

The work involved in the securing of the roofing and cupolas of the Abbey Church in Neresheim

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Discovery of the damage

In 1966 an examination of the Abbey Church in Neresheim was made by Mr. Thier, an engineer from Ludwigsburg. The purpose was to decide whether, and in what manner, the building could be better protected against fire. During the examination it was discovered that the plaster and painted surfaces of the cupolas were cracked in many places and that the displacement of large pieces of plaster was a likelihood to be reckoned with. It was further noticed that the roof timbers in the region of the intersection of the nave and transepts were rotten and had sunk at the important points of the intersection; this meant that the possibility of a collapse could not be ruled out. A particularly acute danger for the loose plaster and rotten roof timbers was seen to lie in the vibrations caused by the sonic boom from jet aircraft. Because of the danger to the building and its visitors the church was officially closed in the autumn of 1966.

Assessment of the damage

In March-April 1968 Mr. Pieper from Brunswick and myself investigated the full extent of the damage in the course of a week's examination. We discovered that the roof timbers at the intersection were badly sagging and in parts were rotten. The fault had originated in leaks in the plain tiling on the roof, through which snow entered each winter, lay in the ridges and soaked through the woodwork. The roof timbers over the nave were, however, better preserved, except at a few intersection points.

In the meantime scaffolding had been erected inside the church, so that we were able to look more closely at the underside of the cupolas. The plaster and paint surfaces were covered with cracks; in some places the plaster had been pushed outwards owing to expansion in the mortar. The distinct symmetry of the cracks was particularly noticeable; for the most part these cracks were not new and they were probably there in 1904. The signatures of the restorers, written in pencil, can invariably be seen between them. We were able to establish that they had widened since

then by a maximum of 0.5 mm; this was due to differences in the tension of the wires of a mesh put up over the plaster of the lower section of the central cupola in 1904.

Viewed from above, the cupolas themselves showed no visible significant damage. The timbers of the roof adjoining the central cupola had, however, sunk in such a way that they caused pressure on it in two places. We were able to calculate from the bend in one beam that this pressure was about 5 Mp.

It was not only in the roof timbers and in the cupolas that damage was discovered; the stonework was also cracked in various places, in particular in the north wall of the nave and chancel, as well as in the east tower and the adjoining wall of the choir. With the aid of a level we were able to establish that in both places the wall had badly sunk. Later, more precise measurements revealed that the walls were still sinking in these areas. From this we concluded that in both places the foundations were not adequate; our suppositions were later confirmed by test borings.

Composition and supporting effect of the cupola framework

The cupolas consist of wooden ribs 0.35 cm thick, radiating from a central point and nailed to circular laths with an approximately trapezoid cross-section of 0.6 cm. Below the laths, the plaster has been laid on to a thickness of about 2 cm, together with the painted surfaces, and from above the laths are likewise covered with plaster 2-5 cm thick. The upper part of the central cupola is also completely covered by laths and plaster over the ribs.

The cupolas were formerly suspended from the roofing, the central cupola resting in addition on four pairs of columns. During reconstruction in 1828, the cupolas were released from the roofing, and since then they have been carried not only by the four double columns but also by special supports, each of which spans the distance from wall to wall between the cupolas. The central cupola weighs 100 Mp and the neighbouring cupolas each weigh 19 Mp. These weights are carried over to the ribs from the laths, and from here they are transferred to an encircling wooden ring and then through vertical and horizontal suspended beams on to the supports. The wooden ring and the horizontal and vertical beams are all interlocking. Above the four pairs of columns supporting the central cupola the vertical supports become props and lead the weight directly on to the columns.

One of our most important discoveries was that in view of the size of the laths and the way in which they were nailed to the ribs a true spatial cupola supporting effect could be obtained. We therefore had a piece of the plaster used by the restorers removed and were able to ascertain that the laths effectively ran over several ribs without touching and that the pressures of the laths were directly opposed. It was also discovered that the numbers of iron nails and their cross-section in the most important

places were just sufficient — though only just — to suit our measurements. Had this not been the case, the cupolas would have acted merely as adjacent ribbed arches and large bending strains and deformations would have occurred in the ribs.

I would like to add here that the question of the distinction between "cupola supporting effect" and "dome supporting effect" could be of importance for the restoration of other ancient wooden cupolas. At the present time a course is being run at my Faculty which is to include the establishment of an absolute criterion to distinguish between the two cases.

