The Use of Models in the Study of Stresses During Soil Compaction

Stress-tensor analysis by using experimental models and the determination of simulation relationships during soil compaction

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ABSTRACT—In the present study, it is described the experimental method for measuring the direction and the magnitude of stresses during mechanical soil compaction.

These stresses result in an increase in soil density. The greatest effect during the compaction results from developing a vertical component of stress in the soil. This component of stress can be measured experimentally.

This stress is a function of many soil factors and the characteristics of the compaction machine. Considering the particular and, in many aspects, unknown processes of these effects on the compaction, the determination of soil compaction with models becomes very difficult.

The system equation in the model is obtained by means of dimensional and numerical analysis using special computer programs.

Symbols

\[ C = \text{cohesion of the soil} \]
\[ \rho = \frac{\gamma}{g} = \text{wet-bulk density of the soil} \]
\[ W = \text{best relative-moisture soil} \]
\[ U = \text{coefficient of soil uniformity} \]
\[ \phi = \text{angle of soil friction} \]
\[ D = \text{diameter of the cylinder} \]
\[ B = \text{width of the cylinder} \]
\[ g = \text{acceleration due to gravity} \]
\[ G = \text{specific loading of the cylinder} \]
\[ J = \text{number of passes of the cylinder} \]
\[ S = \text{vertical component of stress inside the soil} \]
\[ Z = \text{effective depth of the soil} \]

Other notations are defined in the text.

Introduction

In order to increase the soil strength when roads, foundations, etc. are under construction, an increase in soil density is necessary. This is achieved mainly with mechanical compaction by cylinders, plates, etc.

In this paper, the soil is considered as an elastic-plastic material of semi-infinite extension, on the surface of which there are forces due to compaction by cylinders of specific loading G, width B, diameter D, rolled over the soil a number of passes J.

The distribution of the created stresses (tensor) inside the soil mass depends on the type of cylinder (towed or self-propelled cylinder)\(^1\) and the soil characteristics cohesion C, density \(\rho\), relative best moisture W, coefficient of uniformity U, angle of friction \(\phi\), etc.

In any case, here the distribution of stresses differs, in general, from the one of Boussinesq,\(^2\) because he considers the soil as being an elastic means, while, in fact, it is an elastic-plastic one.\(^3\)

During the experimental process, the tensor of the stresses on a given point in the soil, a depth \(Z\) from its surface, is considered as a basic element for the research and the resulting compaction.

The investigation of stresses in metallic materials is facilitated by the fact that there exists uniformity in the mass of the material resulting in a limited number of random values.

Because of the developing nonuniformity in soil, the random values of the soil mass are usual and the stochastic element is intensely present.\(^4\)

To measure the developing stresses, it is necessary to build an instrument which is so sensitive that it can be adapted to the sensitivity of the soil.

Experiments

The greatest effect on the soil compaction is exerted by the maximum vertical stress \(S\). That is, the vertical component of the stress on a point of the soil which lies in a depth \(Z\) from the surface.

The stresses in the soil are developed during the pass of the cylinder (Fig. 2) and are measured when its center of gravity passes by the vertical which goes through the measuring point.

The stresses are measured with a special electronic instrument, which operates with frequency modulation and consists of the following parts:

1. An oscillator circuit of frequency \(f_1\), which corresponds to the stress gage inside the soil
2. An oscillator circuit of frequency \(f_2\), which corresponds to an adjustable capacitor of the instrument
3. A mixing circuit of the frequencies \(f_1\) and \(f_2\)
4. A gage circuit, which is laid inside the soil

The indicator of the instrument shows the frequency difference \(f_1-f_2\) (see Fig. 1).

The instrument has the following advantages: \(^5\)

1. It has the best combination of spring constants for the measurement of relatively small stresses.
and the avoidance of unacceptable vibrations.

(2) There exist no moving parts which could cause errors due to inertia and friction forces.

(3) The output of the magnitude and the form of the stress being measured is very satisfactory, because of the best response of its parts.

(4) The calibration of the instrument is easy.

The experimental procedure was as follows: Three different kinds of soil were used: one noncohesive, one cohesive and one being a combination of the two. The soil characteristics were measured after each pass of the compaction cylinder.

The soil density changes after each pass of the compaction cylinder (see Fig. 3); moreover, because of the existing nonuniformity, the similarity requirements in the scale terms of the soil remain constant.

The characteristics of the compaction machine do not change with each pass and, therefore, the similarity requirements in the scale terms remain constant and can be carried to the prototype.

The developing stresses S in depth Z are measured on each pass of the cylinder, by means of the stress gage laid inside the soil.

The characteristics of the compaction cylinders and the kinds of soil used for the experiment are shown in Table 1.

Method of Solution

During the experiments, J, γ, Z and S do change, while the characteristics given in Table 1 for the machine and soil remain constant. Buckingham's theorem was used to find the model equation. The Pi terms are the soil and machine factors, which are considered as variables.

The following general relationship is formed, which is the model equation:

\[ R \left( \frac{G_m}{S_m Z_m}, \frac{D_m}{Z_m}, \frac{B_m}{Z_m}, \gamma_m Z_m, \frac{C_m}{S_m} \right) \left( U_m, W_m, \varphi_m, J_m \right) = 0 \]  

Solving eq (1) to find S_m is not recommended. Rather, it is solved with respect to J_m. Then, we get the following results:

\[ J_m = J_m \left( \frac{G_m}{S_m Z_m}, \frac{D_m}{Z_m}, \frac{B_m}{Z_m}, \gamma_m Z_m, \frac{C_m}{S_m} \right) \left( U_m, W_m, \varphi_m \right) \]  

The calculation of S_m becomes possible with the use of a special interpolation computer program.

During the J_m pass of the compaction machine from a point J of the soil, the dimensionless terms of eq (2) assume the values:

\[ \left( \frac{G_m}{S_m Z_m} \right)_{J_l} \left( \frac{D_m}{Z_m} \right)_{J_l} \left( \frac{B_m}{Z_m} \right)_{J_l} \left( \gamma_m Z_m \right)_{J_l} \left( \frac{C_m}{S_m} \right)_{J_l} \]  

The values of S_m, γ_m, Z_m are measured by means of special instruments.

Temporarily, the terms U_m = U, W_m = W, ϕ_m = ϕ will not be taken into account, but they will be introduced into the final relationship.

Equation (2) can be written with the form:

\[ J_{mlp} = \sum_{i=0}^{\infty} \sum_{l=0}^{\infty} \sum_{n=0}^{\infty} \sum_{r=0}^{\infty} \sum_{p=0}^{\infty} C_{mlp} \left( G_m \right)_{J_l} \left( D_m \right)_{J_l} \left( B_m \right)_{J_l} \left( \gamma_m Z_m \right)_{J_l} \left( \frac{C_m}{S_m} \right)_{J_l} \]  

It has been proved that, in this relationship,