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Deformation of Trapezoidal Hydraulic Canal Constructed on Expansive Soils: A Numerical Study

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ABSTRACT :
The trapezoidal hydraulic canals, which are constructed on expansive soil, have been damaged by cracking and/or uplift of the concrete linings. This occurs when canals are constructed on expansive soil and the moisture content of the near-surface expansive soil layer fluctuates due to a variety of circumstances. In the current paper, the behavior of real dimensions trapezoidal canals built on expanding soils has been numerically examined using Plaxis 3D software. The finite element model was employed to determine the surface heave or settlement that results from the swelling of expansive soil acting on a canal. The results of the analysis reveal the location of the highest deformation on the trapezoidal canal lining. Based on these findings, the position of joints on the surface of the concrete lining can be adjusted to reduce the impact of swelling forces.
KEYWORDS: *Numerical Modelling, Swelling, Expansive soils, Canal, uplift, Trapezoidal Canals.*

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I. INTRODUCTION

Expansive soils are a common construction challenge, specifically for light-weight structures. They are a source of concern for civil engineers in general, and geotechnical engineers in particular [1]. Soils that are susceptible to swelling and shrinkage, as well as exhibiting considerable volumetric changes, are classified as expansive soils. As the amount of soil moisture content has increased, swelling soil types have generated heave and swelling pressure, which are both problematic [2]. The following is a list of the types of damage that can occur: Fine cracking of pavements or small displacement of foundations, which is very common, significant cracking of canal lining or massive displacement of footings [3]. Lightweight structures such as the foundations of light buildings, retaining walls, pavements, airports, and canal linings are the most important lightweight structures that are susceptible to damage as a result of swelling and shrinkage [1], [4].

Concrete canals are a sensitive and essential technique of water conveyance. The benefits of lining a canal include reduced canal dimensions, water conservation, no seepage of water into nearby land or roads, and less maintenance. Seepage losses from earth channels are extremely significant in many irrigation projects; therefore, by lining the conveyance systems, this lost water can be conserved to the extent of 60-80% [5]. In practice, it is possible to decrease seepage losses to less than 1 percent on tiny canals that are lined with high-quality materials and are properly maintained[6].

Because these irrigation canals are always built on different types of soil, understanding the geotechnical aspects of soil-concrete liner interactions is crucial to avoiding canal degradation. These damages in the hydraulic canals are exhibited in the form of cracking in the concrete liner and considerable deformation of the canals themselves [7].

The construction of irrigation canals on expansive soils has resulted in considerable damage to the canal structure and, as a result, a significant financial loss in several examples documented around the world. Seasonal wetting and drying of the expansive soil around a surface canal creates pressures in the canal frame, which can lead to canal degradation [8]. The deterioration to these canals imposes a high cost on irrigation and drainage network [9].

According to the findings of the literature research, the construction of canals on difficult soils, such as expensive soils, is unavoidable, and proper techniques should be followed in order to minimize the damage [10]. Because the repair and rehabilitation of damaged structures imposes significant financial burdens on the project, it appears that further research into the mechanism of interaction between the expensive soil and canal lining is required to be conducted.

Sarand (2016) [9] evaluated the irrigation and drainage network of the Tabriz plain canal, which was being constructed over expansive soil. The proposed approaches were examined using two methods: physical and numerical modeling. The physical models were constructed in a laboratory on a tiny scale (1/10). Additionally, the Geo-Studio software package contains SIGMA/W 2007 software, which is utilized for numerical modeling. The physical and numerical models reveal the effect of joints on control and distribution of the extensive contact forces between the earth and the canal. The results show that addressing the joint position of maximum internal stresses in the canal section lowers relative displacement of panels and destructive bending moments of the lining.

Sarand and Hajialilue (2017) [10] used field observations and numerical modeling to investigate the behavior of trapezoidal canals. According to this research, the filter layer is utilized to limit the impact of soil swelling on the canal lining. The soil swelling and relative displacement of canal section panels was determined by survey positions. This behavior is also numerically modelled to some extent. Using the results obtained, the swelling of the bed soil at various points throughout the canal section, both with and without the filter, was estimated, and the sites of the greatest movements were determined. Both field and numerical research have shown the area of the greatest amount of deformation and stress concentration on the canal section.

The goal of this study is to investigate and discuss the effect of swelling forces caused by active expansive soil on open trapezoidal canals using numerical modeling.

