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Preservation of Saint George's Church at Cairo, Egypt

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Abstract

Saint George's church is characterized as one of the most important monuments of Greek Orthodoxy heritage at Egypt. The church is a unique and massive building complex combining the elements of a number of different structural systems constructed at different periods of time. More specific, there were three major periods of construction that influence present behavior: Roman period, 1909 construction and 1941 reconstruction. Although the subsurface conditions are not very favorable (man-made materials with significant thickness), this paper presents the ability of the building to resist the potential impacts caused by dewatering operation taking into account the prevailing geological and geotechnical conditions, since cracks and local failures were observed mainly during the fluctuations of Nile River and during the dewatering process. Finally, the estimated settlements from previous reports were reconsidered and monitoring methods recommended.

Keywords

Saint george • Egypt • Dewatering • Settlement • Monitoring

13.1 Introduction

The Saint George Church at Mar Girgis area, Cairo, Egypt (Fig. 13.1), is a unique and massive masonry building complex combining the elements of a number of different structural systems constructed at different periods of time. Portions of the existing structures, particularly those lying within the cylindrical portion of the church, are believed to have been erected during Roman times, but the foundation elements that were encountered suggest even earlier Pharonic workmanship at the lower levels. The first written references to Mar Girgis monastery occur in the 14th and 15th centuries; however, the Greek Orthodox community had presence in Old Cairo from 5th century. The three major periods of construction that influence present behavior are as follows: Roman period, 1909 construction and 1941 reconstruction (extensive demolition, construction of new exterior wall and restoration of many interior surfaces).

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13.2 History and Pathology of the Monument

The circular Roman tower is one of the most fundamental elements of the church. It was constructed in masonry and measures 28.6 m in diameter and was built

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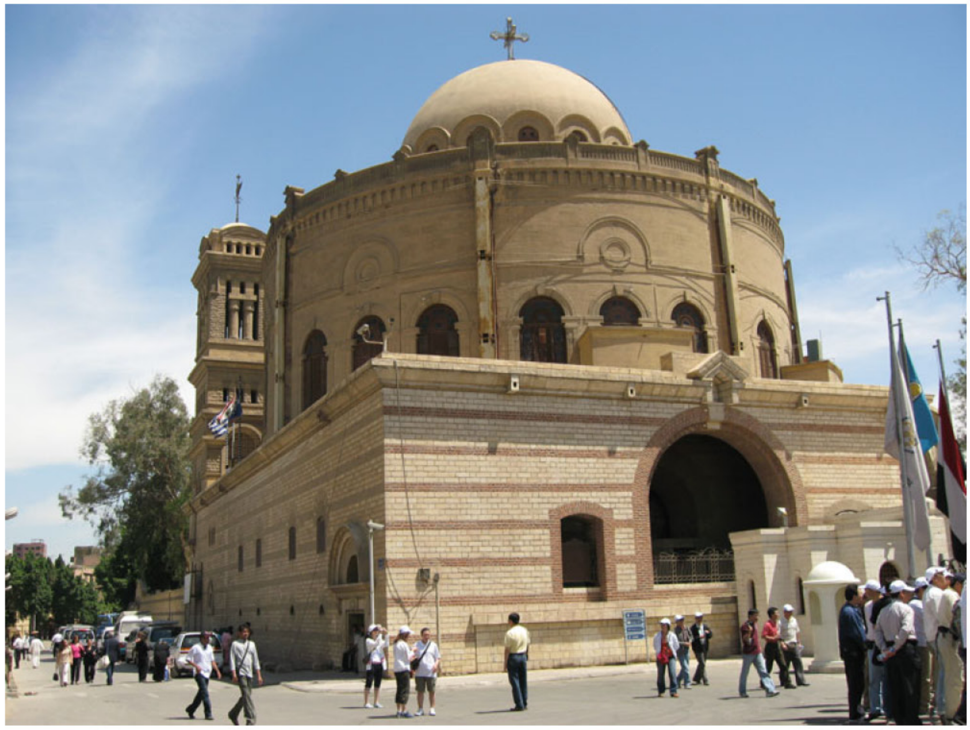

Fig. 13.1 View of the Saint George Church at Mar Girgis area, Cairo, Egypt

immediately adjacent to the Nile River. The foundation is believed to have been constructed on native dense alluvial sands, silts and clayey soils, during the low water periods of river flow. The tower carries loads due to the massive thickness of the walls as well as to the addition of cross walls.

