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Wrocław University's Leopoldinum Auditorium – Tests of Its Ceiling and a Conservation and Strengthening Concept

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Abstract This paper presents investigations of the wooden ceiling in the Leopoldinum Auditorium at Wrocław University (Poland). The investigations included: material, moisture content, mycological, resistographic, thermographic and dynamic load tests. The causes of damage to the valuable polychrome have been identified. A concept of conserving and strengthening the ceiling and the false vault is proposed.

Key words: Historic timber structure, resistance drilling, dendrochronology, rehabilitation.

Introduction

Despite the considerable war damage, several buildings in Wrocław, among them the Wrocław University building complex with its Leopoldinum Auditorium, have survived in their original form. The Leopoldinum Auditorium (Auditorium Academicum) is the most stately room in the main Wrocław University building erected in the years 1728-1732. The building, which belongs to the most precious historic (baroque) buildings in Wrocław, was built as a Jesuit philosophical and theological college. After the merger with Europa University Viadrina in Frankfurt (Oder), the college became a fully-fledged (comprising all the faculties) university. The auditorium was named in honour of Holy Roman Emperor Leopold I. The Auditorium's trapeziform, richly decorated interior (length ca 37 m, average width 11.6 m and height 7.4 m) is divided into a dais and an auditorium. A music gallery is located above the entrance. The whole surface of the ceiling is covered with a rich baroque painting (Fig. 1) corresponding to the division of the room into three parts (Lejman 2003).

Towards the end of the 19th century a decision was made to renovate many of the Auditorium's decorative and structural elements. It was also decided to strengthen the existing wooden deal ceiling. Another aim of the rebuilding was to convert the space above the Auditorium into lecture rooms. The floor (amphitheatric in form) with a small downward slope was made of floorboards fixed with nails to wooden joists resting on plate girders. A deal structural ceiling on runners secured to the plate girders was suspended in the haunches of a false vault along the exterior walls. The set of 8 plate girders of different length (11-13 m) and different height (612-740 mm) was made in the Walterhütte Ironworks in Mikołów (Upper Silesia) in 1905. The plate girders' webs were made of 10 mm thick plate and their flanges were made from one (in the support zone) or two (in the span zone) plates 250 mm wide and 20 mm thick (Fig. 2). The flanges were joined to the web via 100×12 mm angle sections by means of 20 mm (horizontal) and 22 mm (vertical) round head rivets. The vertical bracing between the plate girders was made of single 60×10 mm equal-sided angles (Jasieńko et al. 2008, Jasieńko et al. 2009). The yokes used for suspending the wooden deal ceiling from the plate girders consist of 26 mm thick, 75×360 mm flat bars with holes at their ends, laid on the top flanges. Hangers made from 20 mm rods, with M20 nuts at both ends, pass through the holes. Below the plate girders' bottom flanges ordinary channel sections 140 are horizontally suspended from the hangers. The deal ceiling is laid on the channels (Fig. 3).

Currently, the Leopoldinum Auditorium is part of the university museum and major university celebrations are held in it.

