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Kari Avellan oli kutsuttu toimikunnan TC 301 Preservation of Historic Sites Discussion Session 6.2 Monuments and Historic Sites panelistiksi, jossa pidetty alustus ”Drilled Spiral Pile”s. Muut keskusteluryhmän panelistit olivat C. Viggiani (puheenjohtaja), S. Aversa, J. Burland ja G. Calabresi.

KONFERENSSIJULKAISU

Drilled spiral piles in St. John's Church of Tartu, Estonia

Pieux vrillés de l'église St. Jean de Tartu, Estonie

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ABSTRACT

This article focuses on original working method devised for an important underpinning project in Tartu, Estonia in the 1990s. Because of the sinking and uneven settlement of St. John's Church of Tartu, jacked piles, and especially designed drilled spiral piles, were used to strengthen its foundations. The drilled spiral pile was developed for a particular circumstance, in this case the underpinning of a long massive stone wall without lateral bracing and for rebuilt columns. The piles were drilled down with a hydraulic machine after each segment was welded to the previous one and the initial spiral treaded close toe of the pile. Practical pretesting and end jacking procedures for drilled spiral piles were developed. Every single installed drilled spiral pile was pre-tested and end jacked to a dense layer. In addition, other attributes of the new technique is its low cost, portability of equipment and small space requirement for its implementation.

RÉSUMÉ

Le renforcement de fondations par reprise des efforts en sous-oeuvre est un secteur du génie civil qui offre la possibilité de développer de nouvelles méthodes de travail et où chaque site offre un défi particulier. Cet article met l'accent sur une méthode originale concue pour un important projet de ce type à Tartu en Estonie, durant les années 90. En raison de l'affaissement progressif et inégal de l'église St. Jean de Tartu, des pieux de fondation enfoncés par contre-effort ou vrillés furent installés pour renforcer les fondations. Les pieux vrillés d'une conception nouvelle furent installés pour renforcer les fondations d'un long mur de pierres massives sans contreventement. Ces pieux ont été enfoncés par rotation, à l'aide d'une machine hydraulique, où chaque section de pieu fut soudée à la précédente à partir de l'extrémité fermée munie d'une vrille. L'auteur a aussi développer des méhodes pratiques de pré-tests et tests en fin d'installation d'application des charges sur les pieux vrillés. Ces tests ont été appliqués à chaque pieu, et les niveaux de tassement mesurés. D'autres avantages de la méthode: son coût modique, équipement facile à porter, applicable dans un espace restreint. La méthode est en accord avec les principes (anastylosis) de préservation de l'authenticité des structures.

Keywords: underpinning, pile testing, pretested drilled spiral pile, end jacking.

1 INTRODUCTION

The strengthening of foundations for St. Johns Church of Tartu was a project of historic significance which presented many challenges. To underpin the foundations of this massive structure, original solutions had to be devised throughout the work period. This article focuses on one innovative piling technique developed by the author and employed extensively in response to the difficult circumstances at site: pretested "end jacked” drilled spiral piles. Special method and equipment were conceived to install these drilled spiral piles and a practical pretesting and end jacking procedure was developed for them.

2 HISTORY OF ST. JOHN`S CHURCH

Among the many examples of medieval architecture in Estonia, St. John’s Church in Tartu remains an outstanding piece of art within the European context. It is the most prominent Gothic style building of the country and is unique for its terracotta sculptures and decorative details Fig 1.

It is understood through written records that in 1323 the church, or, to be more precise, a congregation existed. From the evidence of archaeological findings, the building of the stone church can be firmly established as dating from the end of the 13th century or the early 14th century at the latest. The story of the church is a history of multiple destructions and rebuilding, with many of the original features being lost during the process. In 1944, the church burned down and remained in ruins for the whole period of the Soviet occupation.[1] The Church was already protected site during Soviet time. Fig. 2 shows the state of church before the strengthening in 1990´s.

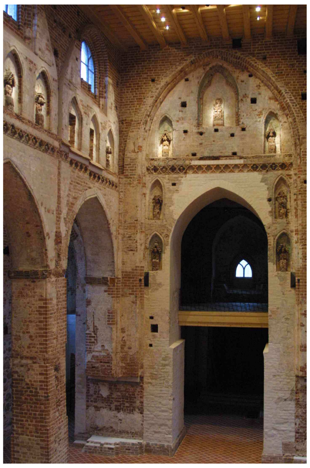

Figure 1. There is almost 1 000 terracotta sculptures inside. and outside the building. Number, size and artistic quality of figures are unique.