II. NUMERICAL MODEL

In this study, a trapezoidal canal with a depth of 2 meters, a base width of 2 meters, and a sidewall slope of 1 (vertical) to 1.5 (horizontal) is considered for finite element analysis. To evaluate the effectiveness of the trapezoidal canal constructed on expansive soil, two independent numerical analyses were performed. Firstly, a trapezoidal canal is surrounded by expansive soil that does not swell. Secondly, a trapezoidal canal is surrounded by expansive soil with a swilling effect. The typical schemes of the model under consideration in this paper are illustrated in Fig. 1. The soil profile under consideration has an expansive soil layer with a thickness of 6 m and a stiff clay layer with a thickness of up to 15 m underneath it. The active zone was considered at various depths of 1 m, 2 m, and 3 m. Rainfall and surface water are assumed to be the only sources of wetness that influence the depth of the active zone.

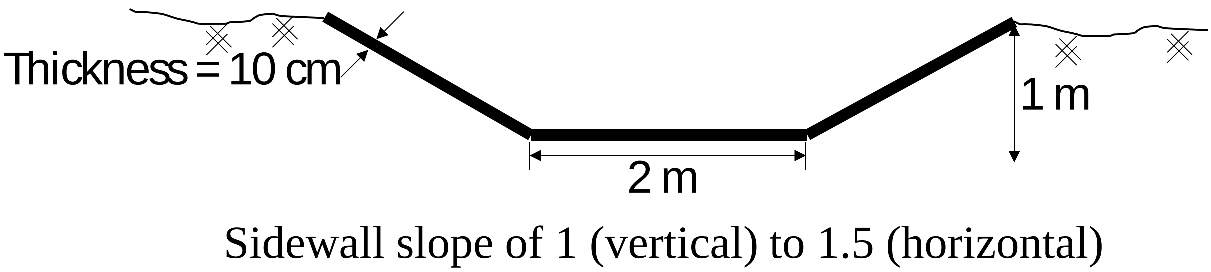

Fig.1. The geometry of a trapezoidal channel.

PLAXIS 3D software was used to create the finite element models (FEM). The soil layer profiles were modelled using borehole feature available in PLAXIS 3D. The Mohr-Coulomb material model with undrained conditions was used to model the expansive clay and stiff clay. The soil layer parameters were determined by previous research conducted at Wad Medani, Sudan [11]–[14]. The interaction between the concrete and the surrounding soils is automatically modelled by the PLAXIS 3D program [15]. The mesh size is refined to provide the greatest and most consistent performance. The boundary condition was taken as standard fixity in which roller supports are assumed for vertical boundary surface and entirely fixed state at the base of the soil bed. The concrete lining was created utilizing plate elements.Table 1 shows the material characteristics for expansive soil, and stiff clay. The parameters of the concrete lining are shown in Table 2.

Table .1. The value adopted for the FEM of soil layers.

Parameter	Expansive Soil	Stiff Clay
Unsaturated unit weight, (kN/m^3)	17	19
Saturated unit weight, (kN/m^3)	19	20
Cohesion, (kN/m^2)	60	200
Friction Angle, (°)	20	27
Elastic Modulus, (MPa)	10	50

Passion Ratio	0.3	0.4

It is critical to determine which zone of the soil is being irrigated and its expansion in order to determine the soil's heaviness [16]. The active zone of the expansive soil is defined by the moisture depths that were chosen to be 1 m, 2 m, and 3 m, In the wet active zone, the swelling deformation action is simulated by applying a positive volumetric strain to the active zone.Numerous researchers utilized this approach effectively to simulate the swelling of expansive soils, and it has proven to be effective[17]–[19].In-depth investigations were conducted in two cases. First, as illustrated in Fig.2., the active zone influences all trapezoidal canal sides and the base, and second, as illustrated in Fig.3., the active zone influences only one trapezoidal canal side. The initial phase was considered before applying swelling. The generation of initial affective based on the default k_0 procedure values is based on the formula $(1 - sin\phi)$for normally consolidated soils. The following stage is the calculation phase, which is divided into parts like the construction stage.

Table .2. Material properties of concrete channel.