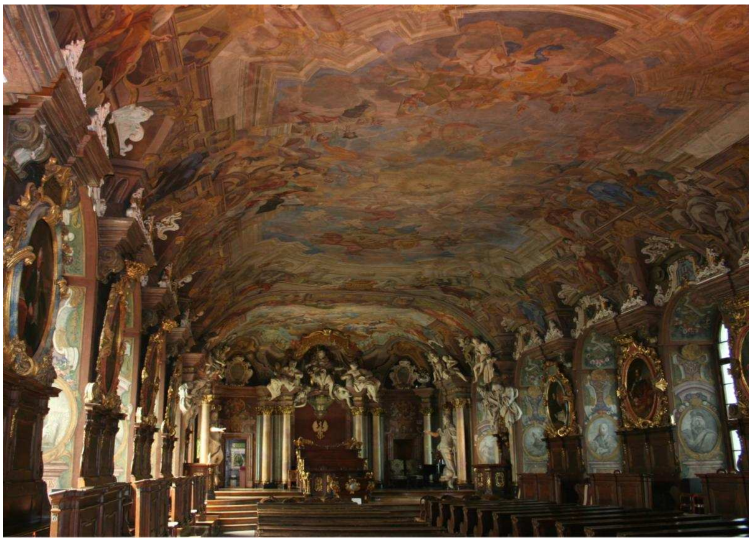

Figure 1: Interior of Leopoldinum Auditorium

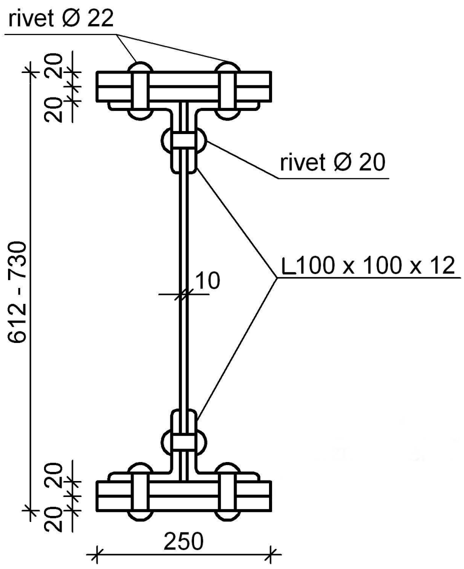

Figure 2: Cross-section of plate girder in span section

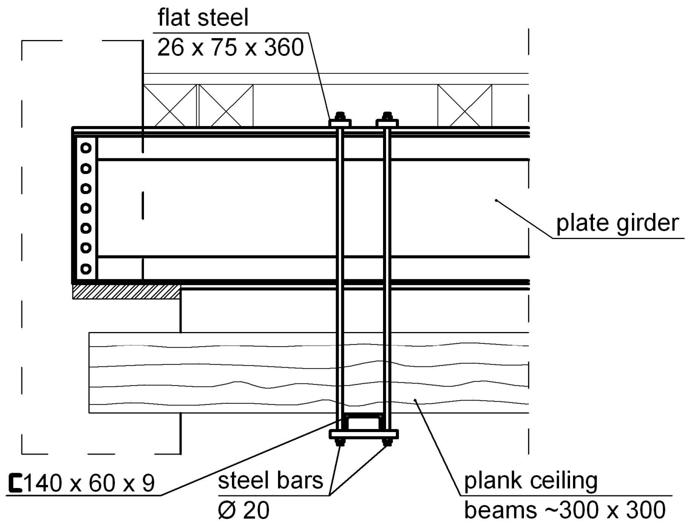

Figure 3: Suspension of deal ceiling from plate girder

In order to carry out construction-restoration work aimed at preserving this unique in the world structure the state of preservation of: the wooden ceiling components, the steel girders and the false wooden vault components needed to be determined.

Strength tests of structural ceiling materials

Assessment of the technical condition of ceiling components The structural ceiling consists of timber deals (300×300 mm in cross section) partly resting on the bearing walls and also suspended from the structural steelwork (plate girders) made in a later period. The false vault structure is made from timber bar girders with carpenter's joints.

The upper part of the deals is impregnated with creosote oil (a hard coal distillation fraction) for a depth of ca 0.3 mm. In places the wood of the deals is unbarked and impregnated from top together with the bark. An expert mycological analysis showed that the timber deals are considerably damaged in their terminal parts in the south-western corner. Fungus Poria vaporaria and insects (timber vermins) belonging to the Anobidae family occur there.

The structural steelwork is in good technical condition and its components are properly protected and no corrosion centres are visible.

Steel strength tests The number of samples for the tensile strength testing of the structural steelwork in the Leopoldinum Auditorium's ceiling was limited to one because of the destructive character of such tests. The steel sample was taken from the web of one of the plate girders. The tensile strength of the steel was tested in a Zwick Roell UFP 400 testing machine (calibrated for accuracy class 0.5) in accordance with standard PN-EN 10002-1.

