

Strengthening the foundations of St. John's Church in Tartu, Estonia

Renforcement des fondations de l'église St-Jean à Tartu, Estonia

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ABSTRACT: The foundations of St. John's Church were strengthened by method of underpinning, using jacked piles and spiral drilled piles. A Practical and simple technique was developed to enable to screw the spiral drilled piles in very limited space. Steel tube piles have been jacked down under the structure, using the structure itself as counterweight. Spiral drilled piles have been used in those walls without a counterweight condition. The underpinning of the tower was proceeded step by step while at same time concrete was poured to make a monolithic floating piled raft foundation. Reinforced concrete beams were constructed on both side of wall's foundations, and pressed with post-tensioned anchorage against the structure. A field load test was performed on all piles, and the rate of settlement was measured.

RÉSUMÉ: Les fondations de l'église St-Jean ont été renforcées par une méthode de reprise des efforts en sous-oeuvre, utilisant des pieux de fondation verinés et des pieux vrillés. Une technique simple et pratique a été développée pour vriller les pieux dans un espace très restreint. Des pieux faits de tubes d'acier ont été installés sous la structure massive en les verinant contre celles-ci. Les pieux vrillés, quant à eux, ont été utilisés sous les murs, sans une condition de contre-effort. L'installation des pieux sous la tour a été réalisée étape par étape, alors qu'au même moment s'effectuait la coulée du béton pour former la fondation monolithique flottante sur pieux. Des celles-ci ont été pressées contre la structure existante par un ancrage post-tendu. Des tests d'application de charges ont été réalisés sur chaque pieu, et les niveaux de tassement ont été mesurés.

1. GENERAL

The origin of St. John's Church of Tartu, can be traced to the 13th century. It is probably the most prominent building in Estonian Gothic Architecture. The church tower is built of bricks, its outer dimensions are 12.5 m x 14 m and the height is 38 m from the ground level. A previous wooden spire increased the tower to an elevation of 60 m above the ground level. The weight of the tower is 5500 tons and it is divided into four pillars at its base.

The foundation was strengthened between years 1993-1996. The work in the foundations started by strengthening the tower, which was done during 1993-1994. Strengthening other parts of the building was done after the completion of the tower part in years 1994-1996. Chancel of the church was not strengthened because it was considered not to have an immediate need.

Plan and section of the church is in Figure 1.

2. OLD FOUNDATIONS

The existing foundations of the church rest on massive stones on wooden rafts. On the top layer these stones are joined together with mortar, but at the lower level joints are filled with sand.

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

- approx. 6 m layer of loose silt
- approx. 4 m layer of compact silty sand
- approx. 2.5 m layer of compact clayey silt
- layer of compact gravel.

3. REASON FOR THE STRENGTHENING

During recent decades, the building began to sink because of the lowering of the ground water. In the last few years before the strengthening work started the water level had dropped below

