

Andrzej Surowiecki - Zenon Zamiar *

MODEL ZEMNÉHO ZÁKLADU S VYSTUŽENÍM V HLBOKOM VÝKOPE

MODEL OF EARTHEN FOUNDATION WITH REINFORCEMENT IN A DEEP EXCAVATION

V tomto článku sú uvedené výsledky modelu skúmania silových charakteristík pre prípad vodorovne vystuženej sypkej zeminy. Charakteristické veličiny sú teda využité pre vytvorenie modelu s vertikálnou výstužou. Vertikálne vystuženie bolo navrhnuté pre model zemného základu v hlbokom výkope, v ktorej zemina dna je určená na výmenu.

In this paper, the results of model investigation of strength characteristics are discussed for the case of horizontally reinforced loose soil medium. The characteristics are then employed to create a model with vertical reinforcement. The vertical reinforcement has been proposed for the model of earthen foundation in a deep excavation whose bottom is subjected to displacement.

1. Introduction

The paper presents the adaptation of a classical reinforced soil-testing stand for the model with vertical reinforcement.

Investigation results for the model with vertical reinforcement will be applied in the strengthening of a deep excavation bottom subjected to the horizontal pressure exerted by surrounding soil medium. Schema of problem is presented in Fig. 1.

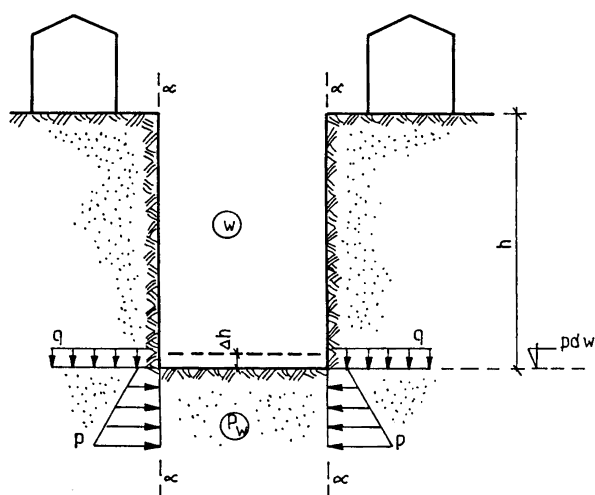


Fig. 1 Schema of problem: w - excavation, pdw - bottom level of excavation, h - excavation depth, Δh - measure of soil displacement from under the excavation bottom, q - pressure in bottom level of excavation from soil overlay, p - horizontal pressure of soil medium in intersections $\alpha - \alpha$, which enclose the excavation, p_w - subsoil of excavation

2. Model description

The subject of testing is a non-cohesive soil sample of cubic or rectangular shape, reinforced horizontally by means of inserts laid in layers with the spacing e_z . The particular layers are made of parallel strips placed with even horizontal spaces e_x . The reinforcement layer planes are perpendicular to the direction of static load. The model investigated is presented in Fig. 2. The reinforced soil is treated as a composite material.

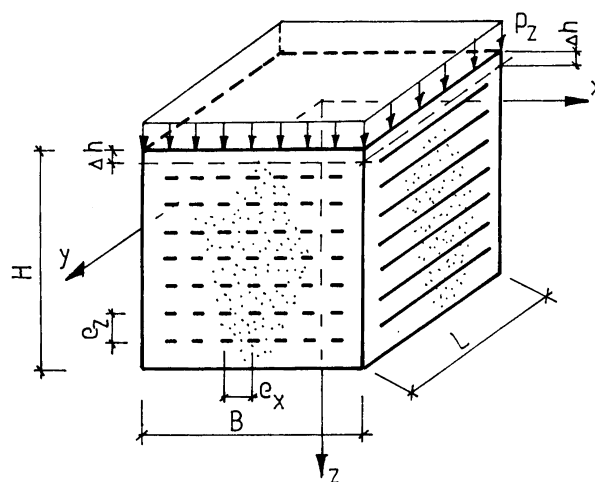


Fig. 2. Model diagram: unitary load p_z

The studies are aimed at determining the macroscopic mechanical features of a composite material, especially the effect

* ¹Dr.hab. inž. Andrzej Surowiecki, ²Doc. inž. Zenon Zamiar

¹Institute of Civil Engineering, Wrocław University of Technology, Wyb. Wyspiańskiego 27, 50-370 Wrocław, Department of Military Engineering, T. Kosciuszko Military University, Obornicka 108, 51-100 Wrocław, Poland

²Department of Military Engineering, T. Kosciuszko Military University, Obornicka 108, 51-100 Wrocław, Poland

of reinforcement on soil cohesion and internal friction angle as well as the deformation module.