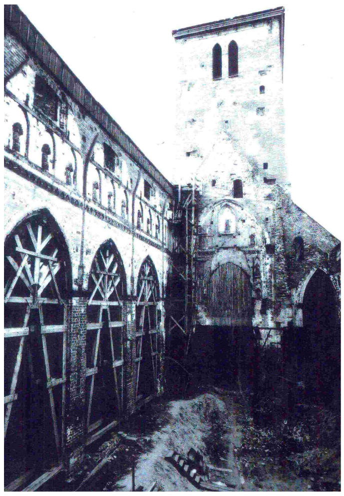

Figure 2. St. John’s Church before the strengthening work. Line A is on the right-side without roof, columns on line B had to be entirely rebuilt (see Fig. 3).

3 REASONS FOR STRENGTHENING THE FOUNDATIONS

The existing foundations of the church are on massive stones, which themselves sit on wooden rafts. The height of the stone setting is about 3 m. On the lowest parts of the building, situated in the south-western and south-eastern corners, the stone setting is 1.5-2 m high. On the top layer these stones are joined together with mortar, but at the lower level the joints are filled with sand. The double wooden raft under the stone setting was made from Ø 30 - 40 cm wood trunks. The ground under the church consists of a variety of different soil layers. The approximate thicknesses of the soil layers under the wooden rafts are shown in Fig. 3.

The consolidation process of the loose sandy silt layer has ended because of its thickness (5 m) and time-lapse (more than five hundred years). The outside earth surface of the church has risen in the past because of the addition of “cultural layers”. During recent industrialisation decades the building began to sink because of the lowering of the ground water table. In the last few years before the strengthening work was started the water level had dropped below the level of the wooden rafts.

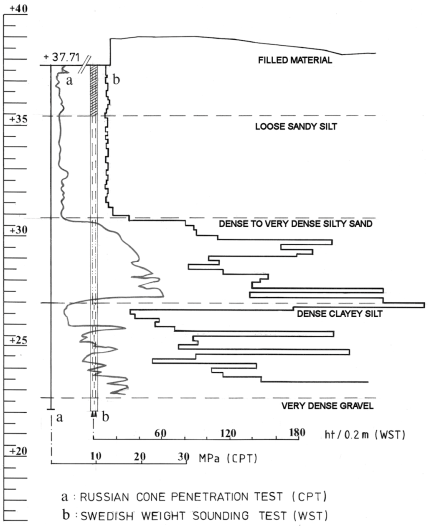

Figure 3. Russian cone penetration test (CPT) and Swedish weight sounding test (WST). Soil exploration results at sample point near the church wall.

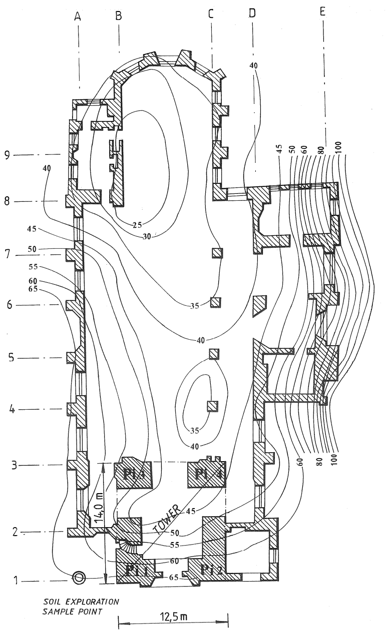

Figure 4. Contour lines of settlement (mm) in the area of the church during the years 1963-87 [2]. Line A is on the left-side without roof, columns on the line B, where the burial chamber is located, had to be rebuilt.

As the result, the wooden rafts had begun to rot, thus accelerating the sinking process. The settlement map in the church area for the period from 1963 to 1987 is shown in Fig. 4 as contour lines foundations of the tower and was mainly executed in 1993-94.

To stop the sinking of the church, the foundations were strengthened during the years 1993-96. The work began with strengthening. The last supporting structures and concreting work pouring for the tower were executed at the beginning of 1995 [3]. The other parts of the church foundations were strengthened in 1995-96. The foundations of the choir were not underpinned since they lie on hard soil and were not considered to be in immediate need of strengthening.