Since a larger number of steel samples could not be taken for tensile strength testing, the strength parameters of the steel were estimated on the basis of nondestructive hardness tests carried out using a portable Zwick PZ-3 Brinell tester in accordance with Polish standard PN-91/H-04350. The diameters of the impressions were measured by means of a microscope with a ×20 magnification. The measurements were performed in the total of 150 points whereby Brinell hardness could be determined at a proper confidence level (Gosowski and Kubica 2007).

The destructive tensile test results and the nondestructive hardness test results for the steel are shown in table 1. The differences in the steel's yield point and in its tensile strength amount to respectively 1% and 3.5%.

In addition, the steel was metallographically examined by means of an EPI TYP microscope and its chemical composition was determined using a BAIRD-DV4 spectrometer.

Table 1: Yield point and tensile strength determined from Brinell hardness and tensile tests.

Determination method	*Yield point [*MPa*]*	*Tensile strength [*MPa*]*
Brinell hardness	230.3	328.2
Tensile test	232.0	340.0

Timber tests As part of materials testing the timber's characteristics, i.e. moisture content, density, static bending strength, compressive strength along fibres and compressive strength across fibres, were tested. The tests were carried out on samples made from collected ceiling fragments.

On the basis of the material strength test results and their analyses carried out in accordance with PN-EN 384 it was determined that the deal ceiling timber corresponds to timber grade C27 acc. to PN-EN 338.

Timber dendrochronological analysis One timber sample (a full-cross section slice) taken from the ceiling was subjected to analysis. Measurement paths on its surface were determined and prepared and then using a LINTAB analyser the width of the annual rings was measured. The measuring accuracy was 0.01 mm. The growth sequences were synchronized and compared with the reference chronologies by means of programmes: CATRAS v. 4.20 (Aniol 1983), TSAPWin (Rinn 2005) and DENDRO for WINDOWS (Tyers 2004). The sample timber was identified to belong to the species common pine (Pinus sylvestris L.). The results clearly indicate that the timber was felled in late autumn in 1728 or in winter 1728/1729. As a rule, timber would be used in the year it was felled, after a few months spent on timber working, transporting and seasoning.

Resistographic tests A resistograph measures the drilling resistance of an up to500 mm long and 1.5-3 mm in diameter needle rotating at a constant speed of 1500 rpm and in this way reveals changes in wood density (caused by biological or damp damage) and the successive annual growths. This method can be regarded as quasi-nondestructive. The test borehole diameter (ca 3 mm) is no larger that that of the outlet holes made by timber vermin. Resistography makes it possible to assess the extent of damage and to approximately determine the strength of wood, i.e. whether the tested wood shows elevated, medium or lowered strength parameters. This technique is highly effective in testing historic timber structures (Ceraldi et al. 2001, Lourenço 2005, Palaia 2007).

An IML RESI F-400S resistograph was used for the tests. In order to avoid drilling through the wood into the zone of plasters laid directly on the deal ceiling's intrados, the boreholes were drilled to a safe depth, each time determined through a comparison with the known deal thickness. The test results are presented as resistance amplitude-borehole depth diagrams for each of the 57 randomly selected measuring points. An exemplary diagram is shown in Fig. 4.

