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3D FINITE ELEMENT ANALYSIS MODEL TO ACCESS THE SETTLEMENT OF SOFT SOIL TREATED WITH NANO-MgO

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Abstract

In this study, a numerical model was developed to assess the settlement and the damaging mechanism of an old masonry church Adormirea Maicii Domnului located in Perisoru village, Romania by using finite element software Plaxis 3D. The main aim of this research was to simulate the ground problems and the structural failures observed. The rectangular foundation is placed on yellowish silty clay-loess, which was modelled and analysed in the present paper. Mohr-Coulomb soil model was used for the soil and the linear elastic model was used for the foundation. After computing the settlements, it was resulted the need of improving the soil. The soil was improved with cement, but some nano materials were considered as well, as an alternative. The results showed that the value of the settlements reduced with an increase in the amount (0.5%, 0.75%, 1%, 2%) of the Nano-MgO. The results have been compared with the soil treated with 2 % cement.

***Key words**: historic structures, Nano-MgO, Plaxis 3D, settlement, soft soil.*

INTRODUCTION

In this study, a numerical model of geotechnical and structural problems was developed using finite element software, Plaxis 3D to assess the foundation settlements, that had been observed and recorded at a masonry historical Church Adormirea Maicii Domnului, located in Romania, Perisoru, 120 km east of Bucharest with coordinate (44°26'12.29"N, 27°32'43.76"E), which was built with area 200m^2 between (1937-1944) AD. The Church form Perisoru village (Calarasi County) has a cross shape and is distinguished by a special architectural beauty. The general dimensions in the plan are 27.40 x 15.50 m with a main opening of 8.75 m.

The height at the cornice is 7.65 m, at the dome of the main tower 20.85 m, and the maximum height with the cross is 23.34 m (elevations compared to the finished elevation of the interior floor +0.00 m, 72 cm higher than the elevation of the landscaped land). The walls are made of 75 cm thick brick masonry (27 x 13 x 6 cm bricks), connected with lime mortar. The roof is a wooden frame with sheet metal roofing. The structure of the towers is also made of brick masonry (alternating solid brick pressed with brick with vertical holes) with lime mortar, supported on a brick masonry pedestal that includes reinforced concrete. In masonry, bricks occupy 85% of the total volume while mortar represents 15%. The total amount of primary energy required to achieve a cubic meter of masonry was obtained from the sum of 85% of the embedded energy in bricks with the 15% of mortar energy (Dragomir et al., 2014).

The physical condition of the church is precarious: fractures, cracks, and fissures have been identified in the masonry, caused by uneven settlements. These settlements which are exceeding 30-40cm are mainly caused by the increase of groundwater table level in time. The roof sheet is corroded, and the water collection and drainage system are damaged. The vertical systematization of the land is improperly made, unfinished and damaged.

The rectangular foundation is placed on saturated yellowish silty clay, soft consistency (wetted loess) at 1.5 m depth from the ground surface. We had considered and applied an effective pressure of 200 kPa. The foundation is that part of a structure that transmits loads directly to the soil, a process known as soil-structure interaction. The foundation must be designed to have sufficient capacity or resistance to support the applied load and to

avoid any large deformation under these loads, which might damage the structure (Abdullah, 2022).
For many years the settlements did not cause any structural problems. One may consider that the consolidation process took place, and no problems were recorded. After heavy irrigation in the area, an increase of groundwater table level had been recorded; the additional water wetted the loess layer and caused additional settlements to many buildings in the area, including the church. After that, a monitoring report showed settlements larger than 30 cm and, most important, showed no decrease in the settlement's incremental evolution. This put in danger the use of the church safely. For this reason, we had studied the option to improve the soil under foundations.