The analysis of reinforced soil is carried out on the basis of the results of tests performed on a large-size lab model by means of a comparative analysis - the "reference" is made up of a non-reinforcement medium model.

The lab test data, referring to the model, necessary to calculate the strength parameters of the reinforced medium include:

- p_z - minimum unitary load necessary to create the limiting condition of the sample's active pressure (the so-called calculation load) [MPa];
- $p_{z,e}$ - unitary load exerted on the sample in the range of elastic deformations [MPa];
- p_y - horizontal pressure created by the load p_z [MPa];
- Δh - vertical deformation of the soil sample measured by the mean vertical displacement of a special plate loading the soil sample [m].

3. Lateral pressure coefficient

The pressure coefficient K_a in the equation of the limiting condition of the sample was calculated from the following dependence:

$$K_a = p_y (p_z)^{-1} \text{ for non-reinforced soil} \quad (1)$$

and

$$K_a^* = p_y^* (p_z)^{-1} \text{ for reinforced soil sample.} \quad (2)$$

The pressure coefficient K_a allows us to estimate the increase in a load capacity of soil due to the reinforcement and to calculate the shear strength of reinforced soil. The value of this coefficient depends on the quantity and distribution of the reinforcement. The model tests imply that in reinforced soil the value of K_a^* is smaller compared to a sample of soil with no reinforcement.

4. Effect of load capacity increase

The possibility of increasing the load p_z at steady lateral pressure p_y is treated as a measure of the increase in the load capacity of reinforced soil compared to non-reinforced soil.

The experimental coefficient of the lateral pressure K for a non-reinforced sand sample (reference sample) is as follows:

$$K = p_{y,mean} (p_z)^{-1} \quad (3)$$

where $p_{y,mean}$ is mean lateral pressure exerted on the surface of a wall of the width B obtained empirically.

The experimental coefficient of pressure K^* for a reinforced soil sample was calculated from the following formula:

$$K^* = p_{y,mean}^* (p_z)^{-1} \quad (4)$$

where: $p_{y,mean}^*$ - mean lateral pressure obtained empirically,
 p_z - external load (treated as vertical stress in the sample).

By adopting the horizontal stress p_y , mean in non-reinforced soil as the basis, it is possible to determine the dependence between the load p_z exerted on non-reinforced soil and the load p_z^* exerted on reinforced soil with the proportionality coefficient $1/K^*$:

$$p_z^* = p_y^* (K^*)^{-1} > p_z, \quad p_z^* = p_y^* (p_{y,mean}^*)^{-1} \quad (5)$$

where: $p_y^* = p_{y,mean}^*$ - basic vertical stress,
 p_z^* - maximum external load, which can be exerted on a reinforced soil sample unless the horizontal pressure p_y^* is exceeded.

The effect of the increase in the load capacity of a sample due to the reinforcement is expressed by the difference between the maximum load p_z^* exerted on reinforced soil sample and the maximum load p_z exerted on the reference sample:

$$\Delta p_z = p_z^* - p_z > 0 \quad (6)$$

or, in other way, by the quotient of the same maximum loads:

$$\delta p_z = p_z^* (p_z)^{-1} > 1.0 \quad (7)$$

The model tests imply that, depending on the change of reinforcement position, one can control the load capacity of a soil sample. The appropriate position is of critical economic importance: a smaller number of reasonably placed inserts brings about a higher increase in soil load capacity than a greater number of such inserts placed accidentally.

5. Shear strength of a reinforced soil sample

5.1. General remarks

The model of loose reinforced soil is analysed according to two cases:

Case I: Loose soil is treated as soil with no cohesion. In such a type of soil, the value of the internal friction angle increases due to the reinforcement. Hence, the following dependences are valid:

$$c = 0; \Delta\varphi > 0. \quad (8)$$

Case II: In a pressure-limiting condition, loose reinforced soil behaves like an anisotropic cohesive medium of the internal friction angle as in non-reinforced soil, but displaying features implying cohesion proportional to the values of the tensile forces transferred through the reinforcement. Then, the model is described by the dependence:

$$c > 0; \Delta\varphi = 0. \quad (9)$$

5.2. The effect of internal friction increase in reinforced soil (case I)

The assumption that the sample remains in the limiting condition of active pressure is valid.

