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UPON THE STRESSES DEVELOPED IN THE SUPERSTRUCTURE INFLUENCED BY LIMITED EXCAVATION AND CONCRETING WORKS UNDERNEATH AN EXISTING FOUNDATION

BY

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Abstract. Underpinning of foundations is a method utilized on large scale with the purpose of strengthening the foundations of an existing building. Traditional underpinning consists in excavated alternate pits afterwards filled with poured concrete.

The aim of the present paper is focused on the normal stress variation into masonry walls when removing an area of soil from under the center of the foundation and filling it with concrete, with the end purpose of underpinning the foundation. The length of the central section should be adjusted so that the additional stresses induced into the wall on the excavation stage as well as on the concrete casting stage to be tolerated.

The model geometry consists of a homogeneous and isotropic layered soil profile, a stone masonry continuous foundation and a brick masonry wall, developed and analyzed in a three-dimensional linear elastic hypothesis with finite element software-ANSYS. The elastic properties of the wall and foundation are framed into a decreasing range of values defining the material aging during service.

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Keywords: finite element analysis; ANSYS software; section length; dimensional optimization; stress distribution.

1. Introduction

A building, in every stage of its existence can exhibit some safety risks and reliability issues. These issues can manifest through the vulnerabilities given by the environmental factors.

Settlement of existing structures during underpinning works can lead to significant damage thus the assessment procedures should highlight the potential for degradation (Cording el all, *2010*).

A structural intervention regarding the foundation system should include all the involved key factors that may influence the outcome of the technical solution. The damage that may develop into the structure along with the foundation system should be kept into the serviceability limits (Gioncu el all, *2009*).

Within this paper, a series of numerical static analysis have been made with the main purpose of a better understanding and observing of the normal stress distribution and variation throughout a bearing wall, for a gradual decrease during service of the mechanical characteristics of structural elements, as a consequence of climate, time and anthropic influence.

2. Case Study Input and Considerations

Within this study, numerical studies of geometry models (Fig. 1) consisting in a layered subsoil ($20 \times 10 \times 10$ m), a continuous stone foundation (10x0.6x0.6 m) and a brick masonry wall ($10 \times 3 \times 0.375$ m) while excavation and concreting works took place underneath the central side of the foundation. The case study has been approached by 3-D finite element models based on the assumptions of the macro-modelling theory for the brick and stone masonry and implied a continuous homogeneous isotropic elastic half-space for the layered subsoil.

When modelling an elastic half-space, it is necessary to create a domain with sufficiently large dimensions so the deformations at the frontiers to be negligible. All displacements at the bottom surface of the subsoil have been constrained against movement and the side surfaces have been restricted against horizontal movements (Fig. 1). A nonlinear surface-surface type of contact available in ANSYS software was used to solve the interaction between the foundation and the soil (ANSYS, 2009). A vertical load with a value of 4,000 kN has been applied on top of the wall, as illustrated within Fig. 1.