History of the church
In 1927, a monk priest named Galaction Negulescu was sent from Gheorghe Lazăr commune, lalomiţa. In less than a year, he managed to set up a religious committee with which he raised funds and initially bought a 318 kg bell. In December 1929, he was ordained and appointed the first ordained priest Dojan G. Nicolae. He reorganized the old church committee and began raising funds to build a new church. 250,000 bricks were made; an estimate and a plan for a church with three cross-shaped towers were drawn up by the engineer Napoleon Constantin essay, according to the type of the Holy Archbishopric of Bucharest (Figure 1).
In 1936, the foundation stone of today's monumental church with an interior area of 200 square meters was laid. In 1937, the plan of the church was redone by the diplomat architect from Paris, Pândele Şerbănescu, and the construction works were completed in 1944. The church was consecrated on 11 of November 1946 (http://www.biserici.org).

Figure 1. Front and side view of the church (photocopy after Church plans, 1927)

MATERIALS AND METHODS

In order to characterize the soil stratification were performed geotechnical boreholes at 20m, the boreholes were located in the area of the church. Based on the field investigation, the following overall stratification is noted:
Layer 1 - Topsoil soil: this layer has a thickness of about 0.5 m;
Layer 2 - Cohesive complex, this layer is made of yellowish silty clay, soft (wetted loess), and has a thickness of about 9.0 m;
Layer 3 - Non-cohesive complex, this layer is made of fine to medium dense sand and has a thickness of more than 10.0 m. The groundwater level was found at -3.0 m from the natural ground level.
In order to establish the depth of the

foundation, a test pit was dug at the foundation of the church, according to that found the depth of the foundation was equal to 1.2 m, the foundation was made from concrete and does not show any degradation, the foundation is placed on soft silty clay (wet loess).
The area is known for the presence of loessoid deposits which are water sensitive. Their thickness may easily exceed 10 m, in Perișoru area. The main reason for problems of the structural failure element (Figure 2) is the rising in the groundwater level, in addition, most of the existing buildings were built during this period when seismic action was not considered in the design, so they were built from the beginning by traditional methods and designed only for rapacious actions (Hemeda, 2019).
Some geotechnical laboratory investigations were done in this research on the soil samples that were obtained from the study area.
In order to establish the optimal foundation solution, an essential geotechnical property is the compressibility of the foundation soil (Olinic et al., 2021). A set of laboratory tests were done on the soil samples to get the numerical model of the soil (Al-Rubaye Ahmed, 2021). The tests were performed on not treated soil and on treated soil with various percentages of nano MgO. Results are shown in Tables 1 and 2.

Figure 2. Deformations and cracks on the Brick Walls of Church Adormirea Maicii Domnului, Perisoru

Figure 3. Deformation and Cracks in the Different Structure inside the Church Adormirea Maicii Domnului, Perisoru

Table 1. Oedometer modulus Eoed (kPa) of the soil samples

Type and percent of additive	Non treated soil	0.5% nano-MgO	0.75% nano-MgO	1% nano-MgO	2% nano-MgO	2% cement
Oedometer modulus E_{oed}, (kPa)	4080	5900	6490	7870	9660	11000

Table 2. Results of direct shear tests for soil samples treated with a different percentage of nano-MgO

Type and percent of the additive	Internal friction angle (Φ’)	Cohesion (c’), kPa
Non-treated soil	16°	15
0.5% Nano-MgO	16°	15
0.75% Nano-MgO	19°	14
1% Nano-MgO	20°	20
2% Nano-MgO	22°	28

RESULTS AND DISCUSSIONS

In this study, Plaxis 3D software was used to determine the behaviour of the wetted yellowish silty clay and the old masonry structure of the church

Numerical modelling for the rectangular foundation by using FEM 3D software was done. The applied load from the superstructure was added to 200 kPa on the foundation, the water is located -3.0 m deep. This study aims to assess the total settlement of the soil by

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stimulating the rectangular foundation of the church in six cases.

In the current situation (when the foundation is placed on natural soil), the results of the numerical analysis of the church show that some of the surface settlement occurs during the construction period, and because of the rising water ground-level, the displacement in and surrounding the soil and foundation developed and increase above the maximum value of about 27.14 cm (Figure 6.a.). Each soil acts differently depending on its mineralogical and granulometric composition: for this reason, there is no 'recipe' for the improvement of difficult soils (Ivasuc et al., 2015).

