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SOIL-STRUCTURE INTERACTION IN EXPANSIVE CLAYS
INTERACTION SOL-STRUCTURE EN LIMON EXPANSIF

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SYNOPSIS Structures founded on expansive clays can be damaged due to differential movements caused by wetting of the clay. The differential movements depend on a number of factors, including lateral variation of clay thickness and water content and nonuniformity of stresses below the structure. A simplified two dimensional finite element model is presented for the analysis of soil-structure interaction in expansive clays. The model has been used in the analysis of a large steel storage tank in an expansive clay, under various loading and wetting conditions. The model provides a simple method for evaluating the influence of various parameters and conditions, for structures in expansive clays.

INTRODUCTION

Expansive clays cover large areas of the earth. Problems associated with expansive clays include heaving and cracking of building foundations, slabs, pavements and channel linings. The damage can result from differential heave, resulting in differential movements between footings, distortion and large moments in continuous foundations and linings. Heave can also result in large tensile stresses in pile and pier foundations (Gromko 1974).

Heave in expansive clays depends on a number of factors including frequency of rainfall, rate of evaporation, depth and activity of the expansive clay. Differential heave below a structure depends on a number of factors including lateral variation in clay thickness and soil water content, nonuniformity of the soil and stresses in the ground below the foundation and other causes related to the use of the structure. Also construction of the structure results in a local modification of the natural processes around the structure, leading to a time varying lateral variation of the soil water content and hence differential heave below the structure(Gromko 1974). In addition, at high stress levels an expansive clay may undergo collaspe upon wetting. Thus under a structure, there may be regions of both heave and collase depending upon the stresses and change in soil water content(Justo and Saetersdal 1979).

In the past thirty years, a large amount of research has been conducted to study the behavior of expansive clays and a number of methods are available to estimate heave and collaspe under one dimensional conditions (Justo and Saetersdal 1979). Research has also been conducted to analyse structures founded in expansive clays. A number of models are available for the analysis of structures in expansive clays. These include simplified elastic models, Winkler type models and finite element models. Both strip and raft foundations (Lytton 1977, O'Neill and Poormoayed 1980, Poulos 1984) as well as pile and pier foundations (Amir and Sokolov 1976, Poulos and Davis 1980, Justo et al 1984) have been analysed. However analysis of expansive clays is complex, as the clay behavior is highly nonlinear and involves both air and water flow and coupled stress and deformation. A number of finite element models are available, which can solve the coupled air-water-stress-deformation problem (Lloret and Alonso 1980, Richard 1984). However these models require a large number of parameters, which are not well understood and difficult to determine. In addition the calculation is computationally expensive. On the other hand, the simplified models are not realistic and do not account for many important factors. Hence there is a need for simple but realistic models, which can provide usefull information to the designer.

A two dimensional finite element model for soil-structure interaction in expansive clays is presented. Nonlinear soil response, nonhomogeneous ground, nonuniform wetting and complex structures can be easily analysed. The parameters required for the analysis can be determined from conventional tests or emprical relations. The model has been used to to analyse a large diameter storage tank on a deposit of expansive clay. The influence of load level, depth of wetting and nonuniform wetting are analysed. The influence of replacing part of the expansive clay below the tank with a nonexpansive material is also analysed. The model provides a simple method for evaluating the influence of various parameters and conditions, for structures in expansive clays. The model can also be used to analyse rafts, piers, piles and other structures in expansive clays.

MODEL

A two dimensional axisymmetric finite element model for the analysis of structures in expansive clays is presented. Nonlinear response, nonhomogeneous ground, nonuniform wetting and complex loading and boundary conditions can be modelled. The response of expansive clays is very complex and ideally a coupled stress and deformation and air and water flow analysis is necessary. However for design purposes a simplified model may be sufficient.

The analysis consists of the following steps:
1. Determine the stresses and movements in the ground before wetting using the finite element method. The analysis may be linear or nonlinear. The hyperbolic model is used for nonlinear analysis. The parameters used in the analyses should be evaluated from samples tested at natural moisture content.

2. Determine the swell/collaspe versus pressure relationship (see figure 1). This may be determined from a number of commonly used tests and methods. (a) Free swell, swell pressure or direct methods (Holtz and Gibbs 1954), (b) McDowells method using free swell (McDowell 1956), (c) Double oeodemeter tests (Jennings and Knight 1957) and (d) Procedures based on changes in suction (Fredlund 1979). As the behavior of expansive clays is path dependent, the parameters should be determined from tests that follow the field loading and wetting paths as closely as possible.