Parameter	Values
Elastic modulus, (MPa)	30×10^3
Unit Weight,(kN/m^3)	24
Poisson's ratio	0.2
Thickness, (m)	0.4

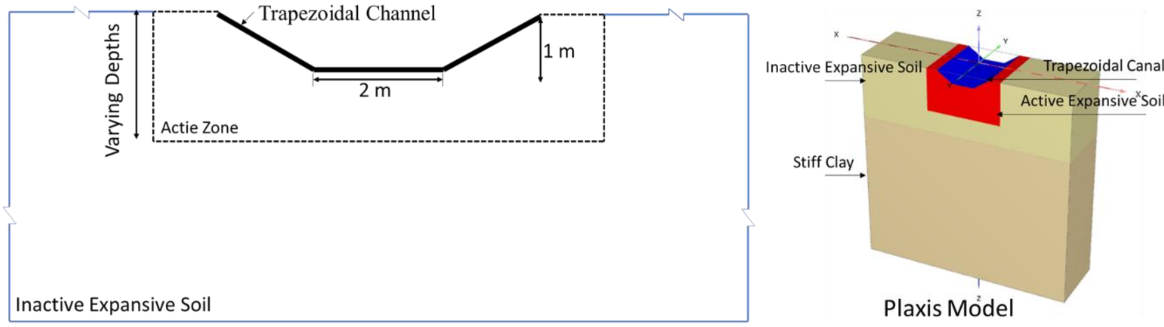

Fig. 2.A schematic representation of the model geometry Case No. 1: All trapezoidal canal sides are surrounded by an active zone.

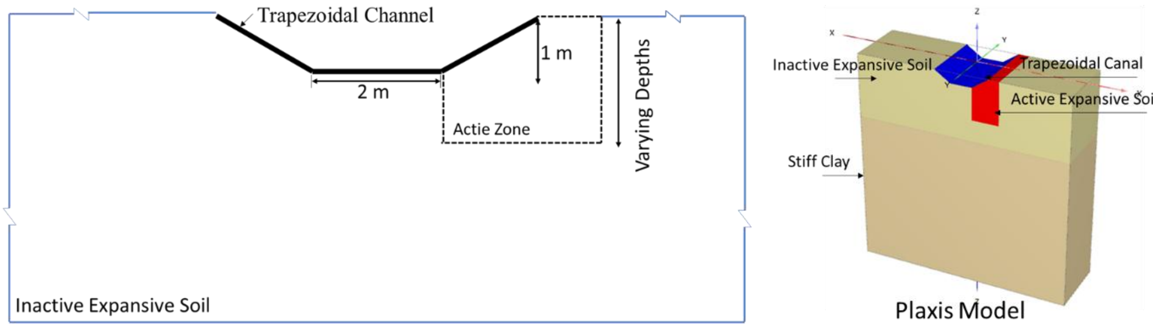

Fig. 3.A schematic representation of the model geometry Case No. 2: Only one trapezoidal canal side is affected by the active zone.

III. RESULTS AND DISCUSSION

Several numerical simulations were carried out in different scenarios to evaluate the deformations of the trapezoidal canal constructed on expansive soils. Using the assumptions stated above, the relevant results of deformationsat various points are calculated with varying amounts of swelling. The numerical results of these scenarios were obtained and explained in this section.

Vertical and Lateral Deformation

In this compression, the trapezoidal canal lies on a 6 m thick of expansive soil. The degree of swelling was simulated utilizing volumetric strain.The depth of the active zone in this comparison is fixed at 3m, and the volumetric strains assessed are 2.5 %, 5%, 7.5 %, and 10%. In-depth investigations were conducted in two cases. First, as illustrated in Fig. 2., the active zone influences all trapezoidal canal sides and the base, and second, as illustrated in Fig. 3., the active zone influences only one trapezoidal canal side. The deformation at the base and sides of the trapezoidal canal is shown in Fig.4. The deformation is divided into two parts: the vertical deformation, which generates the transformed position of the canal, and the lateral deformation, which produces the final deformation position of the canal sides. Whenever an active zone is applied from all trapezoidal canal sides, the sloped walls of the canal tend to displace towards each other.

