PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON GEOTECHNICAL
ENGINEERING FOR THE PRESERVATION OF MONUMENTS AND HISTORIC SITES
NAPOLI / ITALY / 3-4 OCTOBER 1996

GEOTECHNICAL ENGINEERING FOR THE PRESERVATION OF MONUMENTS AND HISTORIC SITES

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OFFPRINT

A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1997

Geotechnical Engineering for the Preservation of Monuments and Historic Sites, Viggiani (ed.)
© 1997 Balkema, Rotterdam, ISBN 90 5410 871 1

St-John's Church, Tartu, Estonia – Underpinning of tower

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ABSTRACT: This work was the result of a tender succesfully accepted by the Estonian Government. The tender had to include solution models and detailed planning. The proposals were evaluated for their feasability by a panel of experts nominated by the Estonian State. The partnership of AS Stinger/KAREG Consulting Engineers was awarded the work.

1 HISTORICAL BACKGROUND

The majority of surviving medieval buildings in Estonia are located in the Western and Northern parts of the country, i.e. in the regions where limestone served as a main building material.

In the Southern part of Estonia limestone can not be found, so medieval urban and ecclesiastic buildings were made mostly of bricks. The know-how to make bricks reached this region of Europe in the beginning of the 13th centrury together with Western European crusaders. For Tartu (Dorpat), the city of Lübeck in Northern Germany has to be stressed as a source of these developments.

Although the medieval brick-architecture is poorly represented in Estonia, St. John's Chruch remains an outstanding piece of art in the context of Europe. With its abundance of terra cotta sculptures it is probably the most prominent building of Estonian Gothic architecture, with more than a thousand terra cotta details, both in the interior and exterior of the church.

The building of the church probably started in the 13th century. From 16th century writings one can read "...the church of John the Baptist, which is built with supreme artistic skill and great expense, and which, among other decorations, boasted the figures of the Saviour and the Twelve Apostles..." (Tillemann Bredenbach. Köln, 1558).

The first data about the church or a congregation dedicated to St.John comes from 1323. The wooden rafts supporting the foundations of the church probably date from the end of the 13th century. The mentioned rafts are below the tower; the choir and the so called Lübeck Chapel on the southern side of the church are built without

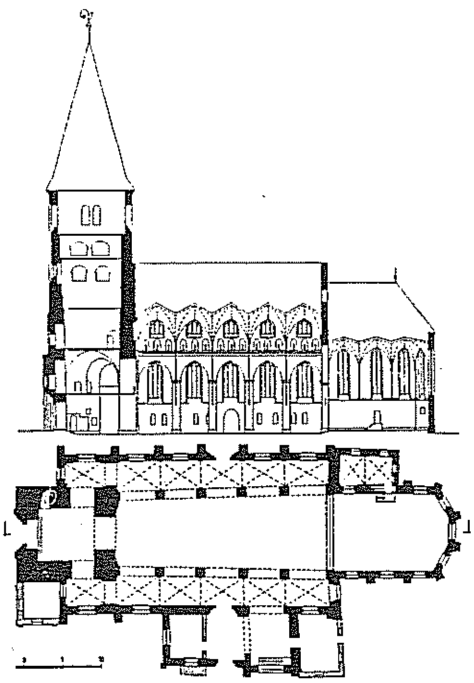

Fig. 1. Plan and section of the church.

supporting rafts. Other parts of the church also rest on wooden rafts.

In modern times there is a cultural layer of about 3.5 meters surrounding the church-building. It contains mainly cemetery material. (The burials in churches, and in the city as it was then, were stopped in 1783.)

The archeological excavations of 1993-1996 have revealed that before the chruch was built there were wooden buildings on the site. Near the western walls of the chruch, are two layers of wooden buildings, the older one having been destroyed in a fire. After the destruction of the buildings the site was turned into a graveyard, on which the church was erected later. Evidence of human activities can be found around the whole territory, although most of the older cultural layers were destroyed by the burials.

The oldest layers of the chruch yard contain burials not typical of Estonian ones. Besides this fact, the anthropological type of the buried is partly alien to Estonia. In this light, the participation of German (Western-European) immigrants (colonists) in the town formation seems evident. This same population can be considered as founders of the discussed church.

The stone church was erected over a burial ground. In the first stage the choir of the church was built on a foundation of sand and granite stones. Initially the choir possessed a straight apse, which during subsequent rebuildings has become an octagonal one. During the next stage the central nave and the tower were added. As the Down-town of Tartu is situated on a relatively soft ground, stability of the building was achieved by placing wooden rafts beyond the foundation stones. There are two layers of logs in the rafts. The rafts have survived partially, but due to the instable ground the church foundations need underpinning as the building has settled unevenly.

The dominating feature of the building is a massive western tower. According to its planning, St. John's in Tartu (Dorpat) resembles the St. Jacob's Church in Torun (Thorn), Poland. Both buildings possess a central nave which is not rectangular but trapezoid. In this connection it is important to stress that both churches belonged to the Diocese of Riga and were built with the involvement of the Teutonic Order.

