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NUMERICAL MODELING OF RESPONSE OF THE ANCIENT POTTERY KILN FROM MAREA (EGYPT) DUE TO THE SOIL LOADING

1. Introduction

The ancient town of Marea, which is located 45 km on the west of Alexandria in Egypt is an example of a unique ancient construction work. With a unique system of ancient sewage and some unusual structures it has been under exploration for 12 years and is still a very promising archaeological site [1]. The Byzantine basilica, a crucial point of the excavations by the Polish Archaeological Mission and is located on the north tip of peninsula, situated on a small hill, descending into Lake Maryut on the north side, and into land on the South. The location and scale of the basilica indicates its importance in ancient times. One of the most mysterious constructions revealed by the Polish Archaeological Mission is a pottery kiln dating back to the II/III century, which is located under the level of the foundations of basilica. The kiln was abandoned before construction of the consecutive layers of the basilica floor, hence the kiln's date is established on the basis of its stratigraphical position. In the future, a new museum is planned around the excavations site and hence an estimation of stresses in the kiln structure is needed prior to this.

2. The pottery kiln description

The kiln structure is one of the largest unveiled so far. It is made of brick and wrapped with a plaster. Its diameter is about 822 centimeters. Figure 1 presents a drawing of the basilica apse with dimensions of the pottery kiln. Figure 2 presents the current state of the kiln's grid. The grid which is made in such a way that it demonstrates that he stove underneath was an open one. Figure 3 presents the picture of the kiln taken inside. From Figures 2 and 3 one

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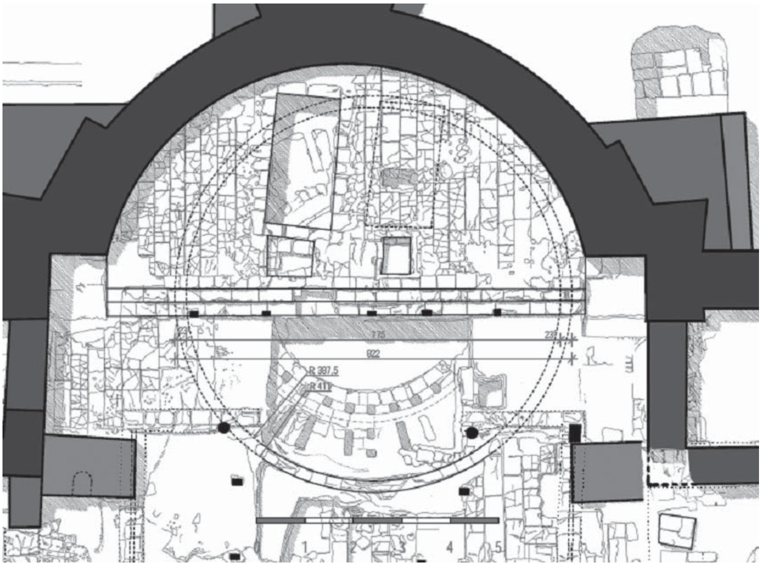

Fig. 1. The drawing of the Marea basilica apse
with the horizontal dimensions of the pottery kiln

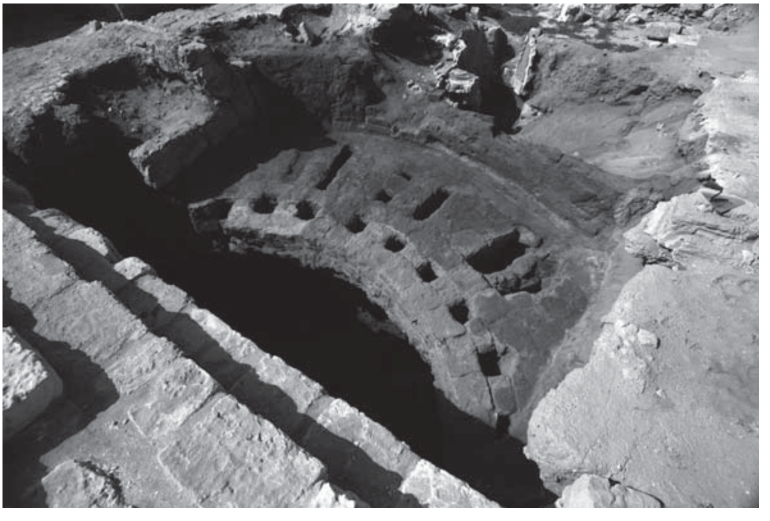

Fig. 2. The pottery kiln's grid before the conservation works

is able to distinguish the regular air-holes required in the technological process of pottery production.

The construction of such a large pottery kiln was a real engineering challenge. Due to the size and structure of the kiln several questions regarding the kiln and the foundations have arisen. They contain many engineering topics such as the main loading, the influence of the soil and foundation as well as the overall stability in every state of kiln and existing structure of basilica.

Fig. 3. The pottery kiln inside picture taken from the position of a stove

The authors investigated the results of the archaeological exploration and the documentation of works performed on the site. The centre of the kiln was later on cut out and then filled partially with stones and used as a part of the construction for the apse staircase. Afterwards, the kiln was filled up with several columns and beams from the basilica, visible in figure 3, which shows a photo taken inside the kiln.