In order to see the importance of soil improvements technologies by mixing, simulations were performed when foundation soil differs. The settlement (Table 3, Figure 6) was calculated when the foundation soil was improved (when the compressibility parameters differ - Table 1).

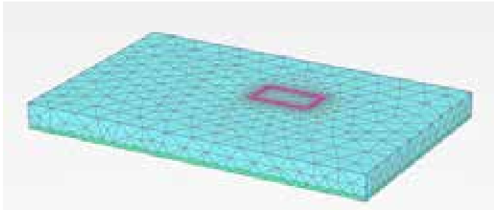


Figure 4. Typical Finite Element mesh adopted for numerical analysis

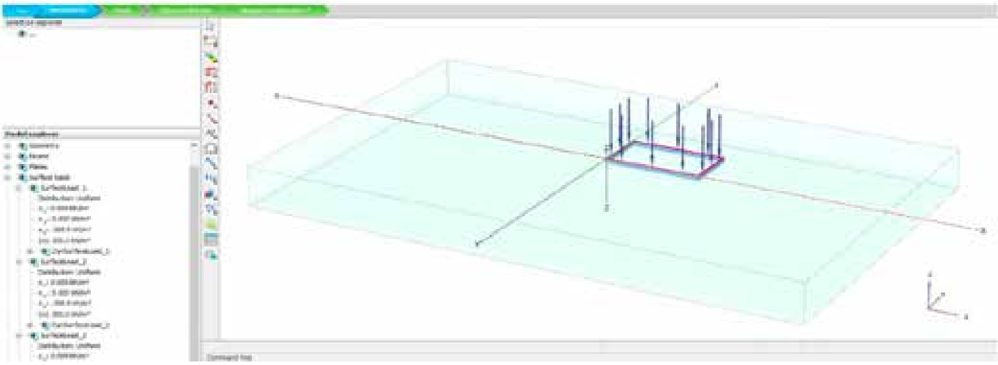
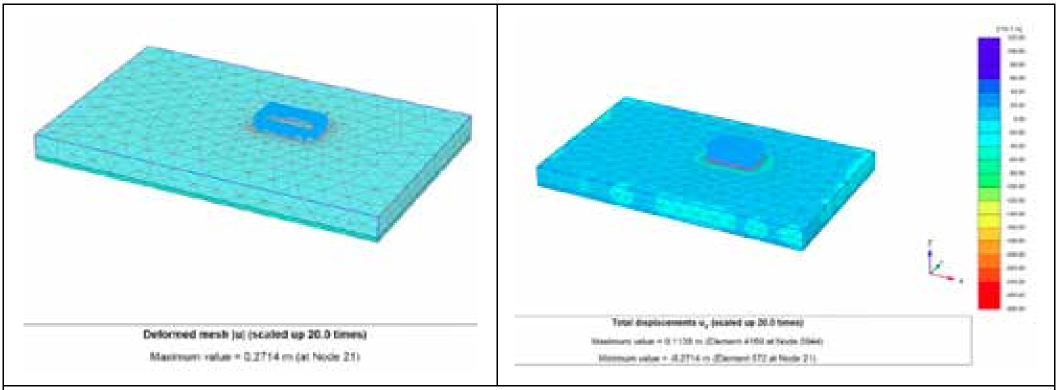


