AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
STRUCTURAL ENGINEERING DEPARTMENT

Performance of Swelling Soil in Arid Areas by Applying Enhanced Numerical Analysis

A THESIS
Submitted in Partial Fulfillment for the Requirements of the Degree of
DOCTOR OF PHILOSOPHY IN CIVIL ENGINEERING
(Structural Engineering)

by

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Cairo 2020

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Thesis : **Performance of swelling soil in arid areas by applying enhanced numerical analysis.**
Degree : Doctor of philosophy in civil engineering **(Structural)**.

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STATEMENT

This thesis is submitted to Ain Shams University for the degree of Ph.D. in Civil Engineering (Structural).

The work included in this thesis was carried out by the author at the Department of Structural Engineering, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

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ABSTRACT OF PH.D. THESIS

Name : **Ashraf Ahmed Reda Mohamed El-Shamy**

Thesis : **Performance of swelling soil in arid areas by applying enhanced numerical analysis.**

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Swelling soils include clays and fine silts which swell while getting wet and shrink if they are dry out. Egypt is regarded one of the countries which has new huge developments under constructions on many urban regions containing swelling soils. The structures constructed on these swelling soils may be exposed to high damage if any significant change in the moisture content of these swelling soils occurs, so the presence of such swelling soils represents a significant hazard. This thesis presents intensive review on swelling soil including its origin, major clay minerals classifications as well as the swelling mechanism. Furthermore, the main characteristics and mechanical behavior of unsaturated soil have been discussed for well-understanding swelling soil behavior. Also, all identification methods for swelling soil are reviewed as well as defining all relevant swell characteristics with explaining for the different Oedometer test methods which commonly used in their determination.

Prediction of ground heave resulted from swelling soils can be done using several methods that may be classified into four categories; empirical methods, suction methods, Oedometer test methods, and numerical

methods. Numerical methods are regarded the best techniques to predict the ground heave of swelling soils as they can overcome the difficulties of solving the nonlinear differential equations of water flow and soil deformations. Finite element method can be considered as the most promising method. However, an appropriate constitutive model representing behavior of the swelling soil is the main challenge for a representative numerical model to simulate the complex performance of swelling soils considering the soil-water and the soil-structure-interaction. Recently, a new constitutive model specialist in simulating swelling soils and rocks has been implemented as user-defined model for *"PLAXIS"* program. The concept of this *"Swelling Model"* as well as its mathematical formulation are introduced and discussed in this thesis.

The numerical analyses conducted in this thesis start with numerical verification to the new introduced *"Swelling Model"* using available results of Huder-Amberg Oedometer test conducted by (Wittke-Gattermann, 1998) on a rock sample from Germany. The suitability of the model to simulate the behavior of this swelling rock is verified by making a numerical simulation to the conducted Huder-Amberg Oedometer test using *"PLAXIS-VIP, 2018"* software via Oedometer *"Soil Test Facility"*. Furthermore, individual input soil parameters are evaluated and assessed through different sensitivity analyses including parameters variations.

Intensive experimental testing program has been conducted on some swelling soil samples collected from some of arid/semi-arid regions in Egypt to determine their swelling parameters. Through this experimental testing program, Oedometer swell test has been firstly conducted on the same soil with two different techniques; namely Different pressure method and Huder-Amberg method. After that, all subsequent experimental tests were performed using Huder-Amberg method as it demonstrated high

superiority in determining swelling parameters. Grob's swelling law was applied to all obtained experimental results to give exact and complete determination for all swelling parameters. Furthermore, the suitability of the *"Swelling Model"* to simulate the performance of swelling soil is verified by conducting a numerical simulation to one of the Huder-Amberg Oedometer tests. This confirms that the new *"Swelling Model"* is applicable with both of swelling clay and anhydritic rock and it can simulate them with true results. Furthermore, the obtained swelling parameters for the experimented swelling soil samples are summarized and presented as a useful key-parameters of these swelling soils which can be used as pre-determined inputs in any further numerical analyses.

Finally, the *"Swelling Model"* is applied with 2D and 3D numerical modelling for three common practical problems including swelling soil. Implementation of *"Swelling Model"* in both of PLAXIS 2D and 3D is validated from this numerical analysis as well as obtaining the results from them with same high accuracy. The obtained results from the conducted models are presented verifying the ability of *"Swelling Model"* to deal with different numerical modelling problems. This enhanced numerical analysis will open new horizons in the field of numerical modeling, along with any other similar applications of swelling soils.

KEYWORDS: Swelling Soil, Oedometer Test, Huder-Amberg Method, Grob's swelling law, Swelling Constitutive Model, Numerical Simulation, Swelling Parameters.

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SUMMARY OF PH.D. THESIS

Name : **Ashraf Ahmed Reda Mohamed EL-Shamy**

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After a short review of the previous related research studies, the main objective of this research is to present enhanced numerical analysis by introducing a new constitutive model specialist in simulating swelling soils and rocks which has been implemented as user-defined model for *"PLAXIS"* software. This thesis consists of seven chapters which have been organized as follows:

Chapter (1) gives a general background information about unsaturated swelling soils problems showing the variable sources of water in developed areas. It describes the main objectives and scope of the thesis.

Chapter (2) presents a review on the following aspects: swelling soil formation showing its main clay minerals, swelling mechanism of swelling soil, main characteristics of unsaturated soil, identification methods for swelling soil, different Oedometer test methods used in swell characteristics determination and different ground heave prediction methods.

Chapter (3) introduces a historical brief about *"Swelling Model"*. In addition, it discusses swelling mechanism of anhydritic rock. It presents the mathematical formulations of the *"Swelling Model"* with explaining its main features. Furthermore, it explains the three different model's routines used as solution procedures for swelling strain. Finally, it describes some general input parameters related to numerical modelling in PLAXIS.

Chapter (4) presents numerical verification for *"Swelling Model"* using available results of Huder-Amberg Oedometer test conducted on a swelling rock sample from Germany. It is done by a numerical simulation to the Oedometer test through *"Soil Test Facility"* available in *"PLAXIS"* software. Furthermore, it presents several sensitivity analyses to investigate the influence of all individual input soil parameters of this new model on different obtained results.

Chapter (5) presents different experimental tests conducted on many collected swelling soil samples from some arid regions in Egypt to determine all their relevant swelling parameters. Furthermore, it confirms that the *"Swelling Model"* is applicable with both of swelling clays and rocks. It gives a useful key-parameters of these swelling soils which can be used as pre-determined inputs in any further numerical analyses.

Chapter (6) presents 2D and 3D numerical modelling for three common practical applications including swelling soil using *"Swelling Model"*. The obtained results from the conducted models are presented verifying the ability of *"Swelling Model"* to deal with different numerical modelling problems.

Chapter (7) displays summary and concluded points for the various aspects of research studies conducted in this thesis. Finally, recommendations for further future studies are pointed out.

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