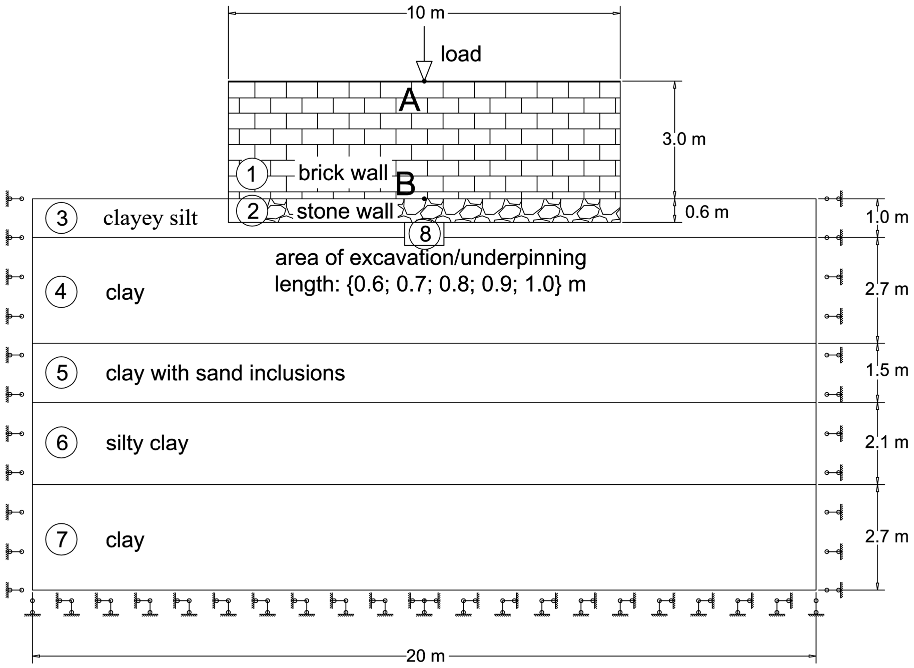

Fig. 1 – Model geometry with load conditions and displacement constraints.

The material characteristics defined by Young's modulus, Poisson's ratio and density for the structural elements and the soil properties for each layer of the ground are given in Table 1. Material properties for the wall and foundation have been considered to be into a slow decay due to material aging and environmental factors. In this respect, the elastic modulus for the masonry wall has values from 4,000 MPa, considered its initial condition, to 1,200 MPa, as its current condition, with a decreasing rate of 400 MPa. On the same assumptions, the elastic modulus of the stone masonry foundation has values from 6,000 MPa (its initial condition) to 1,200 MPa (its current condition), with a decreasing rate of 400 MPa.

Excavations have been carried out underneath the central side of the foundation on the entire foundation width, to a 0.6 m depth and with 0.6, 0.7, 0.8, 0.9 and 1.0 m lengths, for all of the values of the elastic modulus of the wall and foundation presented in Table 1. Concreting works have been considered for segments with 0.3 and 0.6 m widths, having the same lengths and depth as in the excavation works. For these numerical analyses, stress evolution and distribution within the masonry wall have been followed up, specifically in node

A, situated in the center of the upper horizontal surface of the wall and node B placed in the center of the lower horizontal surface of the wall.

Table 1
Material Properties

Element/soil type	Young's modulus, [MPa]	Poisson's ratio	Density kg/m^3
Brick masonry wall – over time condition variation due to material aging	4,000; 3,600; 3,200; 2,800; 2,400; 2,000; 1,600; 1,200	0.2	1,800
Stone masonry foundation – over time condition variation due to material aging	6,800; 6,400; 6,000; 5,600; 5,200; 4,800; 4,400; 4,000	0.2	2,200
Concrete	29,000	0.18	2,400
Clayey silt	10	0.35	1,900
Clay	16.362	0.42	2,170
Clay with sand inclusions	16.667	0.42	2,080
Silty clay	13.076	0.35	1,980
Clay	18	0.42	2,070

3. Results and Conclusions

Ranging the elastic modulus of the wall, the elastic modulus of the foundation and the length of the excavation/concreting segment, analyses have been carried out in order to follow up and evaluate the variation of the normal in-plane stresses.

Graphical outcomes of the stress analyses for an elastic modulus of 4,000 MPa for the stone masonry and the variation of the elastic modulus of the brick masonry, for each case of excavation performed underneath the central side of the foundation are shown in Fig. 2. The legend on the right side of the graph express the lengths of the segments used in the analyses giving the stress values resulted in nodes A and B. The curves from the lower side of the graph express the stress values for the node A and those from the upper side, for the node B. The "0.0 m" series from the legend represent the stress results in node A and B when no excavation work is undertaken.

Within the Fig. 3 the outcomes of the stress analyses for the elastic modulus of 6,800 MPa for the stone masonry and the variation of the elastic modulus of the brick masonry, for each case of excavation conducted.

The results for the node A are compressive values for all the analyses made. The lowest stress value within the excavation analyses is met for a length of excavation of 0.6 m with the combination of the elastic moduli for the wall and the foundation of 1,200 MPa, respectively 6,800 MPa and the highest stress value is met for an excavation segment 1.0 m long and a combination of the elastic moduli for the wall and the foundation of 4,000 MPa, respectively 4,000 MPa.