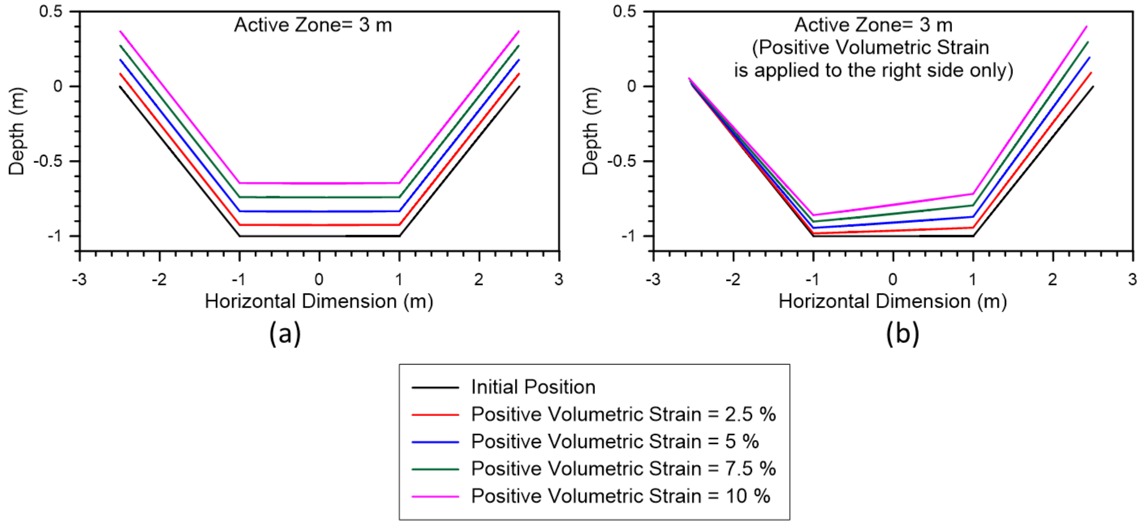

Fig. 4. Deformation of the trapezoidal canal because of applied volumetric strain at: a. all sides and base b. only the left side

Effect of Active Zone Depth

The depths of the active zone were evaluated at 1 m, 2 m, 3 m, and 4 m. The volumetric strain applied to all active zone depths is 5%. The maximum deformation of a trapezoidal canal is shown in Fig. 5. In general, deformation increases as the active zone under the trapezoidal canal increases.

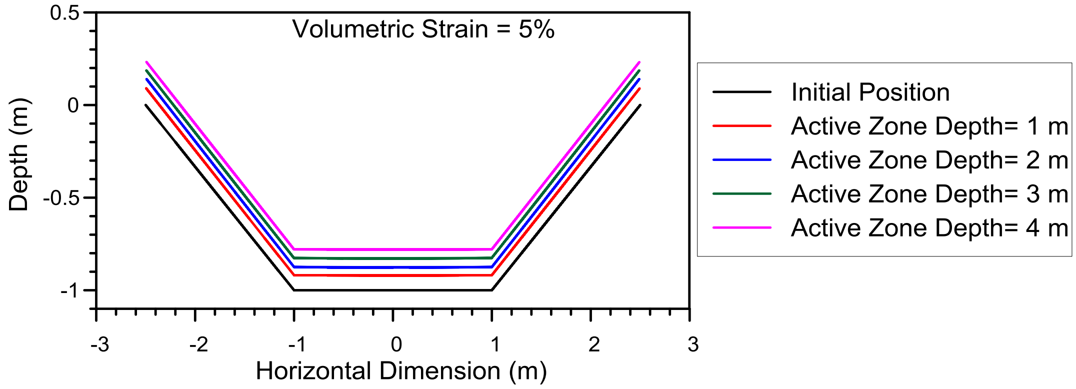

Fig. 5.The maximum deformation of a trapezoidal canal induced by variations in active zone depth.

IV. CONCLUSION

To properly design and construct canals in swelling soil, it is required to estimate the deformation of the canal due to swelling pressures. The designer must consider the forces that are conveyed from the swelling soil to the concrete lining and how they are distributed. The data collected from this model provides an insightful understanding of the canal deformation due to swelling pressures. Furthermore, if the material properties of the studied expansive soil area as well as the wetting process are known, a prediction of future heave deformation values can be established. The following conclusions were drawn from the findings of this research:

- Seasonal wetting and drying of the expansive soils surrounding the trapezoidal canal causes additional stresses in the canal frame, which can contribute to canal deterioration.
- The deformation caused by swelling soils beneath the canal can be classified into two parts: vertical deformation, which generates the transformed position of the canal, and lateral deformation, which generates the final deformation position of the canal sides. Vertical deformation is the most common type of deformation.

- Once an active zone is applied from all trapezoidal canal sides, the sloped walls of the canal tend to displace towards each other.
- The vertical deformation increases in proportion to the depth of the active zone under the trapezoidal canal.
- Based on the findings of this model, the locations of joints on the surface of a concrete lining can be optimized to limit the impacts of uplifting forces. Depending on the characteristics of a canal section, such as geometric characteristics and swelling potential of bed soil, the number and arrangement of joints should be specified.

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