MEASUREMENT OF MECHANICAL PROPERTIES IN SITU AND MODELING OF TIMBER STRUCTURES IN RUHNU CHURCHES (ESTONIA) DAMAGED BY WOOD-DESTROYING INSECTS

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There are two churches in the Baltic Sea island of Ruhnu, the first wooden church was built in 1642 – being the oldest wooden heritage building of Estonia – and the second, a stone church, established in 1912.

Wood-boring insects

Almost all wooden parts in the new **Maarja Magdaleena church** (Fig.1) on Ruhnu Island are intensively damaged by the House longhorn beetles (*Hylotrupes bajulus* (L.)) (Fig.2). The wooden benches, pillars, stairs, and walls show characters of former – yet more important also on-going active – attack. The most intensive characters of attack are found in the structures of the stone church steeple (Fig.3) and in the roof construction.

This overall infestation requires an immediate control measure which – regarding all (local, conservational, and infrastructural) circumstances – should be applied as a humidy-regulated warm air treatment or as a fumigation.

For the old Maarja Magdaleena church interiorly exstinct attack of the House longhorn beetle was found, whereas that of the Anobiid species *Anobium punctatum* (De Geer), *Xestobium rufovillosum* (De Geer) and *Hadrobregmus pertinax* (L.) needs to be assessed by monitoring measures. The exterior panelling and the logs underneath are attacked by House longhorn beetle – the state of activity demanding assessment by biologists assisted by conservators.

Fig.1. Old wooden church and new stone church

Fig.3. Steeple structures facing towards old church

Fig.2. House longhorn beetle (female beetle and larva)

Fig.4. Axonometrics view of steeple timber structures

Fig.5. Steeple joints

Modelling of steeple structures

In the modelling of steeple structures, a resistograph was used to determine the residual cross-sections of the structures and the mechanical properties of timber. Geometric measurements were performed with a digital distance meter and tape measure. In order to determine the mechanical properties on the basis of the resistograph readings, laboratory measurements were carried out with similar timber, using both the resistograph and the standard bending test, as a result of which the density of the test pieces was found. Laboratory tests enabled us to determine the approximate strength class of the timber structures of the supporting structures of the church steeple. The distinct beetle damage on the exterior of the structures' cross-section (House Longhorn beetle) and in the middle of the cross-section (Common Furniture beetle) as seen on the graphs of the resistograph, was excluded from the reference cross-section.

The beams of the supporting structures were modelled (Fig.4), whereas the joints were neither modelled nor calculated (Fig.5). In the modelling of beams, the worst possible option was chosen, that is, the smallest cross-section found was used as the reference cross-section for the beams. In the modelling of the steeple, exterior panelling giving extra strength to the steeple was not taken into account.

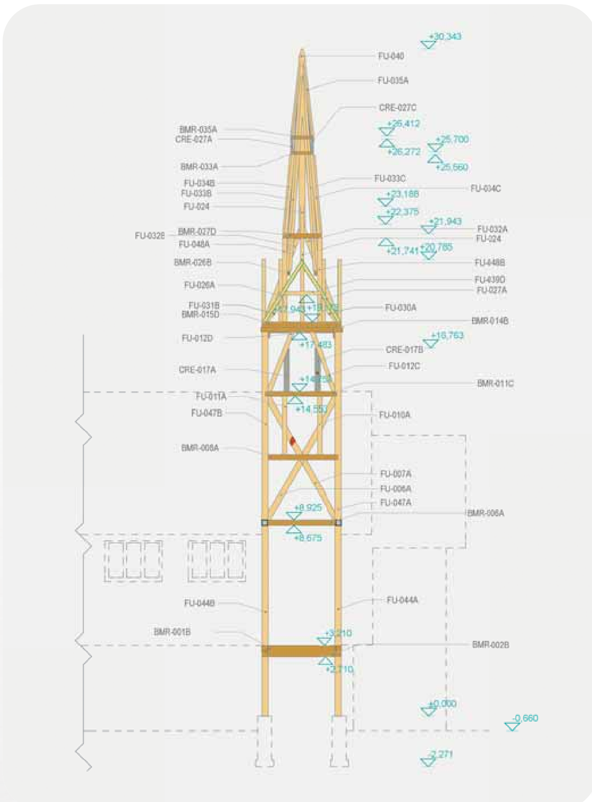

Fig.6. View from north

Calculations of loads, strength and stability of structures

Dead loads, live loads (the church bell was considered a static load), wind and snow loads were calculated. The wind load proved the dominant load, which was calculated according to the standard EN 1991-1-4, applying the Estonian National Annex. The greatest wind speed in the last 50 years, 45 m/s, was taken as the reference wind speed. A combination of 4 load arrangements was used for the wind load, with the wind blowing from each four cardinal points, and the bending load, cross-sectional load, compression load and tensile load of the beams were found for each load arrangement. The strength and stability test of the beams in ultimate limit state was performed with the program Autodesk Robot Structural Analysis v. 22, which showed that two beams, BMR-014B for wind from the east and FU-048D (Fig.6) for wind from the west, failed to comply with the strength requirements based on Eurocode 5. The safety coefficient of several beams was small and more non-complying factors may appear upon continuous beetle attack.

Conclusions

The results of this survey revealed the extent of beetle damage in timber structures. The members most severely damaged were found on the first to the sixth storey of the steeple. Damage was caused by various beetle species: *Hylotrupes bajulus* and *Anobium punctatum*

The mean arithmetic value of the residual cross-sections of measured members was 84.64% of the initial cross-section. In testing the strength and stability of the timber structures in ultimate limit state, it was observed that strength was not guaranteed in the case of two members; the quotient of the reference load and strength was 1.02 in both members. Thus, it may be suggested that despite extensive beetle damage, the strength of the steeple has been guaranteed as the supporting structures of the steeple had initially been over-dimensioned. The internal forces of four two-dimensional church steeple structures act on each other similarly in the members of opposite walls.

Proposed steeple restoration activities include the suspension of beetle attacks (general treatment of the timber structures of the church), reinforcing steeple members and making additional calculations for testing the strength of joints.

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