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# Numerical Analysis of deformation of foundation in the process of constructing soil dam

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**Key words:** Drucker-Prager model; Sand Well; Equivalent Sand Wall; Finite Element Method;

**Abstract.** Matching Mohr-Coulomb parameters to the Drucker-Prager model is deduced and the method of transferring to equivalent sand wall in drain pile ground is introduced in detail. Numerical simulation is conducted in the process of constructing soil dam. The results show that the maximum vertical displacement happens in the center of the dam and the maximum horizontal displacement happens in the toe of the dam. The numerical method in this paper may be used to predict the consolidation process in drain pile ground in the process of constructing soil dam. Those results gained by numerical method may provide reference to engineering practice.

## Introduction

When dams, embankments and other buildings are constructed, stress of foundation soil will vary, which will change deformation of foundation[1-3]. Many research results show that in the earth-rock dam or other foundations, when they are constructed, there exists obvious deformation, which will require additional soil filled. Therefore it is important to calculate deformation of foundation in the process of constructing dam and other buildings. Accurate calculation results are helpful for assessing project cost[4-5].

Mohr-Coulomb model and Drucker-Prager model are the most two commonly used models because few parameters are required and they are easily obtained by experiment. This paper deal with Matching Mohr-Coulomb parameters to the Drucker-Prager model in detail. Numerical simulation is conducted in the process of constructing soil dam.

## Matching Mohr-Coulomb parameters to the Drucker-Prager model

Plane strain problems are often encountered in geotechnical analysis; for example, long tunnels, footings, and embankments. Therefore, the constitutive model parameters are often matched to provide the same flow and failure response in plane strain.

The matching procedure described below is carried out in terms of the linear Drucker-Prager model but is also applicable to the hyperbolic model at high levels of confining stress.The linear Drucker-Prager flow potential defines the plastic strain increment as

$$d\varepsilon^{pl} = d\bar{\varepsilon}^{pl}\frac{1}{(1-\frac{1}{3}\tan\psi)}\frac{\partial}{\partial\boldsymbol{\sigma}}(t - p\tan\psi), \tag{1}$$

where $d\bar{\varepsilon}^{pl}$is the equivalent plastic strain increment. Since we wish to match the behavior in only one plane, we can take $K = 1$, which implies that $t = q$. Thus,

$$d\boldsymbol{\varepsilon}^{pl} = d\bar{\varepsilon}^{pl} \frac{1}{(1-\frac{1}{3}\tan\psi)} \left( \frac{\partial q}{\partial \boldsymbol{\sigma}} - \tan\psi \frac{\partial p}{\partial \boldsymbol{\sigma}} \right). \tag{2}$$

Writing this expression in terms of principal stresses provides

$$d\varepsilon_1{}^{pl} = d\bar{\varepsilon}^{pl} \frac{1}{(1-\frac{1}{3}\tan\psi)} \left( \frac{1}{2q}(2\sigma_1 - \sigma_2 - \sigma_3) + \frac{1}{3}\tan\psi \right), \tag{3}$$

with similar expressions for $d\varepsilon_2^{pl}$ and $d\varepsilon_3^{pl}$. Assume plane strain in the 1-direction. At limit load we must have $d\varepsilon_1{}^{pl} = 0$, which provides the constraint

$$\sigma_1 = \frac{1}{2}(\sigma_2 + \sigma_3) - \frac{1}{3}\tan\psi\, q.$$

Using this constraint we can rewrite $q$ and $p$ in terms of the principal stresses in the plane of deformation, $\sigma_2$ and $\sigma_3$, as

$$q = \frac{3\sqrt{3}}{2\sqrt{9-\tan^2\psi}}(\sigma_2 - \sigma_3), \tag{4}$$

and

$$p = -\frac{1}{2}(\sigma_2 + \sigma_3) + \frac{\tan\psi}{2\sqrt{3(9-\tan^2\psi)}}(\sigma_2 - \sigma_3). \tag{5}$$

With these expressions the Drucker-Prager yield surface can be written in terms of $\sigma_2$ and $\sigma_3$ as

$$\frac{9-\tan\beta\tan\psi}{2\sqrt{3(9-\tan^2\psi)}}(\sigma_2 - \sigma_3) + \frac{1}{2}\tan\beta(\sigma_2 + \sigma_3) - d = 0. \tag{6}$$

The Mohr-Coulomb yield surface in the $(2,3)$ plane is

$$\sigma_2 - \sigma_3 + \sin\phi(\sigma_2 + \sigma_3) - 2c\cos\phi = 0. \tag{7}$$

