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STRESS ANALYSIS OF MASONRY WALLS IN CASE OF LIMITED EXCAVATION FOR FOUNDATION UNDERPINNING

BY

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Abstract. The assessment of safety and structural integrity of existing buildings is often an intricate task regarding the optimum structural intervention measures on superstructure, infrastructure or both. When the cause of structural deterioration is related to the geotechnical condition unfit for the new load regime, a widely used method for the rehabilitation of infrastructure is the underpinning of foundations.

This paper is focused on the analysis of the stresses developing into a masonry wall when excavating in segmented areas with limited lengths under and on both sides of the continuous foundation. In this respect, a linear elastic analysis for a three-dimensional model was carried out by using finite element software ANSYS.

The excavation for the underpinning is assumed to start from the middle of the wall, with variable lengths, from 0.60 m increasing with a rate of 0.10 m, up to 1.00 m. The depth of the excavation is considered constant, as 0.60 m under the foundation, to exceed the frost depth by a final value of the foundation depth of 1.20 m.

The model of the wall, foundation and soil was developed with ANSYS interface for all excavation ranges, considering a frictionless contact between foundation and soil and the program run for all modulus variations and

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excavation geometries. The results are given in diagrams correlating the *E* modulus versus in-plane and vertical stress for all the excavation geometries.

Key words: ANSYS software; finite element modelling; excavation; underpinning; stress analysis.

1. Introduction

The underpinning is a traditional method used to strengthen and develop higher bearing capacity of the soil beneath the extended foundations.

The structural rehabilitation can be accomplished with different technical solutions depending on many factors, so the right method should be thoroughly appraised.

In case of shallow foundations, the traditional underpinning consists in segmented excavations of the soil beneath the foundation and replace it with concrete with or without a lateral enlargement of the foundation, thus obtaining an increase of the bearing capacity.

Excavation of the soil underneath the foundation may develop some considerable risks concerning the safety of the structural elements within the superstructure and/or the infrastructure of the building, particularly when dealing with historical buildings (Betti & Galano, 2012).

In other cases, the underpinning can be supplemented with the addition of concrete beams or using micro-piles, the loads being transferred to the soil through the mixed system: existing footings and new added elements.

2. The Finite Element Approach

A 3-D static structural analysis in Workbench platform of the ANSYS software has been performed in order to calculate stresses in the investigated masonry wall when excavating a section underneath its continuous foundation with the purpose of underpinning.

More than 685,000 nodes and 108,000 elements resulted with the discretization of the model geometries.

As a frictionless (non-linear) contact between the continuous foundation and the soil was used, over 190 spring elements (COMBIN14, which is an uniaxial tension-compression element (ANSYS Release)) were automatically added to stabilize the model and to achieve convergence and a reasonable numerical solution.

The soil, foundation and the wall have been meshed with SOLID186, a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior (ANSYS Release) with isotropic material properties.

CONTA174 and TARGE170 have been used to represent the contact with sliding between 3-D target surfaces of the foundation and the deformable surfaces of the soil layer (ANSYS Release).

3. Parametric Study

In this paper the integrated wall-foundation-soil system has been analyzed with the finite element software ANSYS, based on direct method of soil-structure interaction (SSI) assuming linear elastic behavior of all materials (Potts & Zdravkovic,1999; Malekova & Jendzelovsky, 2012; Srilakshmi & Rekha, 2011). The 3-D model was used to analyze the influence of in-plane and vertical tension and compression stresses (Fig. 3, nodes A and B) under a vertical load applied on the wall for a variety of elastic modulus of the brick masonry wall for a no excavation hypothesis and for a variation of the excavation length between 0.6 and 1 m with a rate of 0.1 m.