The central elevated dome and its associated walls, built above the present level of the upper terrace, are supported by series of arches that span to a circular colonnade. The flat portion of the roof is carried on a vaulted arch system, while the vault loads are transferred to the inner colonnade and the main exterior rotunda walls. The entire building rests upon a concrete slab located at terrace which in turn transfers all loads to the Roman structure below.

During the third period of construction, structural modifications have been performed using a hard cement mortar. According to CDM report (2002) the masonry church structure is judged to be at moderate risk to continued damage from any external movements caused by excessive construction vibrations, excessive differential settlements from ground water lowering or seismic events. From their point of view some areas of major concern are:

- The cupola window arches which are cracked through the entire thickness of the masonry arches.
- The ceiling of the hollow clay block vaulted roof is cracked around the peak of the vaults.
- The bases of six central columns have unsupported areas underneath them.
- The interior central core colonnade of masonry arches supporting the main sanctuary floor are slightly cracked due to stress concentrations.
- The eight cracked marble columns in the central well area that are supporting the intermediate period masonry above give the appearance of instability.

The internal ancient Roman stairway is suffering from deterioration and degradation.

13.3 Geotechnical Conditions

Three separate subsurface investigations in different time have been performed in the area of Saint George's church. Based on boreholes' findings and results from in situ and laboratory tests, the following geotechnical units encountered (CDM 2002).

Fill layer

This layer ranges in depth from 4.0 to 14.5 m below ground surface, while the average depth of fill is about 11.5 m below ground surface. The depth of fill is deeper north of Saint George's church and slopes gradually up towards the south. The fill is comprised of red bricks, asphalt, timbers, gravel, sand, and fines.

Stratum 2

This layer was encountered in all boreholes at Saint George's church. All boreholes were ended in Stratum 2, while its thick was over 13 m in places, and its depth was significantly deeper than other areas in the city of Old Cairo. This layer was comprised of very loose to dense, yellowish to brown and grey, silty—clayey sand with gravel, limestone fragments and clay in some places. According to Unified Soil Classification System (USCS) this layer characterized as silty sand with no cohesion. In CDM's report stratum 2 divided in two sub-stratums: 2a which is presented as cohesive and 2b which is presented as non-cohesive.

Limestone layer

This layer was not encountered in any of boreholes in Saint George's church area and estimated to be significant deeper in this area than other parts of Old Cairo.

Some of the physical properties of the aforementioned geotechnical units are presented to Table 13.1 as results from laboratory tests.

Groundwater table encountered at each borehole during drilling, its depth fluctuated from 6 to 7.50 m below ground surface. Water readings measured in boreholes should not necessarily be considered to represent stabilized groundwater levels, while water levels are expected to fluctuate seasonal.

13.4 Groundwater Lowering

The existing high groundwater level in the Old Cairo area has flooded lower floor levels of some ancient structures. The Contract 102 (Johnson and Malhotra 2000) groundwater control system has been constructed to lower the water table below that floor levels. The groundwater control system consists of groundwater lowering elements and discharge elements, which namely are: (a) perforated shafts, (b) filter walls adjacent and connected to the perforated shafts, (c) horizontal perforated drainage systems below building floor, which will discharge to collection shafts or to the closest perforated shafts, (d) discharge pipes installed using micro-tunneling technique, and (e) shafts collecting the water from the horizontal drains.

The entire groundwater control system operates by gravity flow, thus pumping is not required to discharge the water into the main sewer. CDM refers that the groundwater will typically be lowered within fill layer, which is a non-homogenous material with a wide range of grain sizes. The CCJM (Johnson and Malhotra 2000) design calculations of the groundwater control system were based on using a range of permeability. The highest permeability assumed was 1.5×10^{-4} m/s and the lowest permeability was 4×10^{-5} m/s. CDM design calculations were based using permeability equal to 4×10^{-5} m/s.

Table 13.1 Mean values of physical parameters of geotechnical units

Soil type	LL	PL	W %	Fines %	γ_d, kN/m^3
Fill	44	15	40	36	17.56
Stratum 2a	41	17	34	75	18.20
Stratum 2b	–	–	23	23	19.72

In order to calculate the radius of influence for various drawdowns as well as coefficient of permeability the following equation was used:

$$R_0 \sim C * h * k^{0.5} \quad (13.1)$$

where R_0 is the radius of influence, C is a factor equal to 3,000 for radial flow to pumped wells (simulation of perforated shafts) and between 1,500 and 2,000 for line inflow to trenches or to a line of wellpoints (simulation of filter walls), h is the drawdown in meters and k is the permeability (m/s). Table 13.2 presents the radius of influence for various drawdowns and permeability values.