By comparison,

$$\sin\phi = \frac{\tan\beta\sqrt{3(9-\tan^2\psi)}}{9-\tan\beta\tan\psi}, \tag{8}$$

$$c\cos\phi = \frac{\sqrt{3(9-\tan^2\psi)}}{9-\tan\beta\tan\psi}\, d. \tag{9}$$

These relationships provide a match between the Mohr-Coulomb material parameters and linear Drucker-Prager material parameters in plane strain. Consider the two extreme cases of flow definition: associated flow, $\psi = \beta$, and nondilatant flow, when $\psi = 0$. For associated flow

$$\tan\beta = \frac{\sqrt{3}\sin\phi}{\sqrt{1+\frac{1}{3}\sin^2\phi}} \quad \text{and} \quad \frac{d}{c} = \frac{\sqrt{3}\cos\phi}{\sqrt{1+\frac{1}{3}\sin^2\phi}}, \tag{10}$$

and for nondilatant flow

$$\tan\beta = \sqrt{3}\sin\phi \quad \text{and} \quad \frac{d}{c} = \sqrt{3}\cos\phi. \tag{11}$$

In either case $\sigma_c^0$ is immediately available as

$$\sigma_c^0 = \frac{1}{1 - \frac{1}{3}\tan\beta} d. \tag{12}$$

The difference between these two approaches increases with the friction angle; however, the results are not very different for typical friction angles.

## The Method of Transferring to Equivalent Sand Wall

The arrangement of sand-wells can increase the speed of consolidation for being shortened the drainage distance. At present, there are generally two kinds of equivalent plane strain methods for sand-well foundation. One is converting sand-well foundation into crude stratum with greater permeability coefficient, the other is transferring sand-well foundation into Equivalent Sand-wall. This paper adopts the latter.

The method of transferring to Equivalent Sand Wall is realized by treating the originally discrete distributed sand drain by the roadbed or dam as continuous sand wall longitudinally distributed in rows, so the foundation can be analyzed as a problem of plane strain. In Reference[5], the theoretical solutions of bidirectional stress and seepage of sand wall foundation were deducted, and compared with Barron's solution of axial symmetry. In the condition of constant degree of consolidation or average pore pressure, the equivalent method of plane strain problem of sand wall and axial symmetry sand drain was achieved. Where the factors are adjusted as follows:

$$k_{xp} = D_x \bullet k_{ra} \qquad k_{zp} = D_z \bullet k_{za} \tag{13}$$

$$D_x = \frac{4(n_p - s_p)^2(1+\upsilon)L^2}{9n_p^2\mu_a - 12\beta(n_p - s_p)(s_p - 1)(1+\upsilon)L^2} \qquad D_z = \frac{2(1+\upsilon)}{3} \tag{14}$$

## Engineering Application

One soil dam is built above a recently sedimentary silt of a lake base, with a depth of 7-10m, underlying by a 7m depth of silt soil and base rock. The physical and mechanical properties of the foundation soil are shown in Table.1. The width of the dam base is 44m, the ratio of the slope is 1:2, the thickness of filling soil is 10m, and the period of operation is 200d. The plastic drainage plate method is applied to consolidate the foundation. First, a cofferdam was constructed and fluidized silt discharged by mud pump. Then a layer of 1m clay was laid to enhance the strength of the ground to enable the movement of the plastic plate plugging machine. A cushion layer of 50cm medium to coarse sand was laid over the silty clay as the path of horizontal drainage. The distribution of the plastic drainage plate is club, with a interval of 1.5m. The plate is placed about 0.5m in the mild clay.

Table.1. Parameters of Drucker-Prager model;

| soil | $\gamma_d$ /(kN/m3) | c(kpa) | $\phi$ | e | $k_z$/(m/s) | $k_r$/(m/s) |
|---|---|---|---|---|---|---|
| Filling soil | 18.5 | 24 | 18 | 0.8 | $5.8\times10^{-9}$ | $6.7\times10^{-9}$ |
| Silt soil | 16.2 | 7 | 10 | 1.0 | $2.21\times10^{-9}$ | $2.91\times10^{-9}$ |