3.1. Input Data for the Model Geometry and Construction Materials

The case study refers to a layered soil profile, consisting of 1.00 m of clayey silt, 2.70 m of clay, 1.50 m of clays with sand inclusions, 2.10 m of silty clay and 2.70 m of clay, with the relevant geotechnical parameters considered

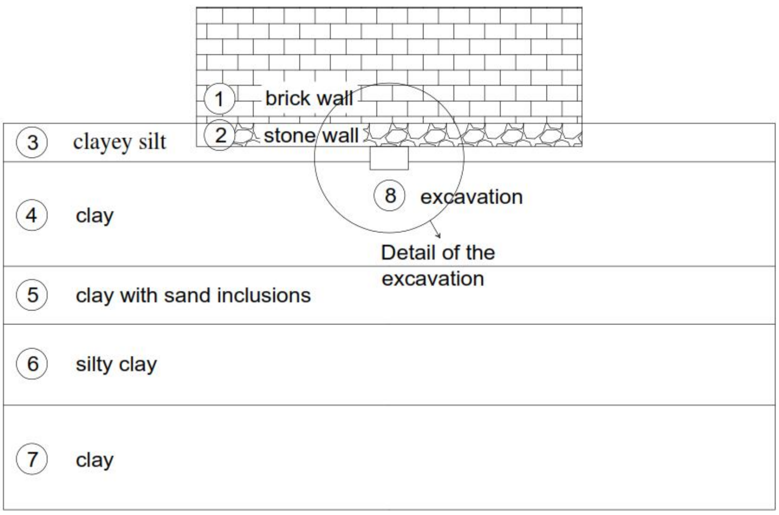

Fig. 1 – The model geometry – lateral view.

constant during service. The structure (Figs. 1 and 2) is considered a brick masonry wall, 3 m high, 10 m long and 0.375 m thickness, supported by a 0.60 m width stone masonry continuous foundation, extended to 0.60 m depth (insufficient at present to satisfy the frost depth restriction) with the specific isotropic material properties as presented within Table 2. During service, the material aging and climate influence within the wall is regarded by a slow decrease of the elastic modulus (E), from 4,000 MPa to only 1,200 MPa.

The foundation is considered located on a layered half-space with the geometries and soil isotropic properties assumed in Fig. 1 and Table 1.

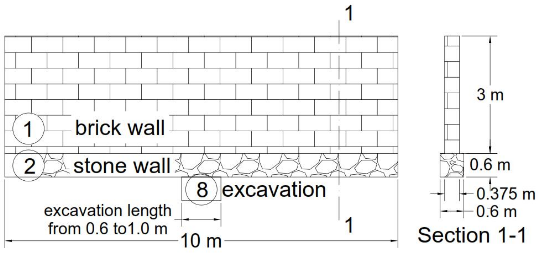

Fig. 2 – Detail of the excavation, with the wall and corresponding foundation.

The stresses developed into the wall have been analyzed for different excavation lengths as presented in Table 3. The initial model considers no excavation, as an assessment of the existing in situ situation. Then, a variation for the length of the excavation has been analyzed and tension and compression stresses for the brick masonry wall have been observed whilst the elastic modulus of the masonry wall, due to the material aging, decreased from 4,000 to 1,200 MPa with a 400 MPa rate.

Table 1

Characteristics of the Soil Layers

Soil type	Thickness of the layer, [m]	Young's modulus, [MPa]	Poisson's ratio	Density, [kg/m^3]
Clayey silt	1.00	10	0.35	1,900
Clay	2.70	16.362	0.42	2,170
Clay with sand inclusions	1.50	16.667	0.42	2,080
Silty clay	2.10	13.076	0.35	1,980
Clay	2.70	18.000	0.42	2,070

Table 2

Characteristics of the Structural Elements

Element	B × L × H, [m]	Young's modulus, [MPa]	Poisson's ratio	Density [kg/m^3]
Stone masonry foundation	0.6 × 10 × 0.6	6,000	0.2	2,200
Brick masonry wall	0.375 × 10 × 3	1,200,…,4,000	0.2	1,800