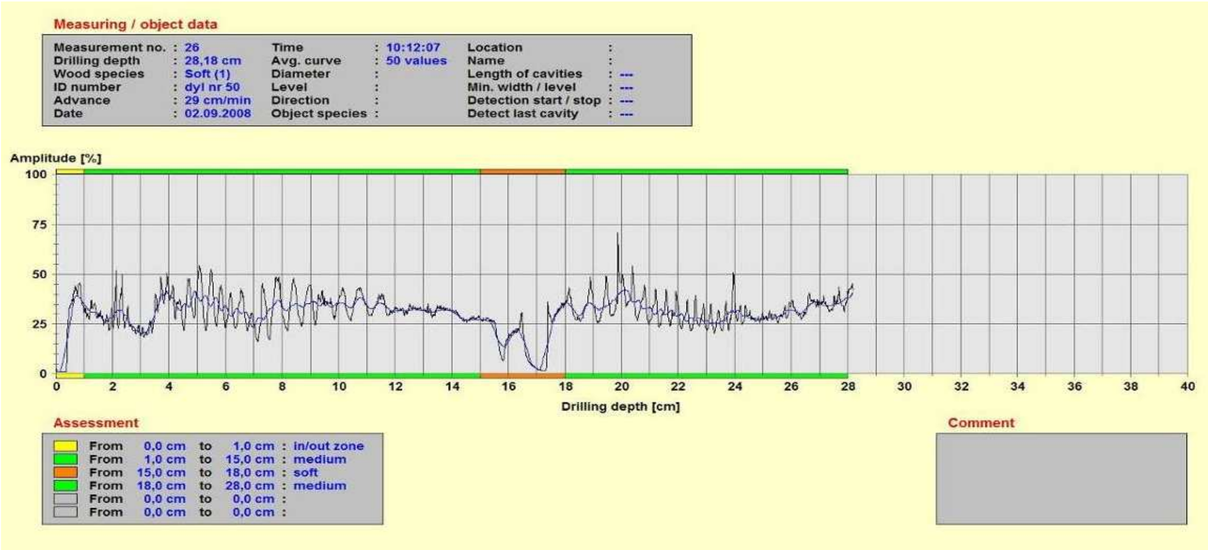

Figure 4: Exemplary resistographic measurement result for ceiling deal (timber beam) above Leopoldinum Auditorium

The resistographic tests showed the historic wood (except for some deals in the bearing zone) to be in good condition. The historic (not tapped for resin) wood in most of the components can be described as healthy wood with average strength parameters. The good condition of the historic wood is also indicated by the determined density – 0.51 g/cm^3 (along undiseased segments). This is a high value for common pine in this region of Europe. For structural pine timber a density of 0.49 g/cm^3 is usually assumed. The deterioration in wood structure properties was found to extend for 1 m from the face of the walls on which the deal ceiling rested.

Static and dynamic tests of ceiling

The aim of the tests was to experimentally determine the displacement and vibration level of the plate girders in the ceiling above the Leopoldinum Auditorium and the degree of vibration transfer from the floor to the deal ceiling. On this basis it could be determined whether there are any displacements of the ceiling plate girders as a result of crowd loading under different static load schemes and what effect this has on the deal ceiling structure and on the painting covering the false wooden vault of the Leopoldinum Auditorium.

Since it is difficult to determine to what degree the Leopoldinum Auditorium polychrome base structure is connected (in the static and dynamic sense) with the floor of the room above the Auditorium, the effect of displacements on the behaviour of the Auditorium's ceiling could not be properly assessed theoretically. Therefore an experimental method, consisting in subjecting the tested elements to crowd loading, was used.

Displacements were registered by Hottinger Baldwin Messtechnik inductive displacement gauges W50 TS (measuring range of +/– 50 mm, class 0.5%) coupled with a PC (running Hottinger Baldwin Messtechnik CATMAN software) and a SPIDER multichannel measurement system made by Hottinger Baldwin Messtechnik.

The static test programme was carried out on a ca 11.66 m wide and 4 m long fragment of the ceiling, located symmetrically above one of the plate girders. The service load was produced by a 110-person group of previously weighed students. The students would stand in precisely specified fields, gradually filling the whole floor space in the tested region, generating both symmetric and asymmetric loads.

The experimentally determined maximum plate girder of 2.48 mm is absolutely safe for the structure.

The PULSE 3560 Brüel & Kjær system was used to register and analyze vibrations. The system includes two sets of different accelerometers with calibration devices made by the same firm. Seismic accelerometers DeltaTron 8340 and TEDS-based THETASHEAR 4507 miniature accelerometers were used for the measurements.