13.5 Estimation and Monitoring of Settlements

For Saint George church and according to Contract 102 (Johnson and Malhotra 2000) it was decided a maximum drawdown of 2.5 m below the present average level. According to CDM's report (2002) the Old Cairo area has historically flooded periodically before the construction of the Aswan High dam on the Nile River. These floods caused loading and unloading of the soils for at least decades up to hundreds of years as the vertical effective stresses in the soil changed with the rising and falling waters. Finally CDM concluded that the maximum settlements varied from 0.7 to 0.9 cm for the most realistic cases. It has to be considered that parts of the church are founded on shallow depth,

Table 13.2 Radius of influence for given drawdown and coefficients of permeability

Drawdown (m)	Permeability k (m/s)	Type of drawdown	R_0 (m)
2	4×10^{-5}	Perforated shafts	38
2	4×10^{-5}	Filter walls	19
2	1.5×10^{-4}	Perforated shafts	73.5
2	1.5×10^{-4}	Filter walls	36.7
3	4×10^{-5}	Perforated shafts	57
3	4×10^{-5}	Filter walls	28.5
3	1.5×10^{-4}	Perforated shafts	110
3	1.5×10^{-4}	Filter walls	55
5	4×10^{-5}	Perforated shafts	97
5	4×10^{-5}	Filter walls	47.5
5	1.5×10^{-4}	Perforated shafts	184
5	1.5×10^{-4}	Filter walls	92

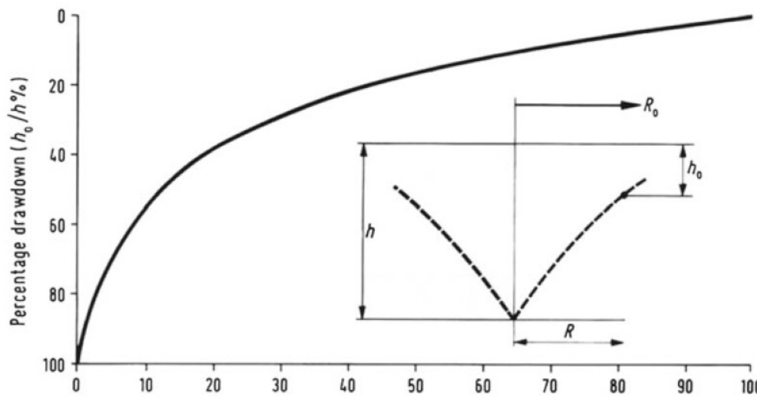

Fig. 13.2 Relation of drawdown to distance from centre of cone of depression (CIRIA 1986)

although the inner part of the church is built on remnants of a Roman tower. This tower has a deep foundation in significantly deeper soils than the foundations of the outer structures. The foundation of the tower is not expected to experience settlements, while for the very conservative case, differential settlements of less than 10 mm may occur, between the deeply founded interior and the shallower founded exterior structures of the church.

Based on various theories for the estimation of settlements and calculate Young's modulus equal to 9 MPa for fill materials, while in a conservative approach the preconsolidation of fill material was not taken into account, the authors calculated settlements up to 9 mm at the areas of filter wall and perforated shaft. In certain distances from shaft and wall, various diagrams (Fig. 13.2, Ciria 1986), which relate the drawdown to distance from center of cone of depression, can be used.

Finally, after the termination of the groundwater lowering, differential settlements were observed between parts of the Roman Tower and the structures around the perimeter terrace. Those settlements were less than one centimeter and confirm not only CDM's calculations but also the abovementioned calculations.

Before the beginning of the renovation of the church, another monitoring program with additional Elevation Reference Points (ERPs) at the inner columns and walls of the outer circle of the Roman Tower and the 1941s additional structures should be performed. Readings should be taken weekly for a period not less than six months. In case of no additional movements the works of renovation will commence.

13.6 Conclusions

Saint George church is located at Mar Girgis area in the old city of Cairo, Egypt, and combines the elements of a number of different structural systems constructed at different periods of time. Since the existing high groundwater level has flooded the lower floor levels it was decided as part of a greater dewatering project to lower the water table. Therefore this paper presents the geotechnical evaluation of the encountered subsurface layers, as well as estimates the excepted settlements, which are in good agreement with the measured.

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