Table 3
Dimensions for the Excavations

Depth, [m] (constant)	Length, [m] (variable)	Width, [m] (constant)
0.6	0.0	2.6
0.6	0.6	2.6
0.6	0.7	2.6
0.6	0.8	2.6
0.6	0.9	2.6
0.6	1.0	2.6

3.2. Analysis Set-Up

The bottom surface of the 3-D model geometry is restrained against displacement in all directions and the vertical sides are free to move in-plane, but confined to move out-of-plane (Fig. 3). Due to the symmetry of the model, symmetrical boundary conditions have been applied in order to reduce the computing time. The symmetry condition prevent any nodes from moving through the symmetry plane during the analysis.

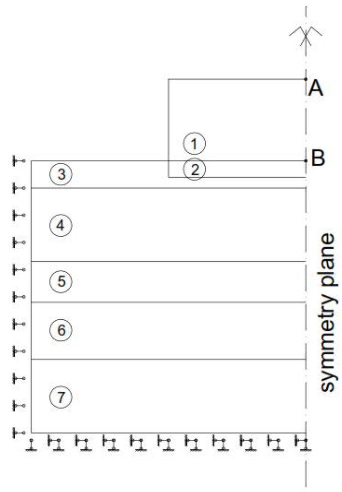

Fig. 3 – Applied symmetry on the wall – foundation system with restrains against displacements.

The stone masonry foundation, as well as the brick masonry wall have been modelled based on the assumptions of the macro-modelling strategies which consider the masonry as a homogeneous continuum able to replicate the masonry behavior. This assumption is applicable when analyzing bigger parts of a structure or an entire building, the amount of computational time being reduced (Soveja *et al*., 2013).

A frictionless contact between the foundation and the soil has been considered in order to allow free sliding of the bodies, gaps being allowed to develop depending on the intensity of the load.

The upper part of the model geometry has been meshed with 0.1 m sizing elements and the bottom part with 1 m sizing elements (Fig. 4).

A load of 2,000 KN has been applied on the upper surface of the brick masonry wall for the symmetrical model.

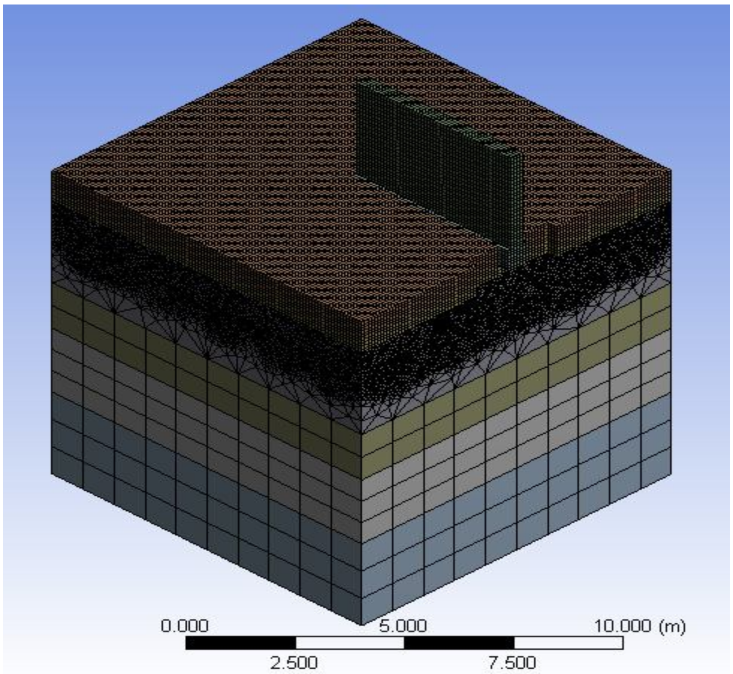

Fig. 4 – 3-D mesh pattern for the symmetrical geometry of the wall-foundation-soil system – the excavation with 1 m length.