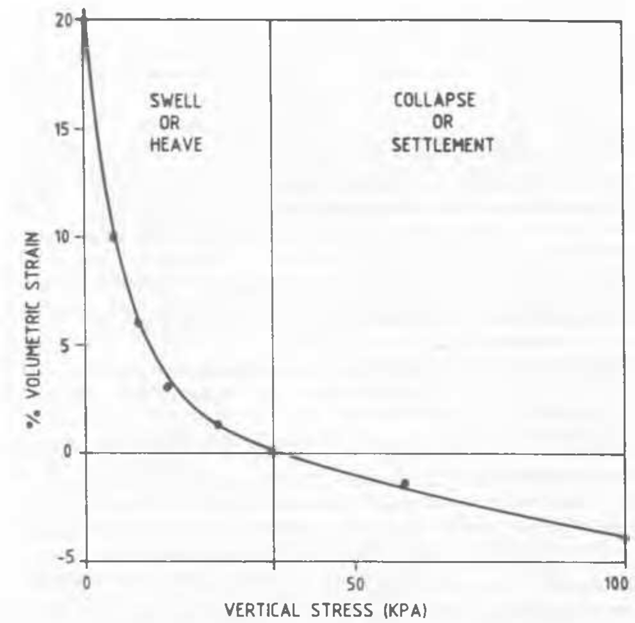

FIG.1 SWELL/COLLAPSE - PRESSURE RELATIONSHIP

3. The swell or collaspe is converted into a load vector and applied in a second finite element analysis to determine the respone due to wetting.

$$R = \int_v B^T D \epsilon_s dv \qquad (1)$$

R = Load vector
B = Strain displacement matrix
D = Stress strain matrix
ϵ_s = Strain vector due to wetting

The analysis may be linear or nonlinear. It should be noted that it is assumed that the zone of wetting is fully saturated in the determination of the parameters. Although the soil below a structure may not be saturated and the degree of saturation may vary with time, for design purposes, this is likely to be the critical case.

RESULTS AND DISCUSSION

The model has been used to analyse a large 40 M diameter steel storage tank on a deposit of expansive clay. The site consists of a deposit of potentially expansive clay 10 M thick, underlain by a stiff layer. A linear variation of the modulus is assumed, with an average modulus of 7250 Kpa. The Poissons ratio is assumed as 0.35. The swell/collaspe-pressure relationship illustrated in Figure 1 is used in the analysis. As the tank bottom is flexible, the tank is modelled as a uniform circular load on the clay surface. The influence of load level, depth of wetting and nonuniform wetting are analysed. The influence of replacing the expansive clay below the tank by a nonexpansive material is also investigated. Although steel storage tanks are flexible structures and can tolerate large settlements, distortion of the tank bottom due to uneven movements can cause problems. Allowable distortion limits are given in various codes of practice.

Figures 2 and 3 illustrate the movements of the tank bottom due to uniform and nonuniform wetting for an empty and loaded tank. Three types of wetting are considered (a) a uniform wetting of the ground upto a depth of 3.0 M (b) Nonuniform (edge) wetting of the ground upto a depth of 3.0 M and penetrating one third of the tank radius from the tank edge below the tank and (c) Nonuniform (center) wetting of the ground upto a depth of 3.0 M and limited to a distance of two-thirds of the tank radius from the tank center. For the empty tank, uniform wetting results in an uniform heave of 87 mm. Nonuniform wetting results in large distortions of the tank bottom, specially near the tank edge. In case of the loaded tank, uniform wetting results in collaspe below the tank and heave outside. Nonuniform edge wetting causes large distortions near the tank edge. Nonuniform center wetting results in collaspe below the tank center, with little movements outside the wetted area. Thus under wetting, the ground undergoes both heave and collaspe depending on the loading and this increases the tank bottom distortions.

