

# **THE ROOF OF THE CHURCH OF NATIVITY IN BETHLEHEM**

F.WENZEL<sup>1</sup>, S. SZAKTILLA<sup>2</sup>, H. PLIETT<sup>3</sup>  
Em. Professor Technical University of Karlsruhe<sup>1</sup>, Architect<sup>2</sup>, Civil Engineer<sup>3</sup>

## **SUMMARY**

The Church of the Nativity shows extensive damage to the wooden roofing and its lead covering. Systematic examinations have shown that the damage is essentially due to holes in the roof covering and condensating indoor moisture. On the basis of the results of the examinations proposals and plans for specific technical repairs have been developed.

## **1 INTRODUCTION**

The Church of the Nativity in Bethlehem is not only one of the most significant historical sacral constructions in the Christian world, but also one of the oldest, preserved early Christian basilicas. The valuable interior featuring wall mosaics and paintings has always been admired by visitors. For centuries the Church of the Nativity has been the destination of pilgrims from all over the world. Several

thousand tourists now come to Bethlehem every day to view this church (Fig. 1, 2).

Figure 1.  
General view on the Church of  
Nativity.

Figure 2.  
Main nave with open roof con-  
struction.

In the first half of the 4th century A.C. Emperor Constantine the Great had the first column basilica constructed. Adjacent to the fivefold nave of this first church was a crossing incorporating an apse and two transepts. It was already at the start of the 6<sup>th</sup> century that the entire structure was reconstructed – probably on instructions from Emperor Justinian. In doing so, the fivefold ground plan of the initial church was preserved and extended on the west side by adding a narthex and an atrium (Fig. 3, 4). Apart from some minor alterations, the basic substance of this structure has remained unchanged to date.

Figure 3.  
Ground plan  
(original build-  
ing in black,  
later applica-  
tions in grey)

Figure 4.  
Cross section.  
See roof con-  
structions of  
main nave and  
side aisles.

The basilica was protected by a lead-covered wooden roof. The roof structure was originally – as was characteristic for structures of this type – open on the underside, however was retrofitted with a suspended ceiling during modification work. Today the wooden roof structure is once again visible from below (see fig. 2). At the time of the Crusaders, after carrying out first comprehensive repairs, the interior of the church was decorated in valuable wall mosaics and paintings around 1150 [1,2]. Reports exist from 1435 and 1479 concerning the poor state of the roof and the ineffective repairs undertaken at that time. After this news reached Europe, wood was shipped from Venice to Bethlehem and the roof was quickly repaired. It is likely that most of the roof supporting structure dates from this era. Repeated leaks approximately 200 years later – i.e. around 1670 – and again in 1832 resulted in more repairs to the roof structure and the covering. In the 20<sup>th</sup> century, the roof was covered several times in bituminous fabric sheets and later on in a white plastic mass, i.e. the so-called coating (see fig. 1).

Today the interior condition and appearance of the Church of the Nativity again suffer from the leaky roofs. When it rains, water regularly penetrates into the interior through the roof, pours down the walls or drops from the roof structure. Large areas of loose plaster and water stains on the walls have damaged the wall mosaics (Fig. 5); the floor is covered in various puddles, which are major in some places. These puddles are damaging the preserved remnants of valuable floor mosaics and prevent visitors from walking round the church.



Figure 5.  
Inner side of south wall with water flags and damages in the wall plaster.

## **2 STRUCTURAL EXAMINATION**

### **2.1 Examinations conducted by our team**

In February 1997 we carried out extensive examinations on the roof structures to determine the causes of rain leakage and damage to the wooden roof structures [3]. Examination of the roof truss, which is open on the bottom, was not easy without hampering the day-to-day functioning of the church and without erecting extensive scaffolding. This was accomplished by using a movable stand and wooden boards, which were inserted into the roofing. We were thus able to map the structural damage systematically and to gain an almost complete image of the condition of the roofs and their coverings.