4. Results and Discussion

The output was focused on the in-plane and vertical normal stresses resulted in nodes A and B represented in Fig. 3, as mid points at the top and base surfaces of the wall.

Results of the in-plane tension and compressive stresses for nodes A and B are reported with the graphic representation within Fig. 7, for all excavation lengths corresponding to the entire range of the elastic modulus variations of the brick masonry wall.

A display of the resulted contours for in-plane normal stresses for one of the geometry model is given in Fig. 5 (excavation length of 1 m).

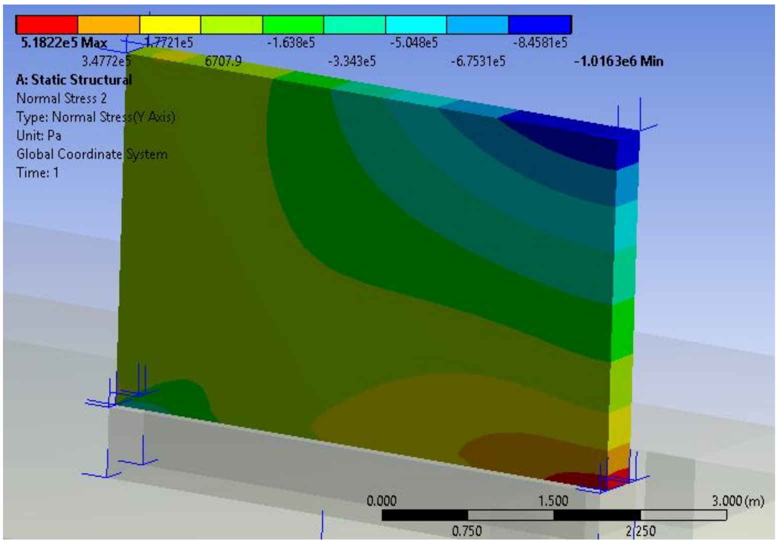

Fig. 5 – Typical in-plane stresses within the symmetrical model for the brick masonry wall – the excavation with 1 m length.

As seen in Fig. 6, the upper part of the wall (node A) is subjected only to compression, as for the lower part of the wall (node B), it withstands compression stresses for the smallest values of the elastic modulus, then tension stresses develop as the values for the elastic modulus and the excavation lengths increase gradually.

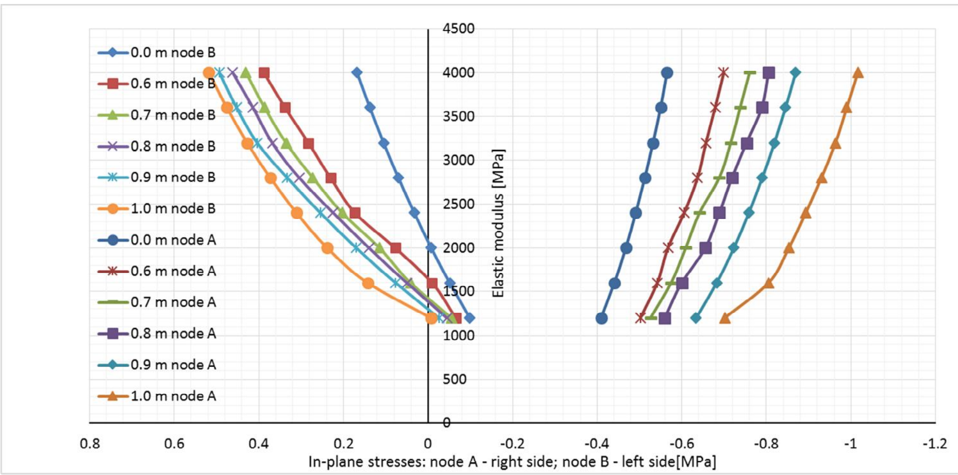

Fig. 6 – The evolution of the in-plane stresses correlated with the variation of the elasic modulus of the masonry wall for all the excavation lengths.