The vibrations generated by crowd loads simulating the service load of the ceiling were measured. The service load was produced by a 110-person group of people (students). The students entered and stood in precisely specified load fields, gradually filling the whole space of the floor, generating both symmetric and asymmetric loading configurations. The students stood motionless or moved in the fields and between them according to a specified programme. They also generated dynamic loads in chaotic and synchronized ways.

The dynamic load tests showed that the existing steel construction, which supports the floor of Balzer's Hall and partly also the Auditorium's wooden deal structure suspended from it, nonuniformly transfers the vibrations generated by the floor load onto the ceiling structure. The vibrations of the wooden deals under the steel plate girders are much larger than those of the deals located in the middle between the plate girders. The vibrations may cause cracks in the Leopoldinum Auditorium's ceiling polychrome base, propagating parallel to the deals. Thermovision examinations confirmed that the base under the polychrome randomly separated from the wooden deal ceiling and from the curvatures of the timber deal vault. Hence it was concluded that the floor structure should be separated from the ceiling structure, preferably through an independent suspension of the ceiling deals.

Guidelines for conserving the ceiling over the Leopoldinum Auditorium

The investigations have shown that:

- the plate girders of the ceiling over the Auditorium do not need to be reinforced for a dynamic load of 5 kN/m^2;
- the deal ceiling should be suspended from the exterior walls via steel brackets anchored with steel expansion anchors in the exterior walls;
- the steel brackets should be connected with the deal ceiling via a (slightly tensioned) steel tendon with a vibration damper and via a wooden cross-beam secured to each deal with a screw bolt, with the joint additionally bonded with an adhesive based on epoxy resin (Fig. 5);
- one should consider anchoring the steel brackets in the walls via a hard rubber pad in order to dampen even more the vibrations transmitted by the brick masonry;
- in order to stabilize possible slight deformation increments it is proposed to introduce an additional joint between the deals, using steel self drilling screws of the Helifix type;
- the diseased fragments of the deals should be removed and bio-protected.

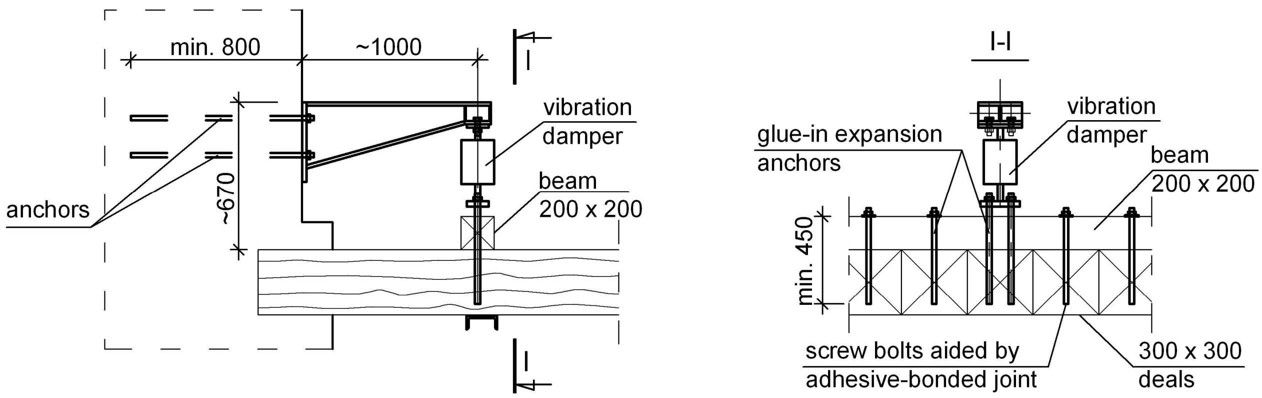

Figure 5: Ceiling deals suspension concept

Besides the authors, the following researchers took part in the project: B. Gosowski, D. Czepiak, J. Dudkiewicz, J. Grossel, H. Nowak, Z. Wójcicki, J. Gańko, P. Grabowski and Z. Matros (from the

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