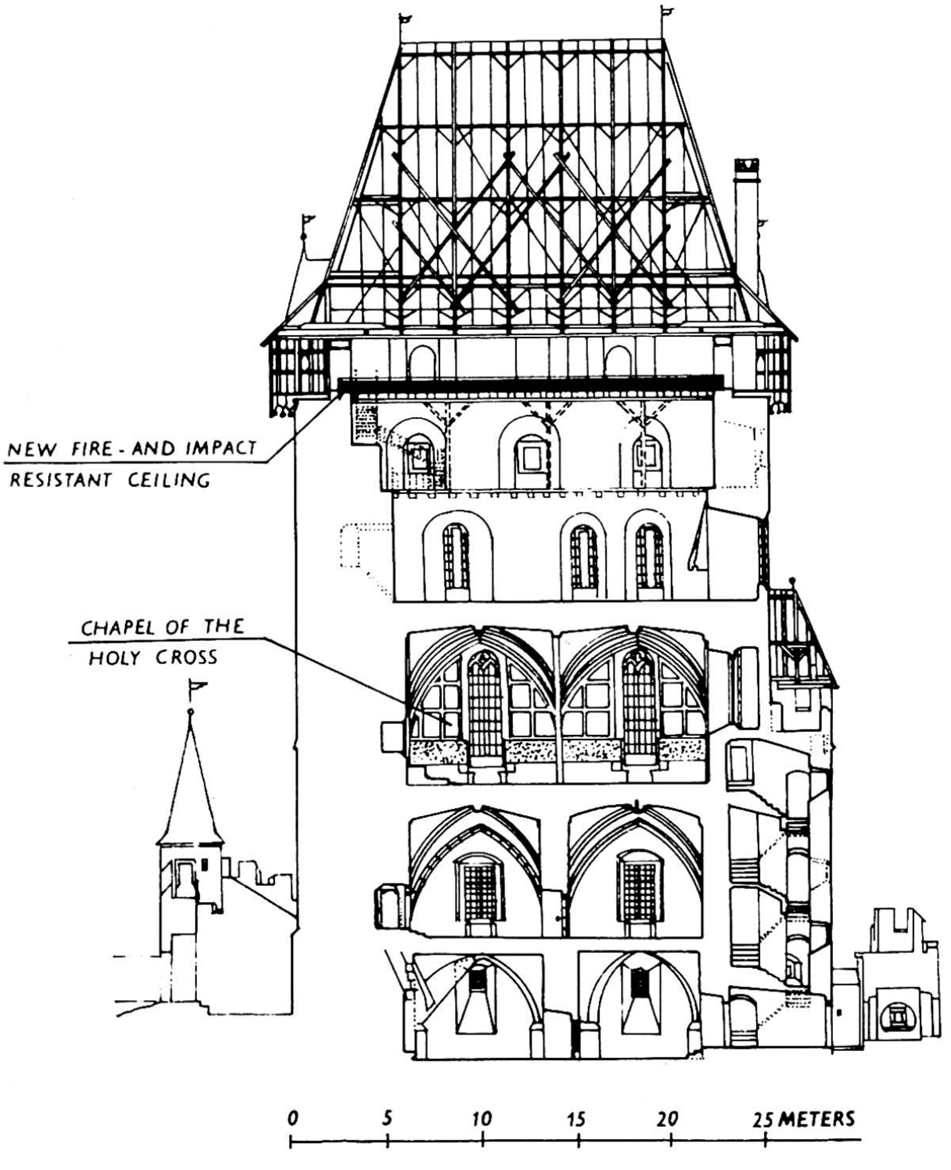

Fig. 3 Cross-section of donjon with position of the new ceiling

During the construction of these new ceilings no surcharge of old roof structures with low bearing capacity was permited. As can be seen the task was rather complicated in every respect, in particular taking into account the dynamic forces acting simultaneously with very high temperature, reaching more than 1200 °C. Solution of this problem was given by the author in form of a sandwich plate, where the upper layers have a heat insulation function damping at the same time the effects of impact. According to the thermal analysis in the first phase the roof crating with slate covering will be destroyed, falling all over the surface of the ceiling nearly at the same time. A protective net supported by cables anchored in a special steel structure was designed to take this first dynamic load, falling down from the height of more than 15 meters and having a weight of nearly 40 Mp. This collapsed steel structure together with the ruins of the roof crating will form another damping layer retaining the impact effects of falling heavy parts of the roof truss.