If we assume, to begin with, that the Neresheim central cupola is continually supported all round by suspension or supports, the following pressures will be found to exist: in the rib-direction, meridian pressures which involve the plaster and laths of the cupola frame as well as the ribs, and in the direction of the laths, ring pressures which appear in the upper part of the cupola as pressure and lower down as tension. The pressure is relatively low and easily absorbed, because the plaster and laths again work together. The tension, in comparison, is greater, and must be borne solely by the laths and nailing; as already said, this is feasible at Neresheim, though only just. Where cracks occur in the cupolas notwithstanding, the fault must lie in another direction.

We then found, with the help of a level that the frames erected in 1828 to suspend the cupolas had sagged in the middle by about 10 cm. We also noticed that the saw-teething in the central part of the under-fascia of the truss frame was in the wrong direction, so that the pressure was borne by only the bolts and the building clamps. With time, this had led to sagging and consequently there was a gap of about 2 cm separating the fascia. Finally we found that the supporting capacity of the spatial struts between the suspensions and the wall must be very slight, because very few nails had been used to attach the struts of the suspension.

We calculated that the suspensions themselves supported only 30 % of the weight originally intended. A further 30 % was supported by the spatial centrifugal struts of the suspension. The remaining 40 % was not carried by the suspensions, as a result of the deformation which had developed over the years, and it was necessarily transferred from the cupola itself on to the four pairs of columns, owing to the deformation resistance of the cupola. This has caused the formation of curved pressure areas, while strains are produced perpendicularly.

The pattern of cracks necessarily resulting from the above arrangement corresponds exactly to the actual pattern of cracks. In addition, the bulges due to the pushing of the plaster outwards mentioned at the beginning of this paper exactly fit the locations of the curved pressure areas. Lastly, the 4-point supporting system was confirmed by the varying tensions in the wire-netting added in 1904: the wires running vertical to the cracks are subjected to considerable tensile stress (high-pitch), whereas those running parallel to the cracks are in general slack.

The cracks in the lesser cupolas are less severe than in the one at the intersection; they are likewise due to sagging of the suspensions.

The safety precautions required

The outward tilting of the walls is to be prevented by means of wall-clamps. These clamps are to be positioned at about 1 m below the crown of the wall, through which they are to be inserted lengthways, though they are also to be stretched from wall to wall. The east tower is to be attached to the choir with anchors, and the cracks are to be pressed so that they close. The foot of the tower is to be underpinned with stakes, while the foundations of the nave are to be strengthened with cement. These precautionary measures affecting the stonework and the foundations should prevent the occurrence of any subsequent cracks between the cupola and the walls through further movement of the walls. The rotten timbers over the nave and transepts cannot be repaired and will have to be taken down; a steel construction is proposed in their place. The roof of the rest of the nave can remain, however; a few of its timbers must be strengthened and some will need replacing.

The building commission finally agreed that the new roofing material should be copper. This will provide a guarantee that in the event of a storm the Abbey Church — which is in a very much exposed position — will be protected by an absolutely weatherproof roof, and its priceless interior will thus be shielded from any bad weather conditions.

Except in a few places the cupola structure itself does not need securing; it is strong enough to stand for several centuries. The plaster surfaces must, however, be very carefully secured by the restorers.

The intersection of the nave and transepts requires a new form of suspension and steel casings are being used to strengthen those supports which need it. Iron braces have been attached to the vertical suspensions of the cupola, which must be attached to the new steel supports and then stretched. The weight is to be transferred from the old suspensions on to the new steel supports in such a way as to prevent any new cracks from appearing. The old suspensions will therefore remain, though being relieved of their function; if they fail at any point the steel structure will be able to support the full weight of the cupola.

The suspensions of the lesser cupolas can be strengthened by the addition of diagonals and strengthening of the point of junction, so that here steel casings will not be necessary.

A few words here about the effect of the sonic boom. We measured 4 supersonic bangs with a vibration measurer and found that the vibration path of the cupola was at maximum only 0.16 mm. Moreover the vibration was damped after a second, which showed that a strong dampening influence was present. The vibration caused by a person jumping on the tip of the cupola was four times as great. Once the rotten parts of the

roof have been replaced and the loose plaster secured it can be considered that the sonic boom danger has been overcome, and in any case there is no risk to any other structural parts.