### **2.2 Examinations conducted by other experts**

Samples of the wall mortar, plaster and roof covering as well as samples of wood and the fruits of plant pests were taken and submitted for analysis to the laboratory at Karlsruhe University in order to provide some clues as to the composition of construction materials and/or the type of wood and type of plant wood pests. The Karlsruhe Institute for Building Material Technology was commissioned to submit a report on the physical and climatic conditions in the roof structure and the church interior.

## **3 STRUCTURAL DAMAGE**

### **3.1 Structural description**

The roof structure above the centre span and above the transverse spans consists of wooden trusses, made of cedar and oak, which are arranged mostly at regular intervals in the axes of the centre span columns. They terminate on wooden beams, which are fully incorporated in the wall masonry. Above the side spans the upper beams of the trusses are cut off and fitted together above the central row of columns. Purlins of different cross-sections are arranged at irregular intervals longitudinally on the trusses, which create a striking roof underside. Planking, which acts as a sub-structure for the lead covering, is located on top of the purlins. This is embedded in a mortar base with a thickness of 1-4 cm. The lead plates, which were probably cast in a sand bed locally, have a length in excess of 2.00 m and are laid at widths of approx. 70 cm. The plates are up to 7 mm in thickness and were fastened to the wooden boarding and purlin area using nails. Due to the lead application method using folded joints, we assume that the covering dates from approximately 1480, when most of the roof structure was replaced.

Figure 6.  
Damages on wooden sub-  
boarding and purlins

Figure 7.  
Brick console under  
damaged beam head in  
northern side aisle.

### 3.2 Damage to wooden roof supporting structure

To be able to analyse fully the wide range of similar structural units, for each individual truss we used prepared measurement sheets in which we recorded information regarding cross-sections, damage and any other specific features.

Numerous instances of damage, which are extensive in some places, have been caused by water seepage running down the wooden structures and the walls.

- ?? In some places the wooden sub-boarding is destroyed extensively for the most part as the result of decay and plant wood pests (Fig. 6).
- ?? Many of the purlins that support the boarding are decayed or damaged (see fig. 6).
- ?? In the side aisles numerous rafter base points and ceiling beams at the support are destroyed; many of the beam heads that terminate concealed in the wall masonry were underpinned many years ago using brick consoles (Fig. 7).
- ?? Iron bands at almost all rafter base points of the main span and supporting wooden consoles under ceiling beams indicate that there is concealed damage in these areas (Fig. 8).

The base point of one of the trusses in the southern side span is destroyed and has slipped out of the support in the wall. This truss is prevented from dropping off into the side span only by friction. If it drops off inside the church, which cannot be ruled out, people might get into danger.

Figure 8.  
Rafter base point  
and beam head in  
main aisle with  
application of iron  
bands and wooden  
console.

Figure 9.  
Local uncovering on the roof  
shows several layers of seals.

### 3.3 Leakages in the historical lead covering

Despite the thickness of the lead, which is up to approx. 7 mm, damage is apparent in several places: holes as the result of mechanical influences, breakages due to material fatigue and cracks in the connections of the side span roofs and the centre span walls. Some holes are up to 10 cm in size, some cracks are more than 20 cm in length. Some nails, which are used to fasten the covering to the sub-structure, can even be removed manually. This indicates corrosion damage to the fasteners or wood damage to the sub-structure. The eaves are in a particularly bad state, parts of the lead flashing are completely missing, others are loose and are about to drop off.

The life expectancy of lead roofs is generally around 150 years. The existing covering originates, for the most part, from the late 15<sup>th</sup> century. The service life of this roof is thus exceeded more than threefold.