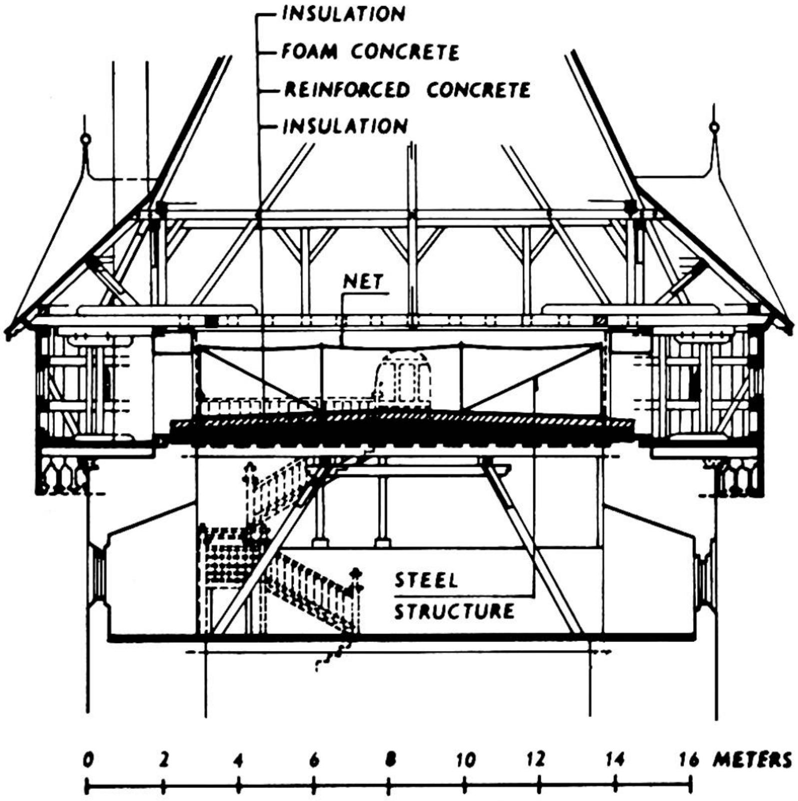

Fig. 4 Location and structural layers of the new designed ceiling

The main part of the new ceiling is formed by a reinforced concrete plate /Fig. 4/ of variable thickness placed on the outer bearing stone walls. As surcharge of old ceilings was not permitted it was designed to demolish the present brick paving with filling on the loft and to use the old battens as a formwork for the new ceiling. Both thermal and waterproofing insulation was proposed to be used on the lower surface, too, and in the lower room a steel centering was designed, taking the weight of the concrete placed in the first phase. The weight of the largest part of the new ceiling is carried by this first - step reinforced concrete structure which is concreted in an elevated position so that no load acts on the wooden old structure.

3. Thermal and Dynamic Analysis

The thermal analysis was made by Mr. V. Reichel, M.Sc.,C.E., as a basis for the next dynamic and static design and basic considerations. The full cubic contents of the roof truss and the crating is about 110 m^3 of wood and the floor space among the outer bearing walls is 221 m^2. The results of the thermal analysis are as follows:

- the collapse of the roof crating will take place at about 20 minutes from the time when the fire starts
- the full breakdown of roof truss will last about 90 minutes
- the weight of the falling parts of the roof truss will be about a fourth part of the original weight, which is due to burning
- the temperature history during the fire on the top of the fire-resistant ceiling as calculated is shown in Fig. 5
- the relationship between fire duration and temperature in the concrete slab when no upper heat insulation layers were assumed shows Fig. 6.