3. Numerical model

The finite element model of the kiln is built using the FEM package Ansys [2] and is based on ancient kiln it represents and is reconstructed using the same technology as in the past. It consists of the bricks as with the ancient version. The initial model is linear and elastic. The walls are homogenized and the following parameters are used: Young modulus [3–5] is in the range of E = 0.01–0.03 105 MPa, and the Poisson ratio is in the range of ν = 0.09–0.15. The density of the material is equal to γ_k = 20 kN/m^3.

The model geometry has been taken from the surveying of the structure. Figure 4 displays the horizontal elements partition. Superimposed on the apse drawing is an ordinary circle with radii at every 12 degrees, which take into account the regular air-holes inside the grid. From figure 4 one can notice that surveying of the old design was marked out very precisely in order that the pottery kiln was accurately erected.

Figure 5 presents the cross-section of the apse foundation which have been superimposed on that of the model of the pottery kiln structure. The apse walls were reconstructed and the top layer was maintained. The model geometry is built as a regular ring around the geometrical center with regular air-holes and an empty space in the centre as it is existing now. In the past, the external wall was established as a dome which covered the stove, while inside the process of backing the ceramic took place. Today, this no longer exists.

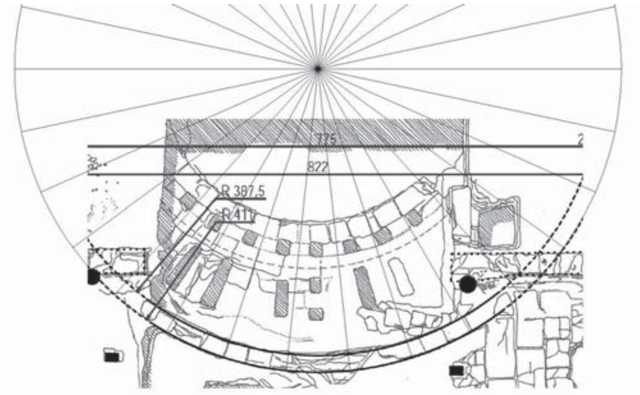

Fig. 4. The drawing of the Marea basilica apse
with the initial elements partition of the pottery kiln

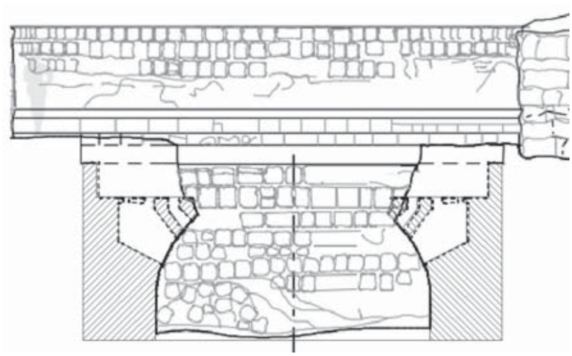

Fig. 5. The sketch of a cross-section of the Marea basilica apse including the wall
reconstruction and floor relicts with the elements the pottery kiln model

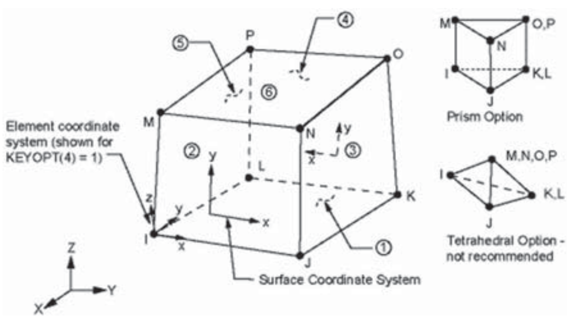

Fig. 6. FEM element details [2]

SOLID45 element is used for the 3-D modeling of the kiln solid structure. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. There is an option giving a six nodes prism and a four nodes tetrahedral element. Figure 6 displays the element in detail. The model geometry of half of the kiln is shown in Figure 7a. The bottom of the pottery kiln is fixed and the kinematic boundary conditions of the model of half of the kiln are along the surface of cut assumed as simply supported. The maximum length of the element edge is equal to 0.20 m and the mesh is generated automatically. There are 10 537 nodes and 46 163 elements in the model mesh. Figure 7b presents FEM mesh of the analysed structure.