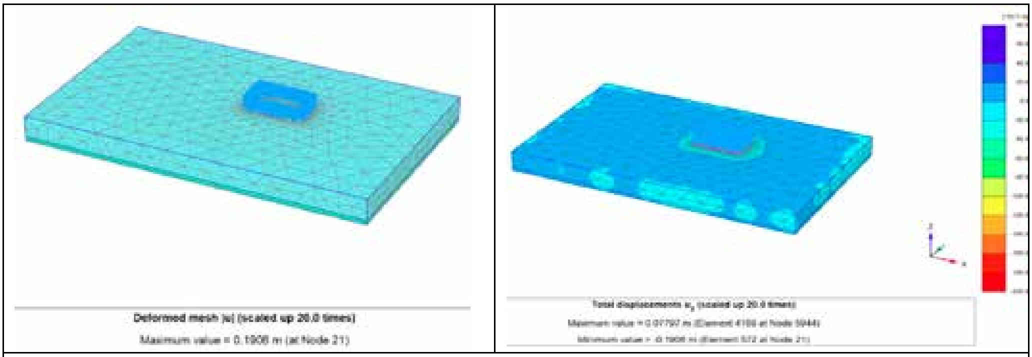
Figure 5. The applied distribution load of 200 kPa from the structure on the soil

Table 3. The value of the settlement for soil samples treated with a different percentage of nano-MgO

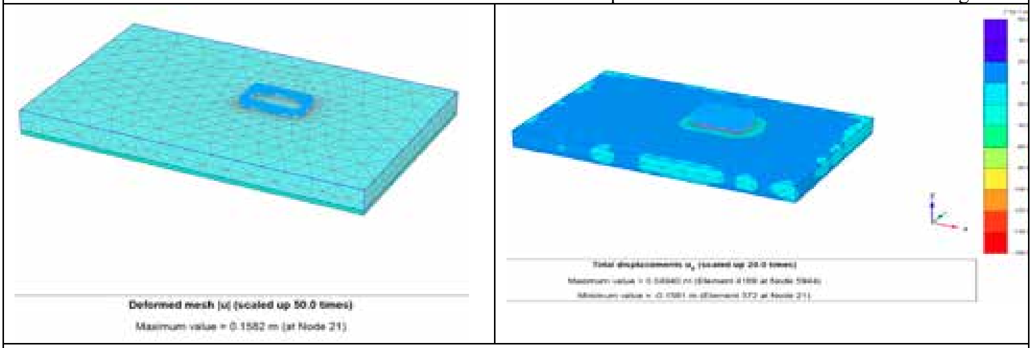
Type and percent of additive	Non treated soil (cm)	0.5% nano-MgO (cm)	0.75% nano-MgO (cm)	1% nano-MgO (cm)	2% nano-MgO (cm)	2% cement (cm)
Settlement	27.2	19.1	15.8	10.6	8.0	6.0



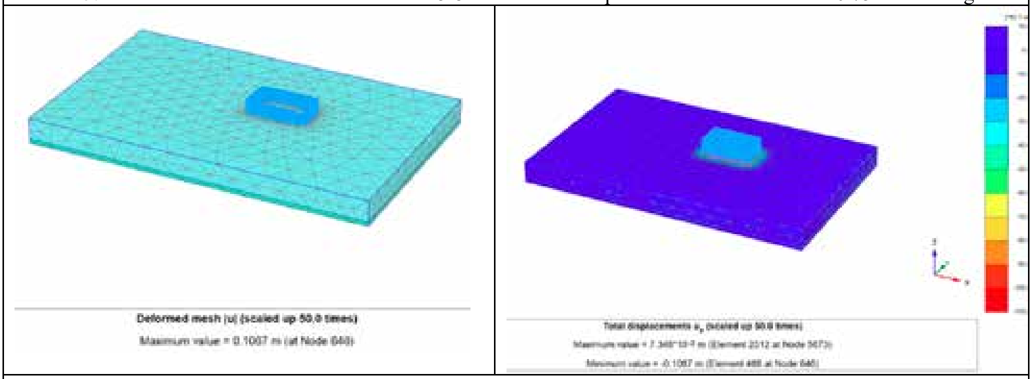
Deformed mesh and a settlement of 27.14 cm for church placed on natural soil