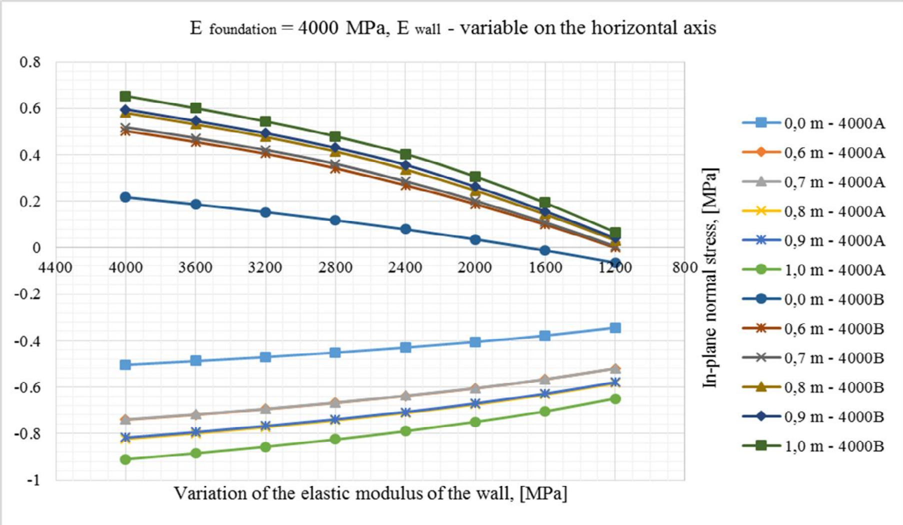

Fig. 2 – In-plane stress variation in relation to the variation of the elastic modulus of the wall, at a fixed value of 4,000 MPa for the elastic modulus of the foundation, for different lengths of the excavation pit.

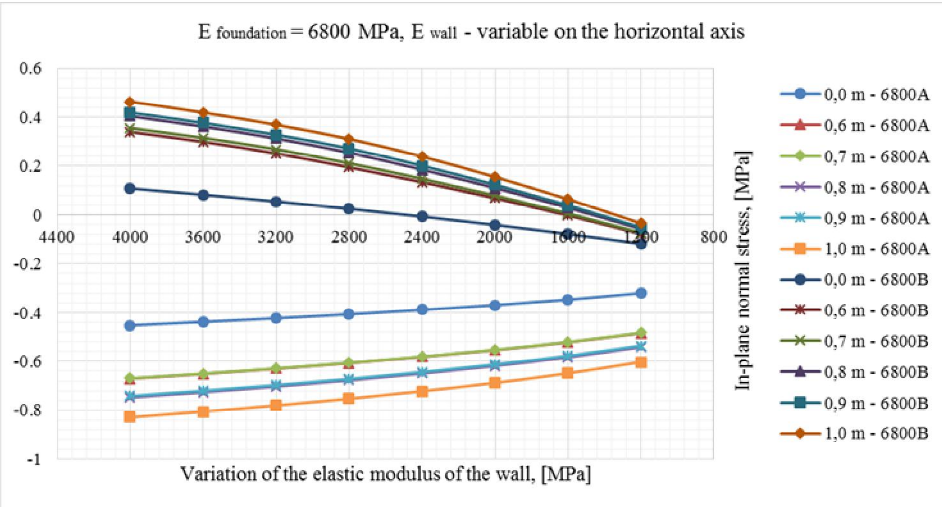

Fig. 3 – In-plane stress variation in relation to the variation of the elastic modulus of the wall, at a fixed value of 6,800 MPa for the elastic modulus of the foundation, for different lengths of the excavation pit.

When compared with the case without an excavation, the compressive value in node A, for an excavation segment 0.6 m long, increases with 51.54% and with 103.19% for a 1.0 m long excavation segment, considering the combination of elastic moduli for the wall and the foundation that gives the lowest values in stress. Likewise, the compressive value in node A, for an excavation segment 0.6 m long, increases with 46.86% and with 80.52% for a 1.0 m long excavation segment, compared with the situation of the analysis without excavation and considering the combination of elastic moduli for the wall and the foundation that gives the highest values in stress.

The resulting stresses in node B are mostly tensile stresses with the highest values for longer excavation segments and decrease along with the elastic moduli for the wall and the foundation.