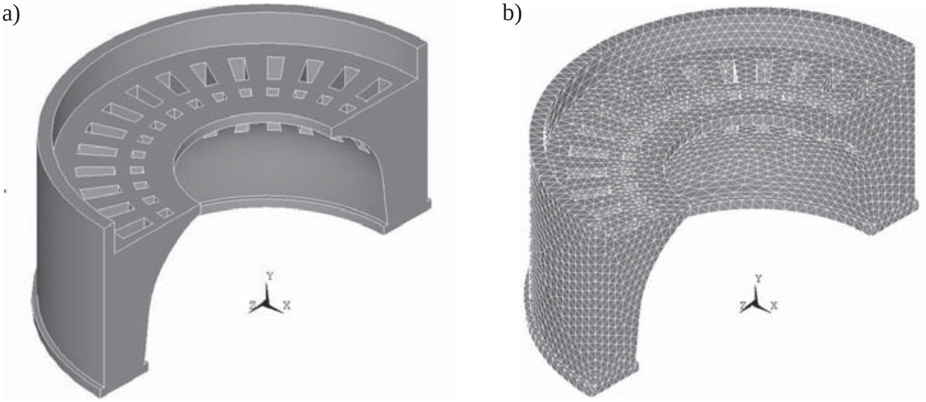

Fig. 7. Geometry of the model (a) of half of the pottery kiln and FEM mesh (b)

The geomorphologic research at the site of Marea has been conducted since the year 2000 [6, 7]. The results of the granular analysis of typical soil sample taken from the soil surface according to [8] show that about 5.8% of the soil is classified as the coarse gravel, 4.2% belongs to the fine gravel, 10.1% of the sample is classified as the coarse sand, 45.4% of the soil belongs to the medium sand, 33.4% of the sample is classified as the fine sand, and remaining 1.1% is classified as the fraction of the fine soil. According to Eurocode 7 [9], this means the soil is classified as a sand (Sa). From the largest sand fraction it might be precisely categorized as a medium sand (MSa) [10] in a loose consistency. Hence, the loading, which is acting on the kiln structure is based on the value of density index $I_D = 0.33$, and internal friction angle equal to $\varphi_s = 32$ deg, which might be transferred as a linear pressure with coefficient of active earth pressure of $K_a = 0.307$. The gravity density of the medium sand is equal to $\gamma_s = 16$ kN/m^3.

4. Discussion of results

The FEM package solution of the total displacements of the pottery kiln model is shown in Figure 8. The soil loading is changing uniformly from 0 to nearly 20 kN/m2 downwards in the vertical direction. There were two different cases computed for the minimum and maximum value of the Young modulus range. The maximum displacement under the earth active pressure is nearly 2.7 mm as it is reached for a minimum value of the Young modulus. Figure 9 presents the solution of stress intensity due to Tresca theory of strain. The maximum value of equivalent stress is nearly equal to $\sigma_{T\max}$ = 0.14 MPa. It is located at the bottom of the structure near the imaginative foundation is placed. The value of $\sigma_{T\max}$ is well below the strength of the masonry. The influence of the air-holes on the stresses in this state of the loading is negligible, which means that the Byzantine contractors were right utilized the ancient pottery kiln as a part of the foundation of basilica.

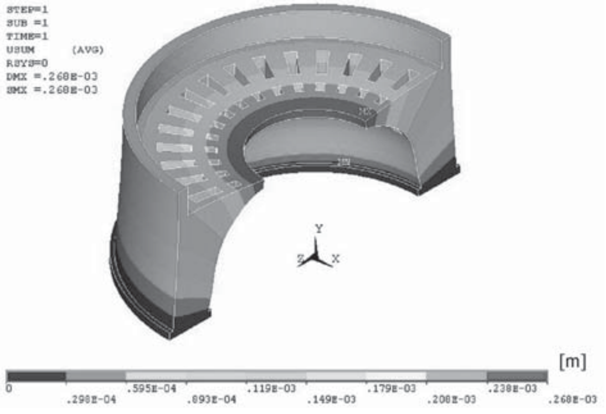

Fig. 8. Solution of the total displacements of the half of the pottery kiln under the soil loading shown on the deformed model

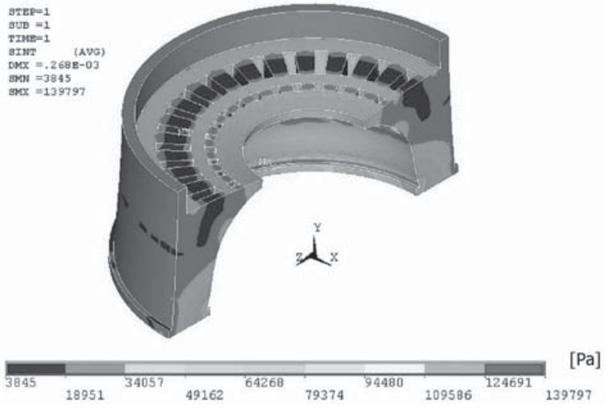

Fig. 9. Solution of the stress intensity of the half of the pottery kiln under the soil loading shown on the deformed model

5. Summary

Development of the numerical model of a unique ancient pottery kiln have been discussed in this paper. Authors focused on the initial analysis of the behaviour of linear elastic model with typical parameters taken both from the study of literature and engineering practise. In case of the Marea pottery kiln and the soil loading, there is no serious risk of failure. The authors have advised that in order to protect the kiln it should be filled with the sand temporarily as a precaution and this has been carried out. In the future, several changes are planned to the model, especially non-linear material and geometry, imperfections based on the observed changes and other types of the loading such as temperature as well as external static and dynamic loads.

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