The vertical stresses (Fig. 7) in the wall (node B) amplify their values with the increase of both the excavation length and the elastic modulus of the brick masonry wall.

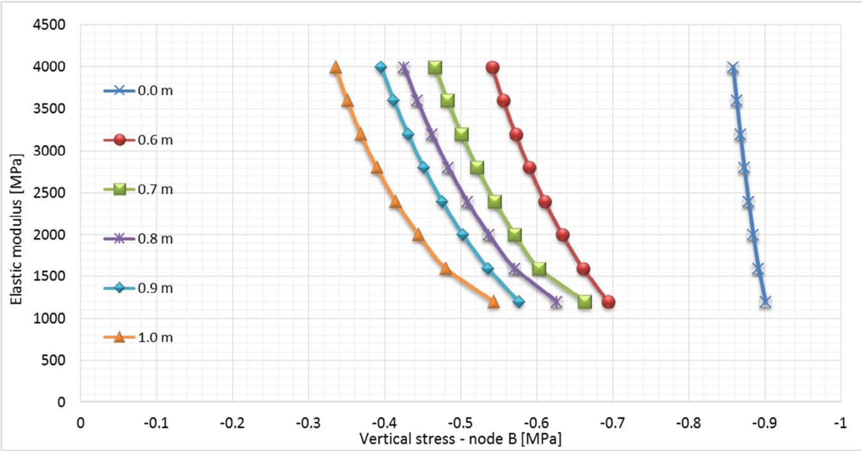

Fig. 7 – The evolution of the vertical stresses correlated with the variation of the elastic modulus of the masonry wall for all the excavation lengths.

4. Conclusions

The stress related behavior of an existing brick masonry wall, as part of a historical building has been analyzed for the case of limited excavation under a stone masonry foundation anticipating its underpinning and simultaneously for the degradation related to the elastic properties of the brick masonry wall. For higher excavation lengths, the values for the normal stresses increase. Thus, the excavation sections should be chosen as not to exceed the strength of the structural materials and avoid damages of the existing elements.

In case of the in-plane stresses recorded in node A, as against the no-excavation model, there is an increase of the stress values of 22.78% for the 0.6 m excavation length for 1,200 MPa elastic modulus and 23.79% for the same excavation, but for 4,000 MPa as the value for the brick masonry wall. For the 1.0 m excavation length, the stress values grew with 71.50% for the 1,200 MPa elastic modulus and 79.90% for the 4,000 MPa. Following the same comparisons, for the stress values in node B, it is noted a significant increase of 33.56% for 1,200 MPa up to 131.27% for 4,000 MPa, for the 0.6 m excavation length and an increase of 93.18% for 1,200 MPa up to 208.76% for 4,000 MPa, for 1.0 m excavation length.

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ANALIZA TENSIUNILOR ÎN PEREȚI DE ZIDĂRIE ÎN CAZUL UNOR EXCAVAȚII LIMITATE ÎN VEDEREA SUBZIDIRII FUNDAȚIEI

(Rezumat)

Evaluarea siguranței şi integrității structurale a clădirilor existente este deseori o activitate complexă în ceea ce priveşte adoptarea măsurilor de intervenție structurală optime pentru suprastructură, infrastructură sau pentru ambele. Subzidirea este o metodă frecvent adoptată în vederea reabilitării infrastructurilor construcțiilor atunci când cauza degradării structurale se identifică prin condiții geotehnice nefavorabile cu noul regim de încărcare.

Această lucrare se axează pe analiza tensiunilor care se dezvoltă într-un perete de zidărie atunci când au loc excavații pe segmente cu lungimi limitate, sub fundație şi în zonele laterale ale fundației continue. Au fost realizate analize liniar elastice pentru modele tridimensionale, folosind programul cu element finit ANSYS.