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# Strengthening and underpinning of stone foundations of St. John Church in Gdańsk

Renforcement et reprise par pieux des fondations pierreuses d'église de St. Jean à Gdańsk

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**ABSTRACT:** The St. John church in Gdańsk, almost 600 hundred years old, has been constructed on weak organic soils. Available records describe numerous attempts to improve the foundations and to stop the observed settlements. In the framework of a recent restoration programme it was decided to conduct underpinning and strengthening of the stone foundations at the eastern part of the church, where significant settlements and horizontal displacements occurred. For technical and economical reasons jet grouting technique was applied. Presented are design considerations, execution of the work and control measurements, with special emphasis on heavily loaded pillar foundations.

**RÉSUMÉ:** L'église de St. Jean à Gdańsk de six cents ans est construite sur sols organiques mous. Les données historiques disponibles contiennent la description des nombreuse tentatives d'amélioration de fondations et d'arrêter des tassements observés. Dans le cadre du programme courant de la restauration du monument, il est décidé de soutenir et de renforcer des fondations en pierre dans la partie est de l'église, où des importants tassements et des déplacements horizontaux se sont produits. Pour des raisons techniques et économiques la méthode de jet grouting est appliquée. Nous présentons des considerations du projet, l'exécution des travaux et les mesures du contrôle avec une attention particulière consacrée aux fondations des piliers transmettant des charges considérables.

## 1 INTRODUCTION

The St. John church in Gdańsk has a long and interesting history, also from the geotechnical point of view, and belongs to oldest buildings in this town (Fig. 1).



Fig. 1 St. John church in Gdańsk (1995).

A small chapel, build between 1357-1358 in the vicinity of the present tower, was changed during 1460-1465 into a large church made of bricks, which now covers an area of about 2150 m<sup>2</sup>. The central nave, 55 m long and 11 m wide, is supported on 14 pillars. The four main pillars located at the crossing with the transept have above the floor level a cross section of 8.35 m<sup>2</sup> and carry a dead load of about 3700 kN. The remaining 10 pillars have a cross section of 3.4 m<sup>2</sup> and carry a dead load of about 1650 kN. The side walls have an average thickness of 1.4 m and are loaded with about 450 kN/m. The layout of the eastern part of this church, where the described jet grouting works were finally conducted, is shown in Fig 2.

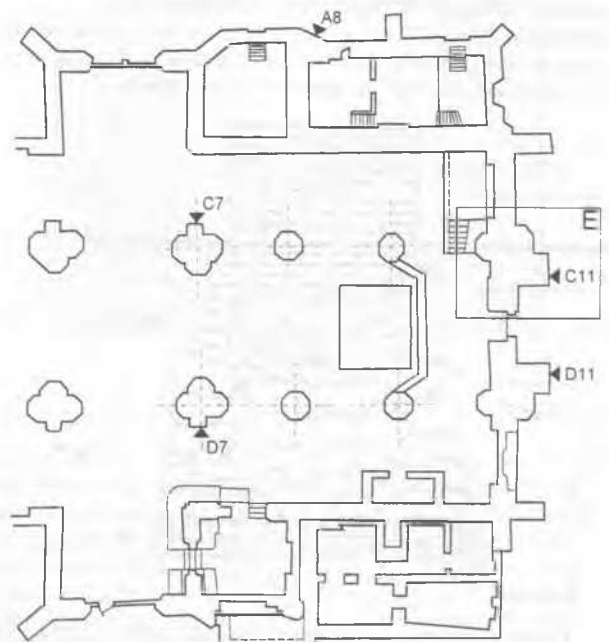


Fig. 2 Layout of the eastern part of the St. John church.



Fig. 3 Side view of excavated foundation wall (1995).

The St. John church has been founded on a very weak subsoil, containing peat and organic silt layers below a thin fill layer at the surface. Initial foundation works started with excavation of the top layer of soil up to the groundwater level, since dewatering techniques were not available at that time. Gravel, stones and weak mortar were subsequently placed inside wooden formwork, which was pushed into the peat layer. On this support stone foundations for church walls and pillars were constructed. A photograph taken from a recent excavation pit at the south site wall of the church shows wooden beams at the depth of about 4.5 m and overlying stones of the foundation wall (Fig. 3).

Due to high loads transferred to the subsoil serious stability problems and uneven settlements occurred soon after, particularly with the pillars. Available records describe numerous „engineering” attempts to improve the foundations and to stop the settlements. Some of these attempts were very advanced and included, in the period of 1640 to 1680, even a total replacement of few foundation pillars, as shown in Figs. 4 and 5.