4 UNDERPINNING METHODS

The foundations of the church were underpinned by piling, using jacked piles and drilled spiral piles. These pile types were employed because in its present state the building would not tolerate the vibrations of driven piles. The layer of dense to very dense silty sand starting at app. 6 m below the old foundation level was chosen as the bearing stratum. The reason for that choice was that the first 4 -5 m layer of loose sandy silt did not have enough bearing capacity. Additionally, the old block foundation could not have withstood the greater forces which would have been needed to jack piles through the compact silty sand layer.

The piles were embedded in the soil by twirling. The joints of the spiral drilled piles were made by welding the parts together and jacking them. The completed piles were filled with concrete. The total length of the piles on axis A varied from 5.5 m to 6.5 m. A practical and simple technique and equipment was devised to enable the assembly of the spiral drilled piles by screwing in very limited workspaces. All the parts of the necessary equipment could be equipment could be carried by workmen Fig 5.

Figure 5. Simple screw driving equipment for drilled spiral piles.

5 WORK DESCRIPTION OF DRILLED SPIRAL PILES

Underpinnings at lines A and B were made with drilled spiral piles. Because of the lack of a suffcient counterweight of the spiral piles in line B, the work was different from that of the line A. In the line A the walls were pre-injected with a water-cement-peipsisand mixture. In the first stage the pile locations were jetted and the piles were screwed as deep as possible because of adequate torque moment of the equipment. Reinforced concrete beams were cast on both sides of the wall above the piles, against an injected stone composition; see Fig. 6.

The concrete beams were forced against the old structure with prestressed anchorage. As the timber material of the plank foundations rots, all the vertical loads will gradually be taken on by the piles. At line A, the piles also counteract lateral loads (Fyk) and moments (Myk) from the rebuilt arch. The lateral load is Fyk = 51 kN and the moment Myk = 624.5 kNm. In line A, three piles of 340 KN allowable load each, and two piles of 360 KN outside the line work in combination. The lateral load of 10.2 kN for each pile is neglected in the design considerations.

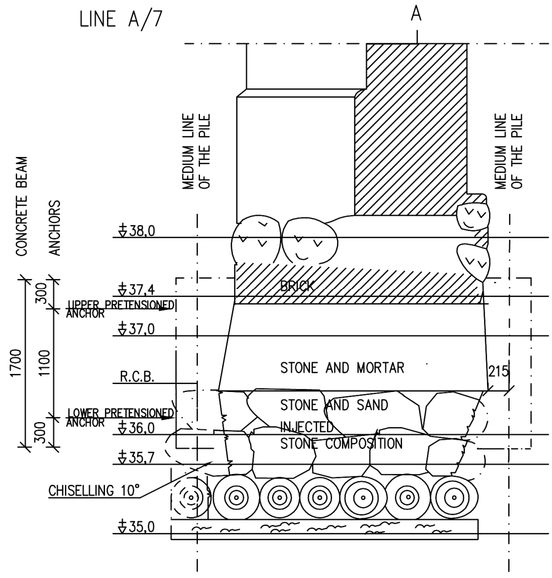

Figure 6. Section in the line A, the injected stone composition, lower and upper pretensioned anchors and beams. Chiseling was required prior to fabricating the concrete beams for them to carry the load to the piles from superstructure.

The drilled spiral piles under the concrete beams were test-loaded, pretested and end-jacked subsequently wedged against them. The steel wedges were embedded inside concrete. The second pretesting sequence was carried out six months later to eliminate any loss of prestressing force resulting from the creep effect in the previously injected stone foundation. After renewals of prestressing, the drilled holes were injected with cement mortar and concrete was cast on the anchor clamps. The sequence of the work on line A is shown in Fig 7.