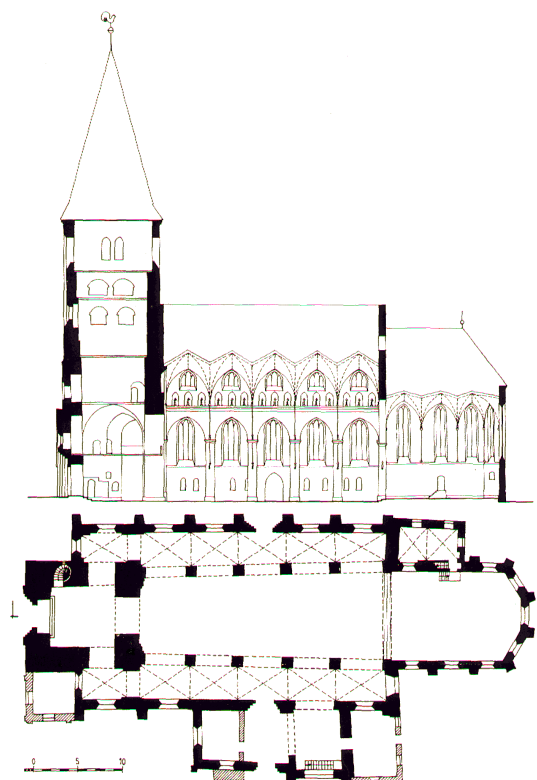


Figure 1. Plan and section of church

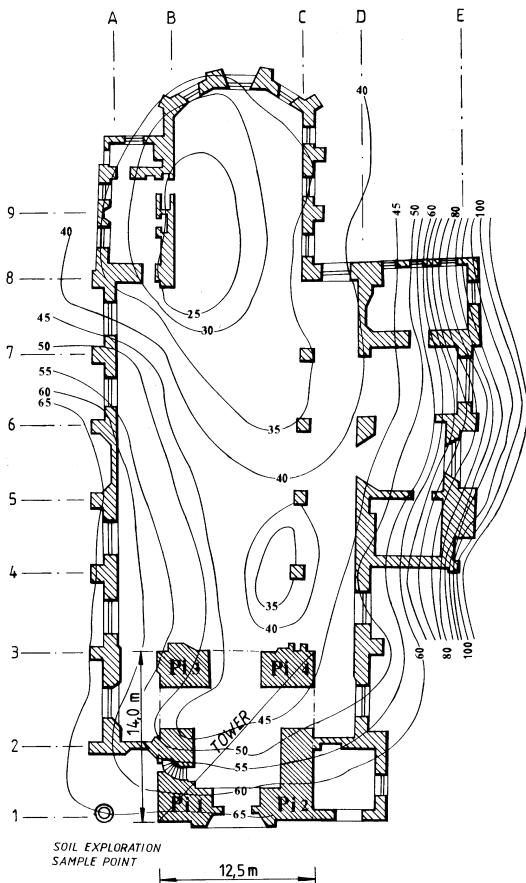


Figure 2. Settlement lines and coordinate lines

the level of the wooden rafts. As a result, the wood had begun to rot, thus accelerating the sinking process.

Restoration work, on the church building, began with underpinning the foundations to end the continuing sinking process that would have caused the building serious damage in coming years.

The settlement lines based on sinking measurement of the church between 1963-1987 are in Figure 2.

4. UNDERPINNING WORK

4.1 Piling

The foundations of the building were underpinned by piling, jacked piles and spiral drilled piles. At the present state the building did not tolerate the vibrations of the driven pile.

The top layer of the compact silty sand that starts 6m below the old foundation level was chosen as the bearing stratum. Reason for this choice was that the first 6 m layer of loose silt does not have enough bearing capacity and is still settling. Also the old block foundation could not have taken the greater forces that would be needed to jack the piles through the compact silty sand layer.

4.1.1. Jacked piles $\varnothing 218 \times 10$ and $\varnothing 140 \times 8$

The type of piles used were steel pipe piles with closed toes. The piles were jacked down under the structure, using the weight of the structure as counterbalance. Stump piles were

joined by wedging. At last the pile was filled with concrete and wedged against the old structure.

Before wedging, every jacked pile were load tested at least 1.5 times the actual load. Allowable maximum loads were 400 kN for $\varnothing 218 \times 10$ and 150 kN for $\varnothing 140 \times 8$.

4.1.2. Spiral drilled piles $\varnothing 218 \times 10$

The spiral drilled piles had closed toes and the first stump $\varnothing 210 \times 10$ had a twist around it.

Spiral drilled piles were used in those parts of structures where jacked piles could not be used for the lack of counter weight as line B in Figure 2, or lack of condition and form of old structure.

Later stage, when concrete structure of upper parts of piles or mass concrete supporting the old structure were ready, load testing of minimum 1.5 load to final load were made. Finally, piles were wedged against the upper part of the supported structure. Maximum load allowable on spiral drilled piles 375 kN were used.

A simple technique was developed for screwing the spiral drilled piles in limited workspace. All the parts of the machine were able to be carried by man power. Photograph 1.

4.2 Foundations of the tower

Jacked steel piles $\varnothing 218 \times 10$ were used to strengthen the structure of the tower. Piling was done gradually, demolishing partly stone composition and simultaneously piling on demolishing part.

The piling order was planned beforehand according the settling and inclination measurements as well as carried on continuously under measurements during the work. In total 138 pc. of piles were installed under the legs of the tower, approximately 0.8 m/c .

A reinforced concrete raft foundation $d = 600$ mm thick was cast part by part with piling work as in Figure 3. Stabilization effect was archived by this reinforced concrete raft cast as floating pile raft foundation. Concrete wall, $d = 300$ mm width and about 1.2 m high, was cast between outer perimeter of the concrete slab and the above lying stone and brickwork as in Figure 3. The purpose of this empty space is to give archaeologist and engineers chance to study the place "in situ" in future, Figure 4. The same figure shows the previous and present situation of the tower foundation.