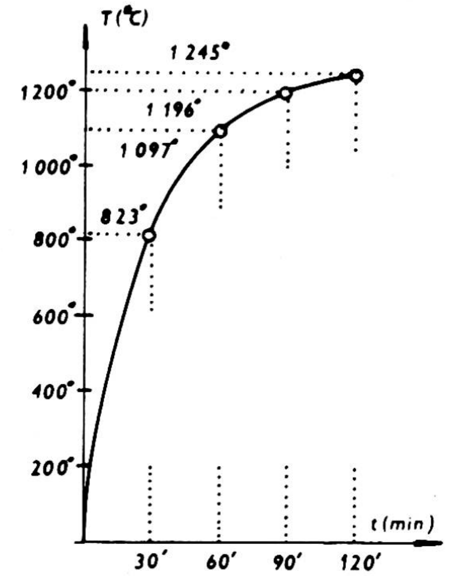

Fig. 5 Calculated temperature history during the fire

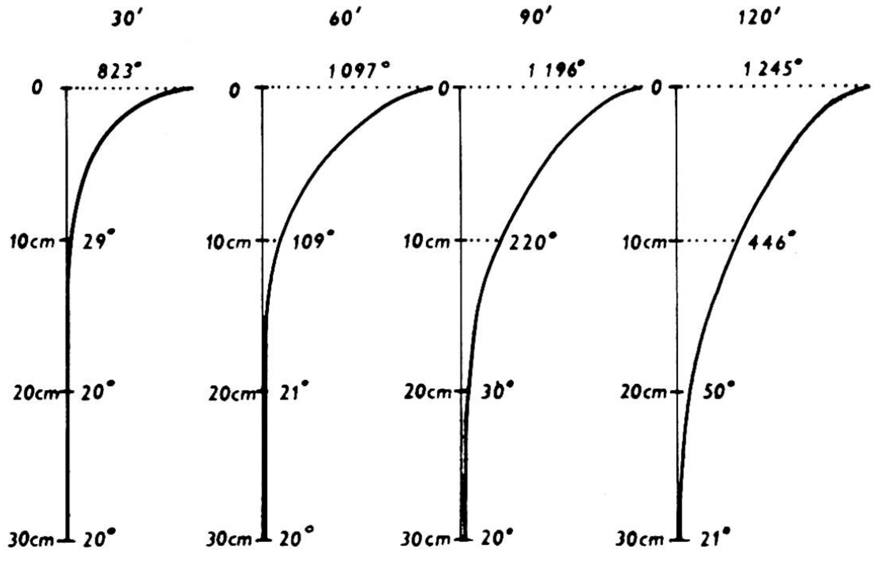

Fig. 6 Relationship between fire duration and temperature in the concrete without heat insulation layers

The dynamic analysis was made by Mr. Z. Podráský, M.Sc.,C.E., in the way shown by Koloušek /5/ and on the basis of the results of thermal analysis. In the present study only a simplified dynamic design took place, using an energy method with reduced mass of the slab calculated by means of net method. The impact factor was calculated from the expression

$$\delta = 1 + \sqrt{1 + \frac{2h}{v_0} \cdot \frac{1}{1 + \frac{G_{red.}}{G_o}}} \qquad /1/$$

where are:

δ......... impact factor
h.........height of the free fall
v_0......... statical deflection of the slab due to the load G_o
G_{red}...... reduced mass of the slab
G_o....... the mass of the falling part of the roof truss

The damping was considered in this design approximately by reducing the height and mass of the falling parts of the roof truss which cannot be, however, determined precisely. The value of the impact factor calculated in this way was 6,2.

4. Conclusion

The design of the fire- and impact- resistant ceilings on the Karlštejn Castle proposed by the author - when accepted - shall be realized in the years 1977 - 78. As many problems dealt with are quite new - some of them formulated here for the first time - much effort must be exerted to come to a complex and satisfactory solution. It shall be not only a question of more precisely defined assumptions and detailed calculation but also a task of much work on construction details, material transport and, last but not least, better understanding of the philosophy of construction of this grand medieval building.

5. References

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SUMMARY

In the paper a design of fire- and impact-resistant ceilings on Karlstejn Castle is briefly described. In this medieval complex the largest collection of Gothic religious paintings in the whole world is deposited and the new ceilings have to protect this treasure against the danger of fire and collapse of the high wooden roof trusses erected during the reconstruction at the end of the last century. This complex problem was solved by designing a sandwich plate and some results of thermal and dynamic analysis of this structure are presented.

RESUME

L'auteur décrit la conception des plafonds résistant aux chocs et à l'incendie du château de Karlstejn. Cette construction médiévale possède la plus grande collection au monde de peintures religieuses gothiques et il fallait protéger celle-ci contre le danger d'incendie et d'effondrement des poutres du plafond en bois datant du siècle dernier. Ce problème a été résolu à l'aide d'un panneau sandwich; quelques résultats de calculs thermiques et dynamiques sont donnés.

ZUSAMMENFASSUNG

Der Entwurf von stoss- und brandsicheren Decken für Schloss Karlstejn wird vorgestellt. Dieses mittelalterliche Gebäude besitzt die grösste Sammlung gotischer Devotionsbilder der Welt; es war deshalb nötig diese gegen die Brand- und Zusammenbruchgefahr von Deckenholzträgern des letzten Jahrhunderts zu schützen. Das Problem wurde mit Sandwichplatten gelöst; einige Ergebnisse der thermischen und dynamischen Berechnung werden dargestellt.