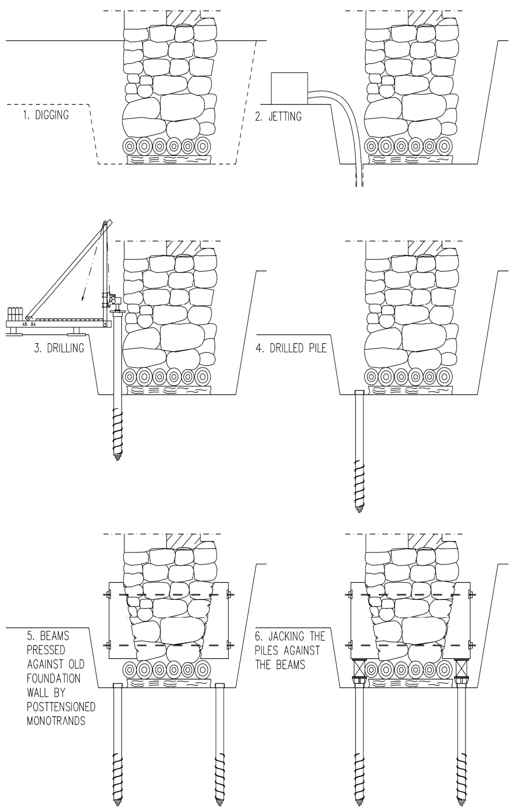

Figure 7. Working phases of drilled and jacked spiral piles.

The sequence of the work on the line A (part of the work could be done simultaneously)

1. Digging, first outside, then inside
2. Injection of wall day 1erection of pipes and shotcreting by hand; day 2: waiting for shot creting to mature; day 3: injection of lower part; day 4 injection of upper part
3. Preparation of piles locations and cutting
4. Jetting of pile locations and installation of piles
5. Torquering the pile step by step
6. Boring of openings for anchors
7. Chiselling of the old stone foundation
8. Casting of concrete beams
9. Prestressing of the concrete beams together
10. Jacking the piles with special pretesting procedure in line A in incremental loading steps at 15 minutes intervals
11. End jacking procedure

The pretesting procedure is illustrated in diagram in Fig. 8, which also includes the end jacking procedure. The pressure was held constant for 15 minutes at each step and the settlement was measured at 3 intervals (5, 10, and 15 min). When the pressure of 450 bar (644 kN) decreased in 5 minutes by less than 50 bar (72 kN) to 400 bar (572 kN), the end jacking could start.

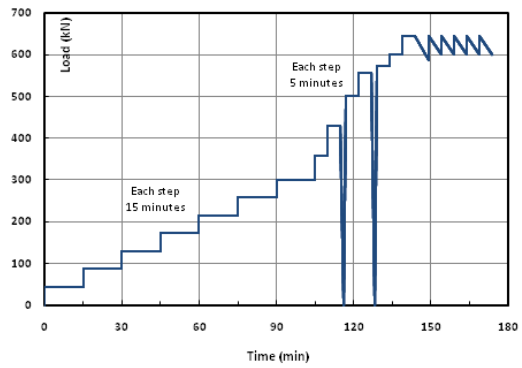

Figure 8. Time intervals for test loading of each of the drilled spiral piles in the line A.

All of the installed drilled spiral piles went through the pretesting procedure with end jacking to ensure their functionality. An example of the pretesting and end jacking procedure of special tested piles Nos. 220 and 222 are presented in Fig. 9.

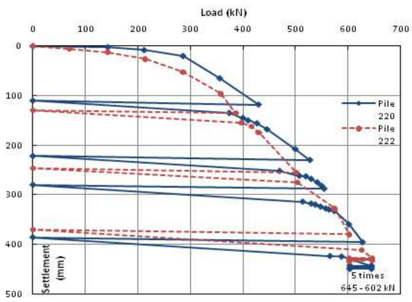

Figure 9. Load-settlement diagrams of drilled spiral piles Nos. 220 and 222 showing the repeated load cycling between 645-602 kN and end of pretesting procedure in the line A.

The soil layer, from dense to very dense silty sand, has about the same thickness (~ 4 m) but the upper level of the layer is slightly inclined. The area surrounding the church has in praxis the same geological strata. The outcome of the procedures with piles Nos. 220 and 222 indicate that using the same pretesting and end jacking procedure of the piles in line A, the allowable maximum load can be 400 kN. The safety factor gamma defined in DIN 1054 is 1.56.

$$\gamma = \frac{602\,\text{kN} + 645\,\text{kN}}{2} \cdot \frac{1}{400\ \text{kN}} = 1.56 \quad (1)$$

The allowable load above is less than the creep load Qc = 525 kN (Fig. 10). The safety factor of creep is then

$$\gamma = \frac{525\,\text{kN}}{400\ \text{kN}} = 1.31 \quad (2)$$

The used allowable load on the spiral drilled piles that were installed was 375kN.