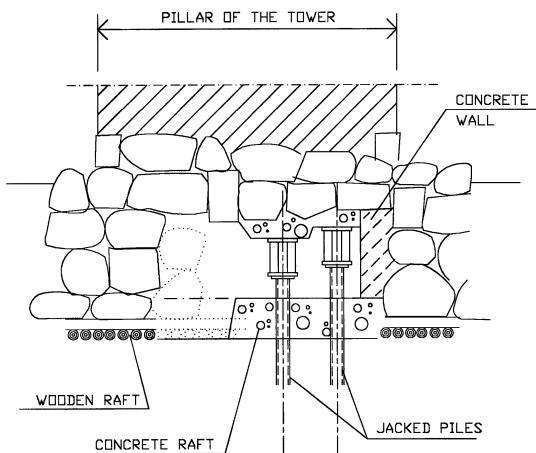


Figure 3. Piles and concrete slab during the work

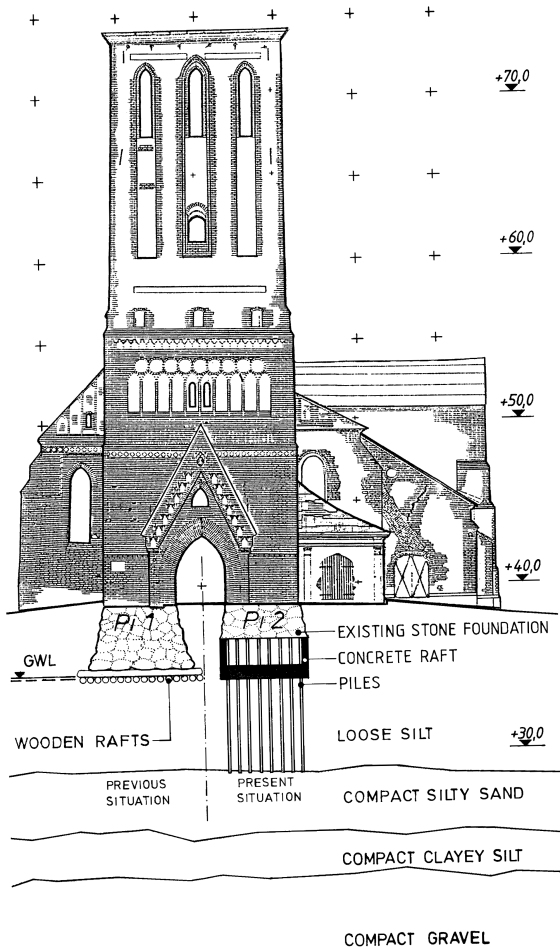


Figure 4. Foundation of the tower. Previous and present situation.

4.3 Line A/2-7 and line C/4-7

The underpinning at line A/2-7 and line C/4-7 was made with spiral drilled piles. Walls were pre-injected with water-cement-peipsisand mixture.

At first stage, piles were screwed to specified depth. Then reinforce concrete beams were cast above the piles against injected stone composition. Reinforced concrete beams were pressed with prestressed anchorage against the old structure. Each prestressed anchorage consists of five plastics-sheathed greased strand (monostrand) SUP1630/1680 $A_s = 140 \text{ mm}^2$.

Tendons were fitted in the hole that drilled with diamond drill through the old foundation. Stressing the tendons were done by jacking up and wedged with VSL-anchorage clamps. Prestressing force of anchorage was used $F = 750 \text{ kN}$. Another jacking was made after six months to eliminate any fall in stress force due to creep effect of the old injected foundation. After renewals jacking the drilled holes were injected with cement mortar and concrete were cast on the anchor clamps.

The spiral drilled piles under the concrete beams were load tested and wedged against the concrete beams as stated in 4.12. and finally steel wedges were cast with concrete.

4.4 Line B/4-7

At line B/4-7 the old column structures had been destroyed during the Second World War and had to be rebuilt.

The new structures were founded on drilled spiral piles as

in 4.12. Reinforce concrete structures were made continuous to get sufficient rigidity. During the jacking some screw piles were used as tension piles too. Test loads and wedging of piles were done as in 4.12.

5. OBSERVATION TO MEASUREMENT

The rate of settlement process of the tower and horizontal displacement was measured during the work period. The direction of inclination followed the piling in various parts of the tower.

Due to the construction technique, the overall settlement of the tower was only 18-20 mm. The horizontal displacement was, at level of 38 m from the ground level, at maximum 50 mm and after the work period, when the settlement process was ended, 20 mm from its original position, i.e. equivalent to 1:1900.

The inclination in other parts of the building was considerably less, due to smaller load and work technique compared with the tower.

6. REFERENCES

Avellan, K. & Lange, K. 1997. St. John's Church, Tartu, Estonia – Underpinning of tower. In Carlo Viggiani (ed). *Geotechnical Engineering for the Preservation of Monuments and Historical Sites, Proc. Intern. Symp., Napoli, 3-4 October 1996*. Rotterdam: Balkema.



Photograph 1. Simple screw equipment for spiral drilled piles.