The story of the church in the post-medieval period is a history of multiple destruction and rebuilding, making the features of the building poorer (less artistic). In 1944 the church caught fire and remained in ruins for the whole period of the Soviet occupation. Because of its abundance of terra cotta details, St. John's in Tartu is unique in the whole of European Gothic architecture.

2 CONGREGATION

The church was originally catholic, however from the time of the reformation, it became a protestant church for german speakers, and remained as such until 1939. Between 1939 and 1944, Estonian became the service language. In 1995 the Lutheran congregation has re-emerged.

3 TOWER STRUCTURE AND REASON FOR UNDERPINNING

The church tower is built of brick, its outer dimensions are 12,5m x 14m. The height of this part is 38m from the ground level. On this part use to rest a wooden spire that previously incresed the tower to an elevation of 60m above ground level. This spire was destroyed during the second World War. It will be reconstructed later as part of the restoration program.

At it's base, the tower is divided into four pillars, P1...P4, two of them measure 7,5m x 3m, the two others 4m x 3,5m, approximately.

The existing foundations of these tower "legs" consist of two layers of wooden rafts, ⌀ 30...40 cm, on which rest 3m of massive stones. On the top layer these stones are joined together with mortar, but at the lower level the joints are filled with sand.

A rough description of the soil layers present under the wooden rafts:

-approx. 6m layer of loose silt
-approx. 4m layer of compact silty sand.
-approx. 2,5m layer of compact clayey silt.
-layer of compact gravel.

During recent decades, the tower began to sink because of the lowering of the groundwater table.

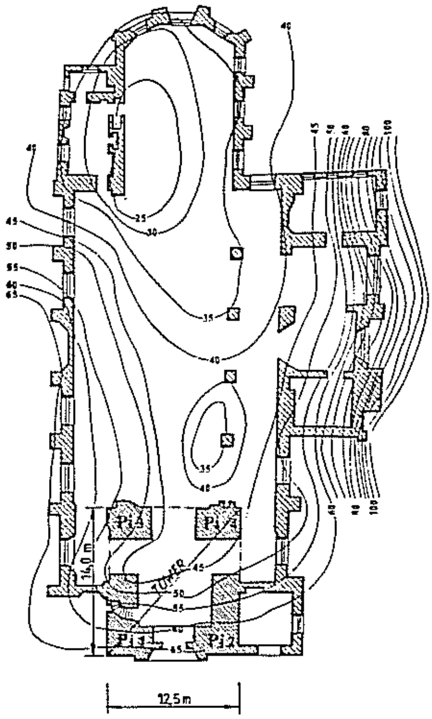

Fig. 2. Settlement lines.

In the last few years the water level has dropped below the wooden rafts. As a result, the wood has begun to rot, thus accelerating the sinking process. For this reason, the work began with the restoration of the tower foundations. The settlement lines are shown in FIG. 2.

4 STRENGTHENING OF THE TOWER FOUNDATIONS

The work was mainly executed in 1993-1994. The last supporting structures and concrete pourings were realized at the beginning of 1995.

The tower weights approximately 5500 tons. Calculated for each "leg", the stress applied on the stone layers is 685 kN/m2.

4.1 Choice of underpinning method

The chosen underpinning type was the jacked pile. Every pile has been pretested.

It was not possible to use hammered piles or root piles, because of the important size and weight of the tower. Another reason of avoiding these methods, was that the vibrations they cause could have damaged the church.

The top layer of the compact silty sand that starts 6m below the old foundation level, was chosen as the bearing stratum. The reason for this choice was that the first 6m layer of loose silt does not have enough bearing capacity and is still settling.

Another reason for this choice, was that the old block foundation could not have taken the greater forces that would have been necessary to jack the piles through the compact silty sand layer below.

4.2 Piling work

The piling work was made simultaneously in separate parts of the tower legs. The type of piles used were jacked steel piles, with closed toes. Each new part was welded after the initial part was jacked down. The completed piles were then filled with concrete and subsequently pressed into position against the tower.

The foundation work was completed for each leg by joining it to a reinforced-concrete raft foundation, thus creating a partly "floating piled raft". This raft was realized casting section by section and providing bond connections with individual piles.One reason for making the rafts part by part for each leg, was to avoid dangerous cavity situations. The floating piled raft and the tower are shown in FIG. 3.

To minimise the use of steel reinforcement, the slabs were in fact designed as a series of inverted arches. As such, a minimum of steel was necessary to join the slab effectively to the piles.

Because of the importance of the tower's weight and the poor soil conditions underneath, as well as the necessity to build for an unusual long life span, the floating piled raft provides an added long-term security factor, while still having been economical in its implementation.