6 SETTLEMENT OF DRILLED SPIRAL PILES

Based on the load settlement diagrams of the tested drilled spiral piles the author noticed that without his pretesting and end jacking procedures the settlement in line A could have been approximately 25 mm. This can be noted from the settlement diagrams in Fig. 9.The surveying results from 21st October 1995 up to 9th June 2011 confirm that the pretesting and end jacking procedures worked well since there is no noticeable settlement in line A. It is therefore verifiable that the procedure is suitable for the dense to very dense silty sand layers of Tartu. One of the levelling points (No. 3) was noted to have risen, probably due the settlement in the strata of the tower. The maximum settlement during the period above mentioned is 5 mm ± 2 mm.

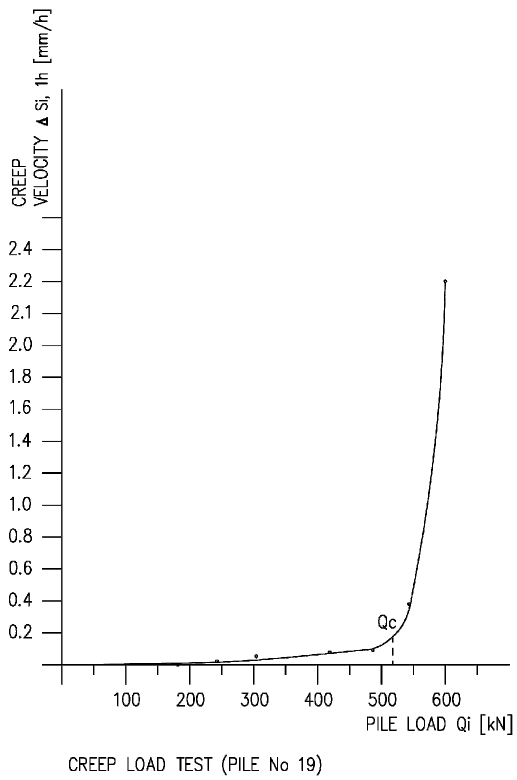

Figure 10. Creep velocity in the creep load Q_c is the load (pile no 19), which the curvature of the diagram corresponds to the minimum radius of the curvature in HGT.

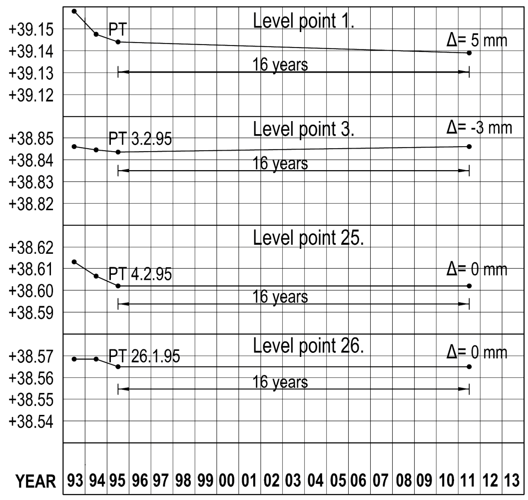

Figure 11. Data from line A: diagrams on 1993, 1994 and 1995. Pretesting and end jacking date (PT). Data added from the monitoring in 2011.

7 CONCLUSIONS

Every installed drilled spiral pile was test loaded using special pretesting and end jacking procedures. According to these, all piles function well in their respective position. The functional success of the drilled spiral piles in St. John's Church also was proven by the fact that the settling of the church has ceased. The strengthening method described in this article can be successfully employed in strengthening the foundations of other heritage structures. The methods can be applied in challenging circumstances, because of the low costs, the portability of equipment and minimal workspace requirements. The drilled spiral piles can be installed where limited space is available.

The low level of investment needed to implement this method also makes it well suited for developing countries. The jetting is used to investigate if there are any boulders in the soil. It helps for drillings and to have the pile in the right direction. The main machinery involved in the installation can be placed outside the workspace. The employed drilled spiral pile is practical for strengthening of historical foundations. Neither injection nor vibrations are involved.

Figure 12. St. John´s Church was opened for visitors in May 2005 and the reopening ceremony of the church was held on 29 June 2005.

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