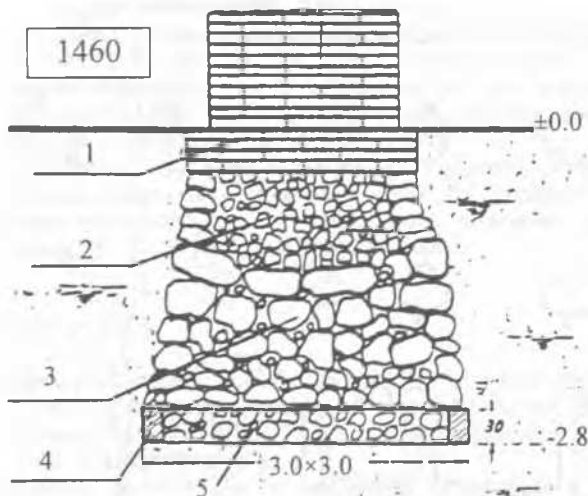


Fig. 4 Initial construction of the foundation under a pillar: 1- bricks and lime mortar, 2- small stones, brick pieces, lime, 3- bigger stones without lime, fill, 4 - wooden box, 5- field stones with clay (Bukowski, 1948).

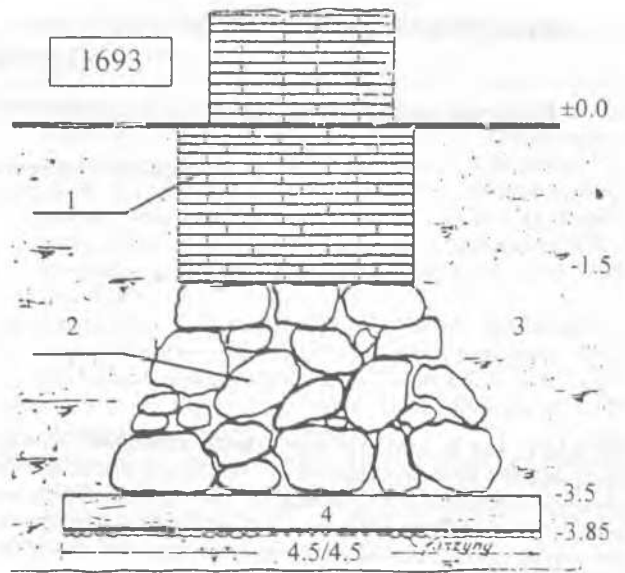


Fig. 5 Rebuild foundation under a pillar: 1- bricks and lime mortar, 2- large stones and lime mortar, 3- refill (sand and peat), 4 - wooden beams on fascine mattress (Bukowski, 1948).



Fig. 6 Cracked pillar pedestal in the eastern part of the church (1995).

All these difficult and challenging engineering works could not, however, stop further excessive settlements. It has been estimated that total vertical displacements could reach about 75 cm from the beginning of church construction. Particularly difficult situation occurred at the eastern wall behind the altar, which started to tilt. In 1679 the horizontal displacements observed at the vault level reached nearly 100 cm (Bukowski, 1948). The outward movement of this heavy wall, transmitted to two rows of pillars through the vault structural elements, caused also significant displacements of six adjacent pillars, which additionally experienced lateral movements at the floor level in the order of 25 to 50 cm. As a countermeasure two buttresses founded on wooden piles were quickly build at the outer side of this wall and the roof in this part of the church was reconstructed and unloaded. Later on this church was also many times burned and damaged, particularly during the second world war, and subsequently partly repaired. Its technical condition became however steadily worse and worse (cf. Fig.6).

In 1995 it has been decided to start restoration of the St. John church, which should become a place of cultural meetings and exhibitions. In the first stage underpinning and strengthening of old foundations at the eastern side was necessary. For technical



Fig. 7 Cracked stone foundation of a single pillar

and economical reasons the jet grouting technique (soilcrete) was applied, while experience gained during this unique project is outlined in the following.

## 2 SOIL CONDITIONS

The subsoil at the eastern part of the church consists of a loose sand fill, underlined by peat and organic silt and dense sands at the bottom. The fill contains occasionally bricks, stones and wooden elements and has a thickness of about 3.2 to 4 m, counting from the floor level. The peat layer is about 1 m thick on the left side from altar and increases in the central part and on the right side to about 2.5 m. Peat is medium to well decomposed and has organic content of 30 to 60%. The moisture content is between 170 to 240 % and the vane shear strength lays between 25 and 100 kPa. The silt layer, with organic content below 15%, is in most cases well compressed and has a thickness of 1 to 2 m. Peat and silt build together organic complex of considerable thickness of 3 to 4 m. In the underlying dense sands there is a groundwater flow towards the river Motława, which flows parallel to the church eastern wall at a distance of about 100 m. In the investigation borings and piezometers the groundwater level raises up to 3.3 m below the floor level.