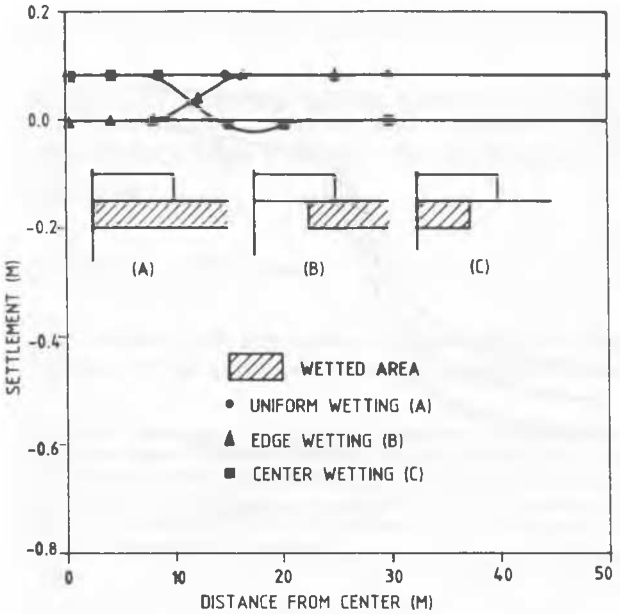

FIG.2 INFLUENCE OF NON-UNIFORM WETTING - EMPTY TANK

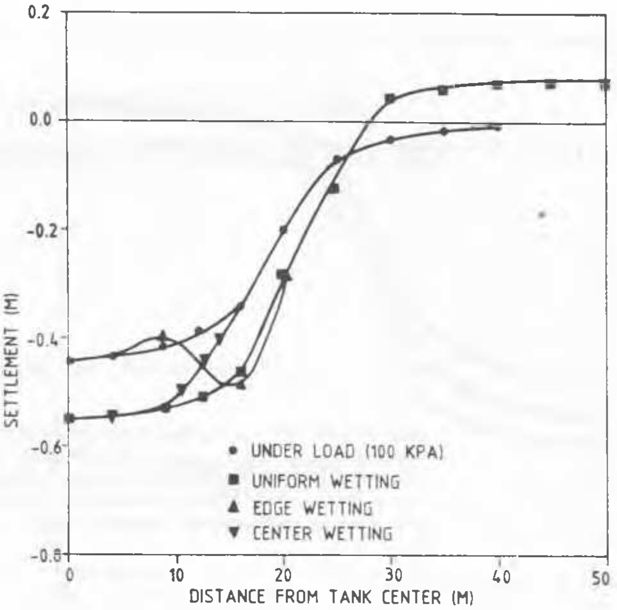

FIG.3 INFLUENCE OF NON-UNIFORM WETTING ON TANK SETTLEMENTS - LOADED TANK

Figure 4 illustrates the influence of depth of wetting on the tank bottom movements for the loaded tank. Two cases are considered (a) uniform wetting upto a depth of 3.0 M and (b) uniform wetting upto a depth of 1.5 M. For both cases, the ground collaspes below the tank, with heave outside. The collaspe is larger for the the wetting depth of 3.0 M as a larger depth of wetting is involved. However the difference in heave outside the tank is small. This is because most of the heave occours in the top 1.5 M of the expansive clay.

Figure 5 illustrates the influence of replacing the top 1.5 M of the expansive clay with an nonexpansive material of simmilar density and stiffness below the loaded tank. The ground below the tank undergoes collaspe, while a small amount of heave takes place outside. Thus replacing the expansive clay by an nonexpansive material reduces the heave to a small value. However collaspe does take place below the loaded tank, although it is significantly reduced. For an empty tank, the movements and distortions would be very significantly reduced.

CONCLUSIONS

A simple two dimensional finite element model for the analysis of soil-structure interaction in expansive clays is presented. The model has been used in the analysis of a large steel storage tank in an expansive clay, under various loading and wetting conditions. On wetting, the ground below the tank undergoes both heave and collaspe depending on the loading. Nonuniform wetting increases the tank bottom distortion. Increasing the depth of wetting results in larger collaspe below the tank, but results in a small increase in heave outside. Replacing the top of the expansive clay by an nonexpansive material, significantly reduces heave outside and also the reduces the collaspe below the tank.

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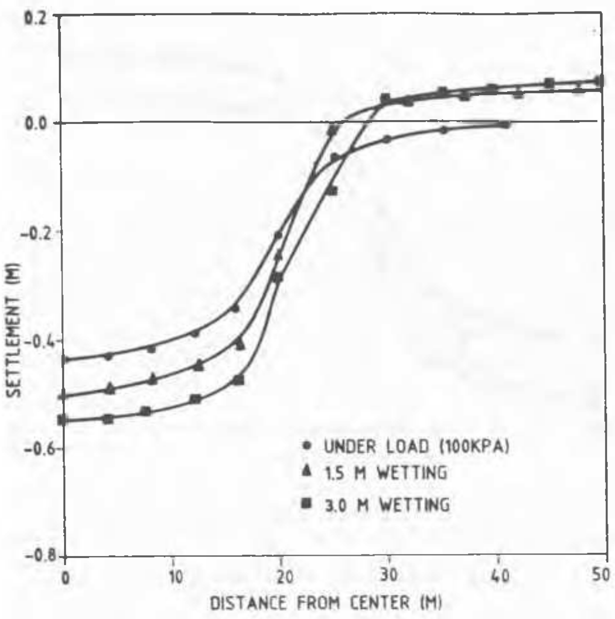

FIG.4 INFLUENCE OF DEPTH OF WETTING ON TANK SETTLEMENTS

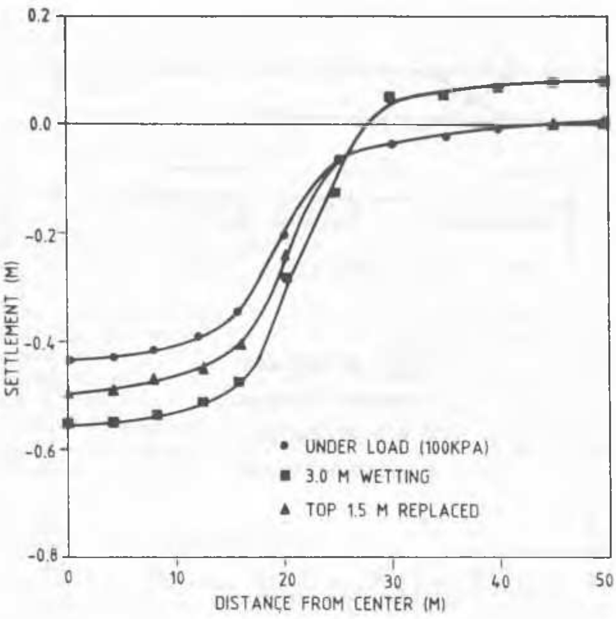

FIG.5 INFLUENCE OF REPLACING TOP 1.5M OF EXPANSIVE SOIL ON TANK SETTLEMENTS

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