Fig. 4 shows the exceedings of the tensile strength in node B for the variation of the elastic moduli of the wall and the foundation and for all the excavation lengths. When no excavation takes place (excavation length equals 0.0 m), there are no exceedings of the tensile strength. For the first value for the elastic modulus of the foundation, the tensile strength exceedings in node B begin at a value of 2,000 MPa of the elastic modulus of the wall for an excavation length of 0.6 m and at a value of 1,600 MPa of the elastic modulus of the wall for all of the other excavation lengths. The upper area in green from Fig. 4 represents stress values in the lower central area of the wall (node B) that do not exceed the tensile strength of the brick masonry, values that are different for each combination of the elastic moduli of the wall, respectively of the foundation and for each length of the excavation taken into consideration.

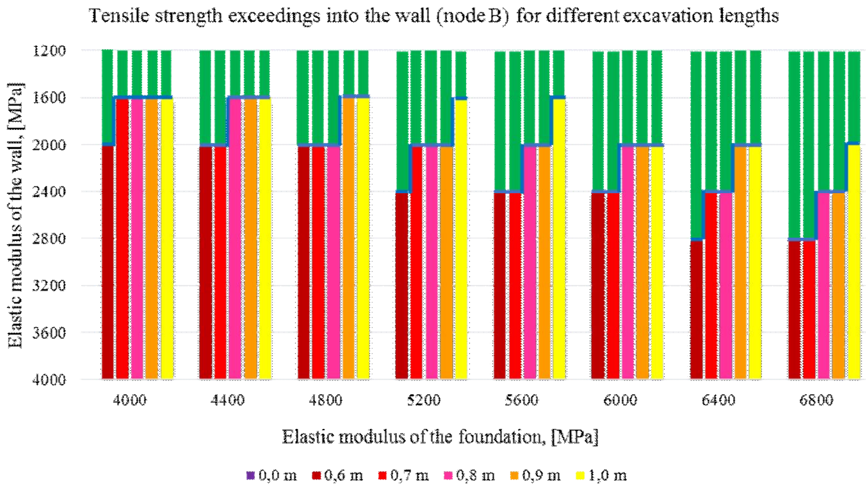

Fig. 4 – Tensile strength exceedings into the wall (node B) for different lengths of the excavation pit.

Considering simultaneous decreases of the elastic moduli of the wall and the foundation, from a value of 0 MPa to 3,000 MPa, with a rate of 400 MPa, the normal in-plane stresses variation goes from high values of tensile stresses to lower values, for all excavation ranges and from tensile stresses to compressive stresses when there is no excavation work (Fig. 5).

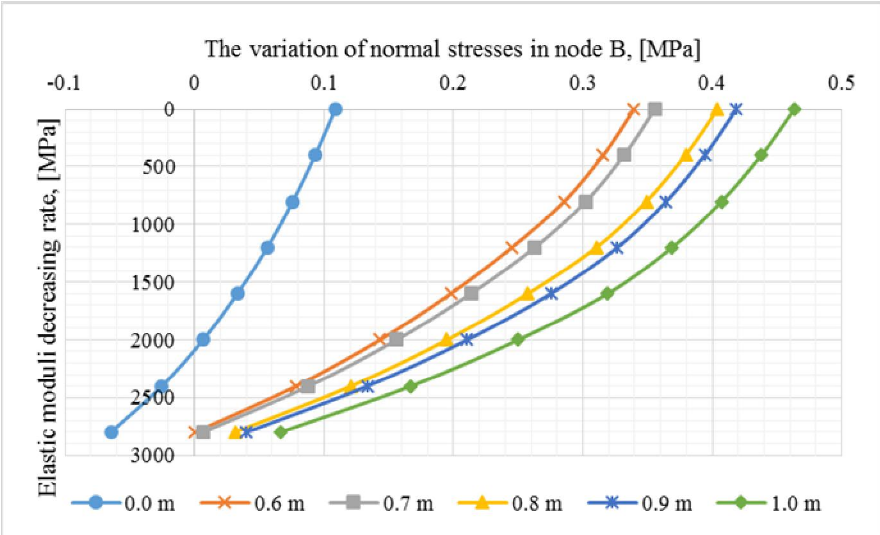

Fig. 5 – The normal stresses variation in node B of the wall for all the excavation lengths and simultaneous decreasings of the elastic moduli of the wall and the foundation.