## 3 UNDERPINNING WORKS

The jet grouting underpinning works were conducted under 4 smaller pillars close to the altar and two main pillars C7 and D7, as well as under the adjacent outer walls (see Fig. 2).

The most difficult works were executed under the pillars, which carry not only high load but also have experienced vertical and horizontal displacements. Therefore it was assumed in the design that the remediation should lead to improvement of the bearing capacity in vertical and horizontal direction and to strengthening of the foundations. The latter became especially important after recognition that some of the foundations had rather wide cracks, extending to a significant depth below the pedestal (Fig. 7).

The jet grouting works started with execution of primary soilcrete elements around the expected periphery of the foundation, determined by old drawings and additional trial borings. The objective was to form a kind of soilcrete "box" around the founda-

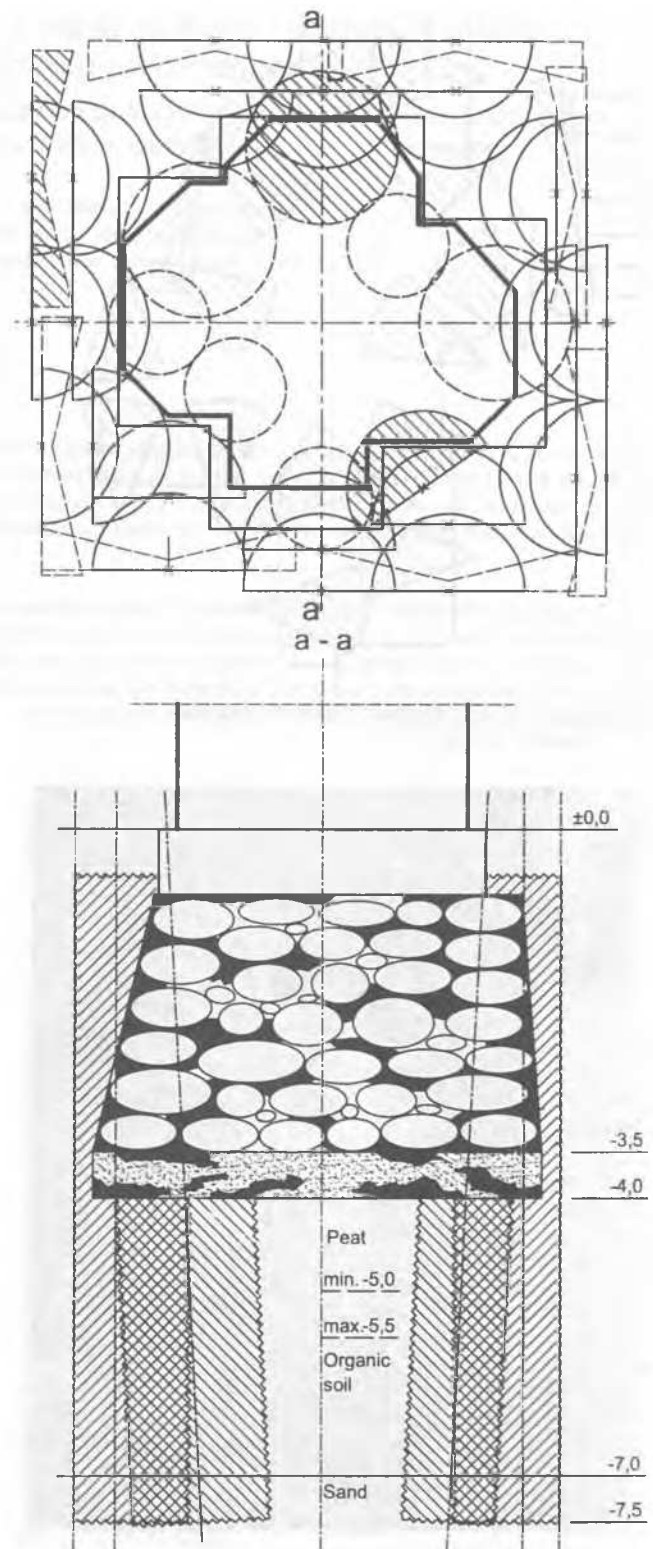


Fig. 8 Layout of soilcrete elements under a pillar C7

tion prior to any attempt to install columns directly under the pillar. These side elements were executed at the bottom part as panels, e.g. in case of pillar C7 between -4 and -7.5 m, and as half columns above the foundation level (Fig. 8). This was achieved by pulling of the drill rod without rotation to create a panel and subsequently by swiveling the rod 90° in the upper part. In this way the conical walls of the foundation were surrounded by soilcrete and the loose stones were fixed.