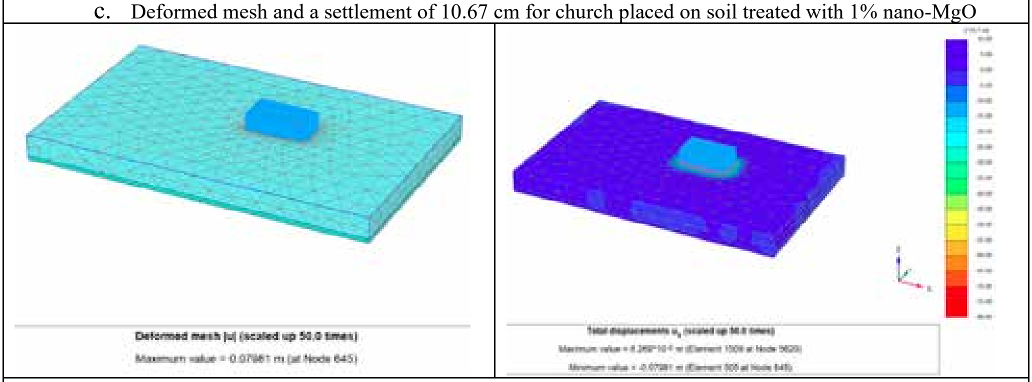
a. Deformed mesh and a settlement of 19.06 cm for church placed on soil treated with 0.5% nano-MgO



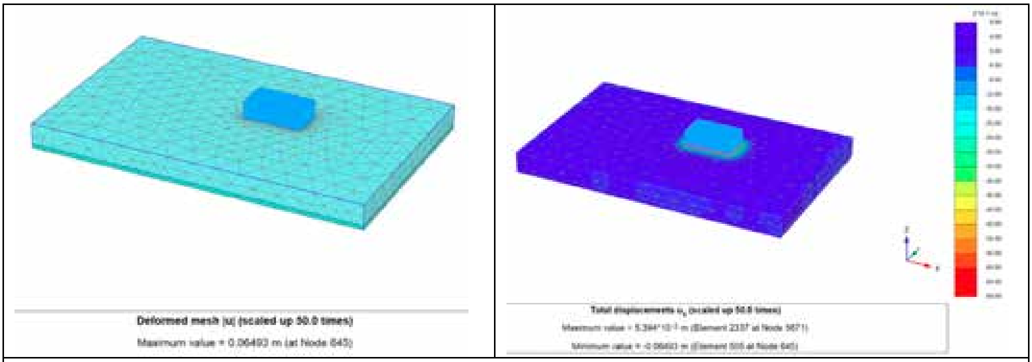
b. Deformed mesh and a settlement of 15.82 cm for church placed on soil treated with 0.75% nano-MgO



c. Deformed mesh and a settlement of 10.67 cm for church placed on soil treated with 1% nano-MgO



d. Deformed mesh and a settlement of 7.98 cm for church placed on soil treated with 2% nano-MgO



e. Deformed mesh and a settlement of 6.49 cm for church placed on soil treated with 2% cement

Figure 6. The settlement of the foundation soil

CONCLUSIONS

This study was conducted to assess the efficiency of the soil improvement meant to stabilize the settlements for the church Adormirea Maicii Domnului, Perisoru village, Romania. A series of laboratory tests and three-dimensional FEM analyses were used to perform this task. The soil parameters, required for the numerical analysis were obtained from laboratory and field tests. The results of the numerical analysis showed that the total vertical displacement of the soil was 27.2 cm. The main reason for this high value of the settlement and the damages in the structures are due to the rising groundwater level in the region. Different percentages of nano-MgO have been used to improve and modify the soil properties. All the results have been compared with 2% soil mixtures with cement. The value of the settlement decreases with an increase in the percentage (0.5%, 0.75%, 1%, 2%) of the nano-MgO (19.0, 15.8, 10.7, 8.0) cm, respectively, and 6.5cm when using 2% cement. It can be observed that the value of the settlement when using nano-MgO is still larger than the value of the settlement when using 2% cement.

In conclusion, the use of cement is more suitable from a technical point of view, in addition to the high-cost difference between cement and nanomaterials, in general.

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