Stress analysis of concreting works underneath the foundation have been carried out only for the current condition of the wall and foundation, consisting in a value of 1,200 MPa for the elastic modulus of the wall and 4,000 MPa for the elastic modulus of the foundation. Lengths of 0.6, 0.7, 0.8, 0.9 and 1.0 m and widths of 0.3 and 0.6 m have been considered for the concreting segments. The results of these analyses in node A and B are shown in Fig. 6. There have been no strength exceedings in nodes A and B.

When excavation and concreting works are required for underpinning existing foundations, the optimum technical solution is chosen based on criteria regarding structural safety and cost of intervention.

Stress analyses for a variety of limited excavation and concreting works underneath the central side of a continuous stone foundation have been carried out under static loads, to evaluate the development of the normal in-plane stresses within the brick masonry wall for a gradually decay of the structural materials due to the aging phenomena. As the structural degradation gradually increases, the stresses developed in the lower central side of the wall during excavation works register decreases of the tensile stresses. Also, the compressive stresses from the upper central side of the wall decrease with the gradual degradation of the foundation and the wall. Higher stresses have been registered within concreting works with segments equal to half the foundation width in comparison with segments of the same widths.

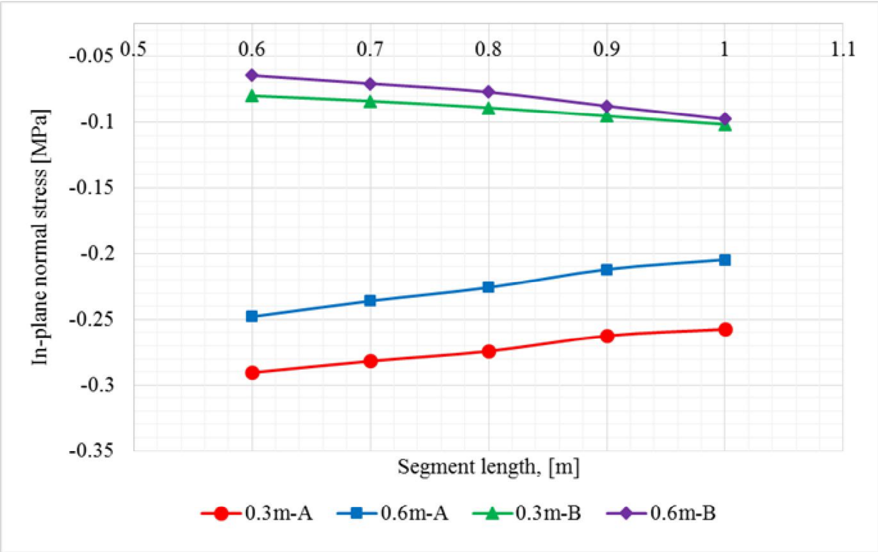

Fig. 6 – Model geometry with load conditions and displacement constraints.

An accurate assessment and analysis of the structure when choosing the dimensions for the underpinning segments can lead to lower risks concerning the structural integrity.

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ASUPRA TENSIUNILOR DEZVOLTATE ÎN SUPRASTRUCTURĂ, INFLUENȚATE DE LUCRĂRI LIMITATE DE EXCAVARE ŞI BETONARE SUB O FUNDAȚIE EXISTENTĂ

(Rezumat)

Subzidirea fundațiilor este o metodă utilizată la scară largă cu scopul consolidării fundațiilor unei construcții existente. Subzidirea tradițională constă în secțiuni alternante excavate, ulterior umplute cu beton monolit. Obiectivul prezentei lucrări se concentrează asupra variației tensiunilor normale în pereți de zidărie la excavarea pământului de sub zona centrală a fundației şi umplerea acesteia cu beton, cu scopul final de subzidire a fundației. Lungimea secțiunii centrale trebuie ajustată astfel încât tensiunile adiționale induse în perete atât în etapa de excavare cât şi în cea de betonare să fie tolerate. Geometria modelului constă într-un teren stratificat omogen şi izotrop, o fundație continuă din zidărie de piatră şi un perete din zidărie de cărămidă, dezvoltată şi analizată într-o ipoteză tridimensională liniar-elastică cu ajutorul programul cu element finit ANSYS. Proprietățile de elasticitate ale fundației şi peretelui sunt încadrate într-un interval de valori descrescătoare care definesc îmbătrânirea de material pe durata de exploatare.