4.3 Construction method

The piling work was carried out in three sequences, the first being the local removal of the stone layer and the excavation of the work area. The second, the pouring of the bed above and the

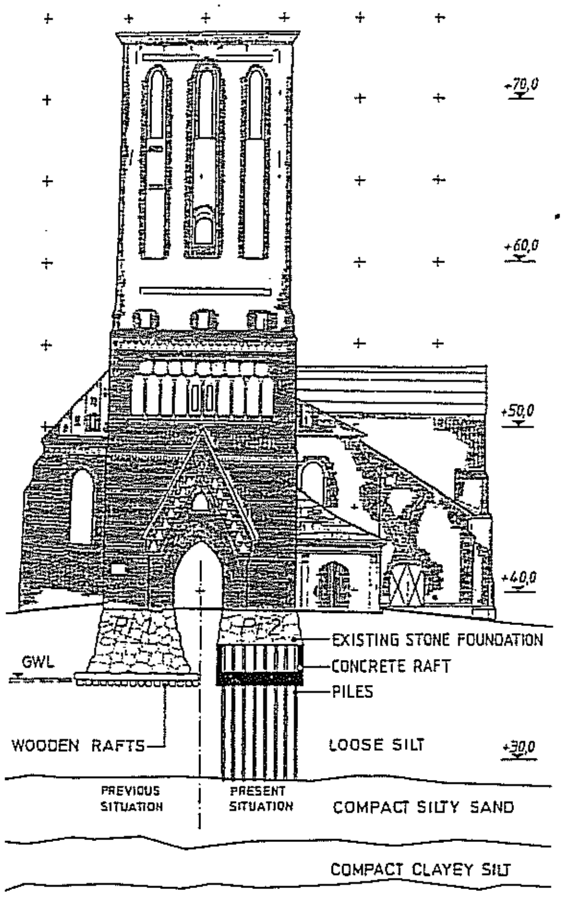

Fig. 3. Western elevation with underpinning of tower.

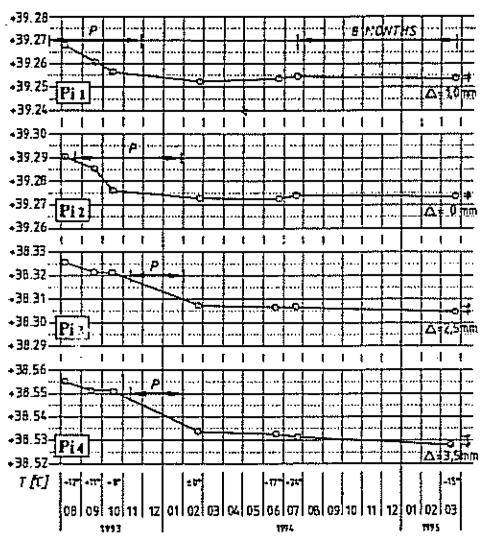

Fig. 4. Piling time (P) and observed settlements.

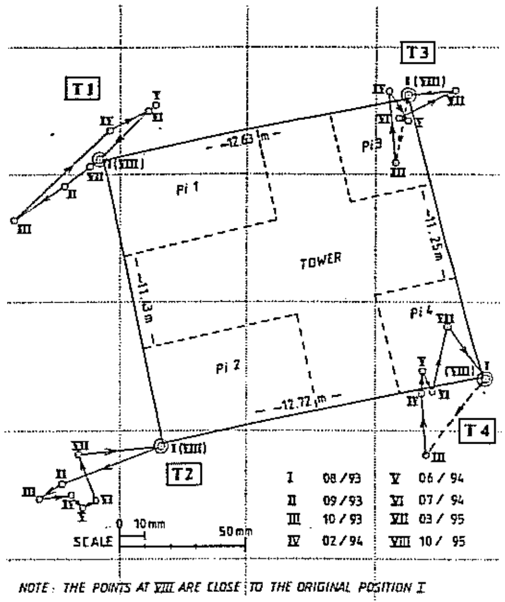

Fig. 5. Horizontal displacements of the top of the tower.

third, the jetting of the hole and jacking of the pile. Three work teams, each one assigned for one sequence, were able to carry out the work simultaneously.

Special attention had to be given to strengthen the smaller pillars (Pi3, Pi4) of the foundation by supporting them temporarily during the work. This was done by supporting them by way of horizontal prestressing. In all, 136 piles (⌀ 210 x 10) were placed under the tower legs, and positioned approximately at 0.8m c/c.

Also, the information about the movement of the top of the tower had critical implications concerning the work schedule. The work was always carried out back and forth, from leg to leg, to compensate such movements.

4.4 Tower movements

During the work period, the movements of the tower as well as the rate of settling were registered. The settling was verified at 4 points, and measured from 18mm to 20mm. (FIG. 4)

Four reference points were also used to register the tower's horizontal movements during the work. These points were taken at 38m height.

During the course of the work, the tower moved from side to side to a maximum of 30mm to 50mm from the original position. This movement coincided with the work that was done in the different parts of its base. (FIG. 5)

The tower has stabilized at 5mm to 10mm from the initial reference point. This represents an inclination of 1:7600...1:3800, that can only be seen with special equipment.

Finally, it shall be pointed out that the work was carried out without incident to the workers nor any real damage to the structure, this inspite of the fact that the workers had no previous experience for this type of work.