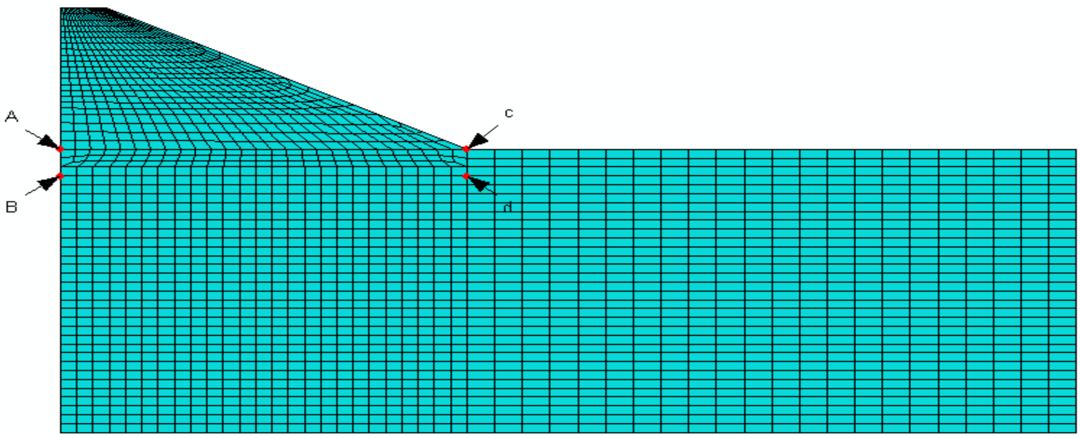


Fig.1 . FE mesh of the dam

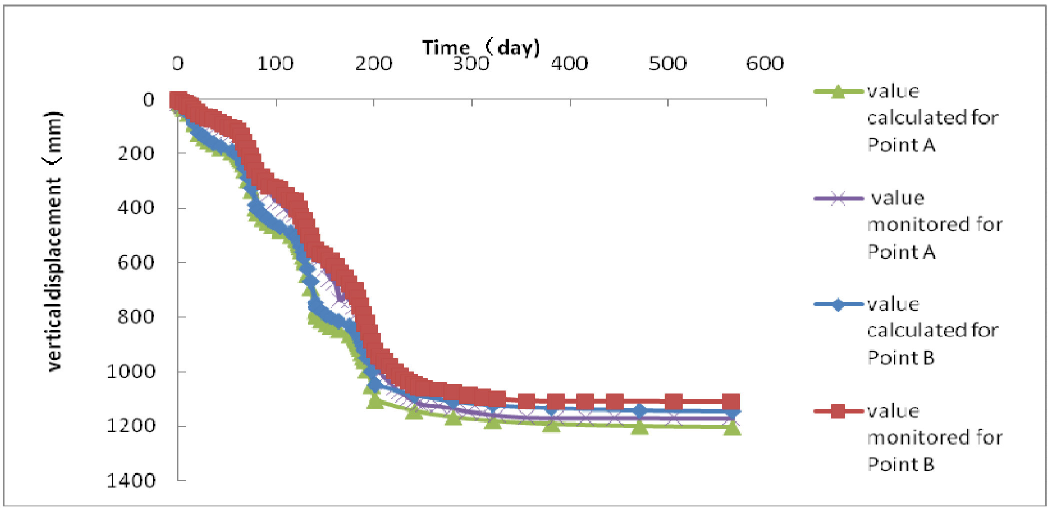


Fig.2. Relationship between vertical displacement and time at the centre of the dam

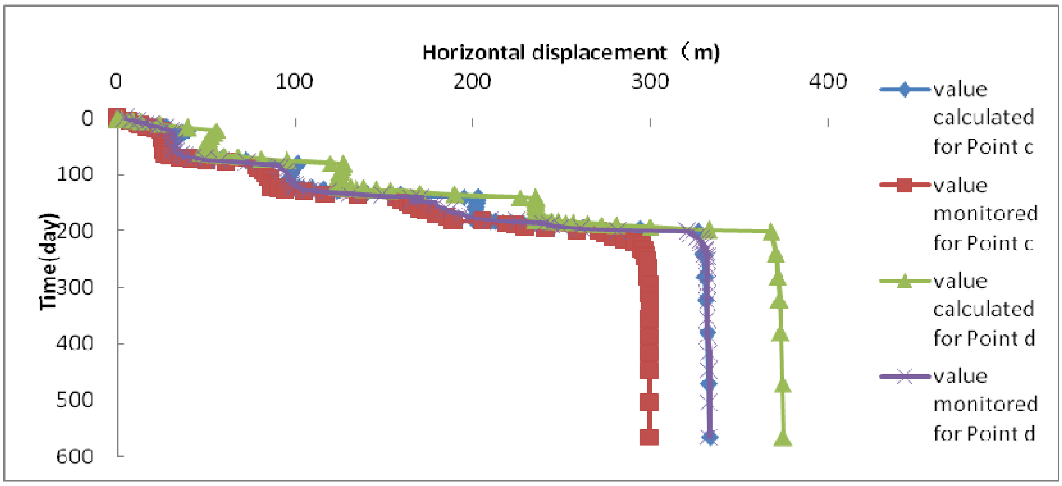


Fig.3. Relationship between horizontal displacement and time at the toe of the dam

## Conclusions

Figure.2 shows that the vertical displacement of the center line under the dam continues to grow, but at a rate significantly higher than during preloading intermittent period. The results monitored have similar variation. When construction is completed, the vertical displacement calculated and the vertical displacement monitored for point A are respectively 110cm and 103cm, and the vertical displacement calculated and the vertical displacement monitored for Point B are respectively 105cm and 97cm. When construction is completed after one year, the vertical displacement calculated and the vertical displacement monitored for point A are respectively 119cm and 117cm, and the vertical displacement calculated and the vertical displacement monitored for Point B are respectively 114cm and 112cm. The vertical displacements calculated and monitored come and go with regularity.

From Fig.3, it is can be seen that the maximum horizontal displacement of the surface happens at the foot of the slope, and the preload position near the center is slightly below the surface. When construction is completed, the horizontal displacement calculated and the horizontal displacement monitored for point C are respectively 31cm and 27cm, and the horizontal displacement calculated and the horizontal displacement monitored for Point D are respectively 35cm and 31cm. When construction is completed after one year, the horizontal displacement calculated and the horizontal displacement monitored for point C are respectively 32cm and 28cm, and the horizontal displacement calculated and the displacement monitored for Point D are respectively 36cm and 33cm. The horizontal displacements calculated and monitored come and go with regularity.

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