The lead covering had several layers of bituminous seals added to it, some of which have fabric inserts (Fig. 9). The top layer above the centre and transverse spans consists of a white coating. Apart from the poor technical finish of the applied seals, the layers prevent the humidity rising from the church interior from escaping through the roof. However, precisely this is desirable due to the increased visitor numbers and the interior humidity caused by them. While the Church of the Nativity did not originally have any windows, it did have large-scale entrance gates, thus ensuring adequate transverse ventilation even with the large number of visitors. But now the rising humidity collects inside the roof structure and condensates there. Rainwater, which permeates through various openings, increases the volume of water. The water seeps through holes in the wooden sub-boarding onto the rafters, ceiling beams and walls.

### **3.4 Other damage**

When examining the connections of wooden beams to the walls of the nave, transverse spans and side spans, we also detected individual points of damage to the masonry and the wall plaster. At some points the damage is so advanced that it has reached dangerous levels:

- ?? at several points large areas of wall plaster have become detached from the sub-layer and threaten to fall into the church interior from a height of more than 14 m at some points;
- ?? individual consoles to support the destroyed bottom runners in the side spans have become separated from the wall structure, some of which can be moved manually (see fig. 8).

These loosened pieces of masonry and plaster represent a serious danger, as these parts can drop off at any time and without any warning directly into areas accessed by users and visitors to the church.

## **4 ASSESSMENT OF CONDITION**

The results of our examinations demonstrate that extensive damage exists not only inside the roof structure and its covering, but also at some points of the walls and the wall plaster. Danger to church users and visitors exists in several places. We can see from the wall mosaics and paintings what damage to the valuable interior has occurred to date as a result of the leaky roof structure: the majority of them are damaged beyond repair, while those remaining will soon also be damaged beyond repair. Urgent repair work is required in order to protect the remaining parts of the interior, the wooden roof structure from the 15<sup>th</sup> century and to ensure the safety of visitors to the church.

## **5 RECOMMENDED REPAIRS**

On the basis of the results of the examination and in accordance with the principle “as much as necessary, as little as possible”, plans for careful repair and overhaul of the roof structure were drawn up. The first task is to repair the damage to the roof structures by reinforcing the weakened components, replacing damaged parts and adding missing parts. The plaster that has become loosened from the walls must be either secured or replaced. A complete replacement of the roof covering is essential in order to protect the roof structure permanently against interior humidity which is condensating as well as to protect the church chamber against rain seepage. It is planned to use the lead plates from the roof once again after they have been removed to cast new ones. To ensure the escape of humid air from the interior an adequate number of ventilation holes must be provided on the roof surfaces. In addition to overhauling the roof structure, an

operational roof drainage system of adequate dimensions must be installed to drain the sometimes considerable volumes of rainwater away from the building in a controlled manner. A lightning conductor should also be installed on the building. The windows, some of which protrude from the exterior wall alignment, should be dismantled and repaired to ensure that no more rain can penetrate into the church via the windows. The flooding of certain grottoes could also be prevented in future, if the entire building drainage system is improved and channelled as part of the requisite roof overhaul.

## **6 SUMMARY**

The results of our examinations of the Church of the Nativity indicated that the historical roof structure from the late 15<sup>th</sup> century and the appurtenant roof covering made of lead plating have been damaged extensively. Holes in the lead covering allow rainwater to penetrate from the outside. At the same time layers that were added at a later date and were not properly carried out do not allow interior humidity to escape, thus condensating on the underside of the roof structure. Many wooden parts are damaged by rot and some are about to drop off. The remnants of mosaics and wall paintings are also in danger as the result of water seepage down the walls. It is not yet too late to take targeted, specific action to repair the damage, renew the roof covering and restore the Church of the Nativity's unique appearance.

## **7 REFERENCES**

- [1] Harvey et al. – “The Church of the Nativity at Bethlehem”. Ed. by R. Weir Schultz, London 1910, 75 p.
- [2] Harvey – “Structural Survey of the Church of the Nativity Bethlehem”, London 1935, 30 p.
- [3] Szaktilla, H. Pliett, F. Wenzel – “Geburtskirche zu Bethlehem – Gutachten zum Zustand der Dachkonstruktion”, May 1997, 23 p.