Repairs completed to date

The strengthening of the foundations of the northern part of the nave has been completed and the stakes are in place on the east tower, where the underpinning of the stonework is shortly to begin. A great many of the wall clamps are already in position.

A steel and corrugated iron roof is to be erected over the intersection of the nave and transepts to provide protection, while the rotten roofing over the intersection of the nave and transepts is removed.

A protective structure has also been put up to protect the intersection cupola against falling material. The roof of the nave to the east and west where it is not to be removed has been strengthened by wooden cross-braces.

At present the new suspension for the cupola is being prepared and the new cupola supports are being made in the steel construction workshop; their erection will begin in August. The new roofing for the nave and transept is also to be erected this year. Next year it will be possible to remove the temporary roof, and during the same year work will be started on the renovation of the rest of the nave roof and the copper coating of the roof as a whole. Hence by then the Abbey Church will at least have recovered its familiar outside appearance, even if the interior work takes a little longer to complete.

RESUME

**TRAVAUX DE CONSOLIDATION AUX OUVRAGES EN BOIS
DE LA TOITURE ET DES COUPOLES
DE L'ÉGLISE ABBATIALE DE NERESHEIM**

En 1966, on a constaté de graves dégâts à l'église abbatiale de Neresheim : le crépi des coupoles était fendu en de nombreux endroits; la toiture de la croisée de transept s'était fortement affaïssée. Une inspection approfondie effectuée au printemps de 1968, a fait apparaître que les nœuds de la toiture étaient pourris par endroits. Il semble bien que les fissures devaient déjà exister pour l'essentiel lors de la dernière restauration en 1904; depuis lors, elles se sont élargies quelque peu. Sur certaines surfaces le crépi présentait des bosses et il était à craindre que des plaques

en tombent. On a également reconnu des dégâts à la maçonnerie et aux fondations. C'est la raison pour laquelle il a fallu fermer l'église par ordre de police.

Les éléments les plus intéressants de la construction sont les coupoles en couples. En raison de l'action conjointe des couples et des lattes, elles représentent des ouvrages réellement spaciaux de support des coupoles. Malheureusement, les ouvrages de suspension exécutés en 1828 pour les soutenir, présentent des défauts. Avec le temps, ces ouvrages ont fléchi à un point tel que la coupole de la croisée de transept doit reporter elle-même une partie de sa charge sur les quatre paires de colonnes de support. C'est cette action de support qui explique les fissures dans le crépi de la coupole.

Il est nécessaire d'effectuer d'importants travaux de consolidation à l'église abbatiale : la maçonnerie doit être haubannée par des tirants. Les fondations doivent être améliorées au transept nord et à la tour située à l'est. La toiture pourrie de la croisée de transept doit être remplacée par une nouvelle charpente métallique. La toiture subsistante de la nef longitudinale est à stabiliser et à réparer. Quant à la nouvelle couverture, on prévoit une toiture en cuivre. Aux ouvrages proprement dits des coupoles, il suffit d'exécuter des réparations locales. Les restaurateurs auront à assurer la fixation des plaques de crépi. La coupole de la croisée du transept sera suspendue à de nouvelles chemises d'acier. La charge ne devra être transférée des anciens ouvrages de suspension aux nouvelles membrures d'acier, que dans la mesure où ne se forment pas de nouvelles fissures. Les ouvrages de suspension entre les coupoles secondaires sont à renforcer; de nouvelles chemises d'acier n'y sont pas requises.

Il résulte de mesures prises que l'église abbatiale ne courra plus aucun danger en raison de la détonation supersonique des avions à réaction, lorsque la toiture de la croisée de transept aura été remplacée et que le crépi branlant des coupoles aura été fixé.

Entretiens, une grande partie des travaux de consolidation des fondations et de la maçonnerie ont été exécutés. Un toit de protection a été monté au-dessus de la croisée de transept. La toiture de la croisée de transept a été enlevée à l'abri de ce toit. La coupole de la croisée de transept a été supportée provisoirement par le bas, par un échafaudage de protection. La toiture subsistant à l'est et à l'ouest de la nef longitudinale a été stabilisée. Il est prévu que les travaux de consolidation d'ordre statique seront terminés au cours de l'an prochain.