At the second stage inclined core drillings of 150 mm diameter were made through the pedestal and stone foundation. This op-

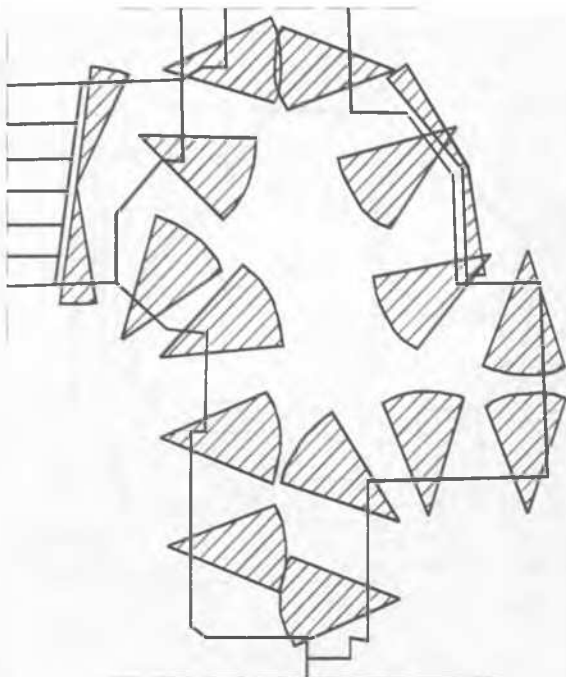


Fig. 9 Layout of soilcrete elements under the east wall (detail E, see Fig. 2)



Fig. 10 Soilcrete works in a limited space in cellar

eration required special equipment and skill of the operator, especially when loose fill was found between large stones. Once the drilled wholes were completed cement grout was injected under pressure to fill all possible cracks and voids. Then the secondary soilcrete columns were made. Under the outer walls special sector elements, the so-called wings, were applied from both sides of the wall (Fig. 9). With this advanced technique it was possible to assure sufficient support of the foundation without drilling through the stones. At the west wall the work had to be partly conducted in cellar using special drilling unit (Fig. 10). Altogether 489.4 m<sup>3</sup> and 541.8 m<sup>3</sup> of soilcrete elements under pillar and wall foundations, respectively, have been installed.

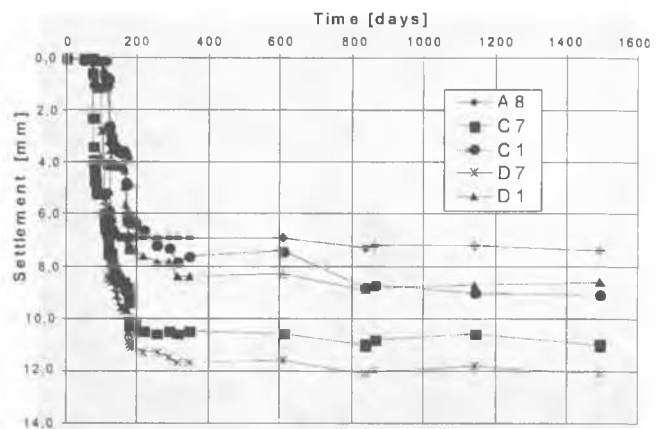


Fig. 11 Settlement recorded during and after underpinning works at 5 reference points indicated in Fig. 2 (Zurowski et al., 1995-2000)

#### 4 CONTROL

Before, during and after underpinning works precise geodetic measurements were conducted (Zurowski et al). Figure 11 shows sample data obtained during almost 5 years of observation. The selected curves refer to observation points indicated in Fig. 2 and demonstrate the subsequent phases of underpinning works. Execution of soilcrete elements within roughly 150 days induced limited settlement of the foundations, while the settlement rates for secondary soilcrete elements are generally smaller than for the primary ones. The subsequent parts of all settlement records, referring to the state after completion of the underpinning works, indicate fairly stable behaviour of all foundations within the period of almost 3 years.

Despite of organic soils in the subsoil high strength of soilcrete samples was obtained, ranging from 5.4 to 16 MPa.

#### 5 CONCLUSIONS

Underpinning of old stone foundations, including individual pillars carrying high loads, represents a challenging project of high complexity and requires experience and flexibility in the design as well as careful execution of the work in particular. The jet grouting technique proved not only to be extremely flexible in application under single and strip foundations but also attractive from the financial point of view.

#### 6 ACKNOWLEDGMENT

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