Hence, the values p_z , p_y and the pressure coefficient K were treated as extreme and the notation K_a was accepted. Having inserted the values p_z and p_y into the classical limiting condition equation, it is possible to determine the effect of increasing the angle in the soil due to the reinforcement. Such a procedure was recognised permissible in order to compare quantitatively the mechanical features of physical models of non-reinforced and reinforced soils subject to identical test conditions.

The limiting condition requirement for non-reinforced soil with no cohesion has the following form:

$$p_y (p_z)^{-1} = \operatorname{tg}^2 (45^\circ - 0.50\varphi) = K_a \quad (10)$$

and, analogically, for reinforced soil:

$$p_y^* (p_z)^{-1} = \operatorname{tg}^2 (45^\circ - 0.50\varphi) = K_a^* \quad (11)$$

Formulas (10) and (11) allow us to calculate the internal friction angle:

- in non-reinforced soil sample

$$\varphi = 90^\circ - 2 \operatorname{arctg} (K_a)^{0.5}, \quad (12)$$

- in reinforced soil sample

$$\varphi^* = 90^\circ - 2 \operatorname{arctg} (K_a^*)^{0.5} \quad (13)$$

There also exists a dependence:

$$\varphi^* > \varphi, \Delta\varphi = \varphi^* - \varphi \quad (14)$$

where φ means the effect of internal friction angle increase.

Having determined the values of φ and φ^* from formulas (12) and (13), we calculated the shear strength of soil from the Coulomb formula [3] for loose soils:

- in non-reinforced soil sample

$$\tau_f = p_z \operatorname{tg} \varphi, \quad (15)$$

- in reinforced soil sample

$$\tau_f^* = p_z \operatorname{tg} \varphi^* \quad (16)$$

5.3. The effect of cohesion in loose reinforced soil (case II)

According to [2], in the considered case of the reinforced soil sample, the destruction curve (Fig. 3) is, in the system of vertical (p_z) and horizontal (p_y) stresses, determined by the equation:

$$p_z = p_y \operatorname{tg}^2 (45^\circ + 0.50\varphi) + p_0 \quad (17)$$

where:

$$p_0 = 2c \operatorname{tg} (45^\circ + 0.50\varphi) \quad (18)$$

is the "initial" stress (when $p_y = 0$), proving that reinforced soil behaves as if it exhibited cohesion.

The maximum cohesion effect was calculated from formula (18):

$$c = p_0 [2 \operatorname{tg} (45^\circ + 0.50\varphi)]^{-1} \quad (19)$$

where:

$$p_0 = p_y^* p_z (p_y^*)^{-1} - p_z = p_z [p_y^* (p_y^*)^{-1} - 1] \quad (20)$$

where: $p_0 = p_z^* - p_z = P$ - the effect of the increase of load capacity due to the reinforcement, according to formula (6),

φ - internal friction angle of non-reinforced soil.

Shear strength of reinforced soil was calculated from the Coulomb [3] formula for soil with cohesion:

$$\tau_f = p_z \operatorname{tg} \varphi + c. \quad (21)$$

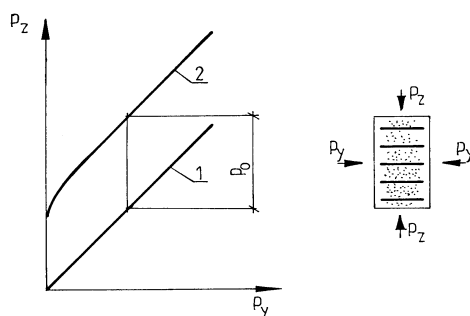


Fig. 3 Destruction curves representing a reinforced sand soil in the plane of main stresses: 1 - non-reinforced sand, 2 - reinforced sand

In this formula, the first component refers to non-reinforced soil, and the second is an addition due to the reinforcement.

6. Deformation module of soil sample

Deformation module E_d was calculated following [3] from the formula:

$$E_d = p_{z,e} h (\Delta h)^{-1} \quad (22)$$

where: $p_{z,e}$ - unitary load exerted on the sample in the range of elastic deformation,

Δh - soil sample deformation as mean vertical displacement of the special plate loading the soil sample,

h - initial height of soil sample.

7. The rationale for selecting the test stand parameters for the model with vertical reinforcement

7.1. Calculation of the length b_1 of the zone of limiting load condition

Fig. 4 shows schematically the vertical profile of the physical model in the form of a cut with its bottom exposed to the displacement Δh suggested for testing. The size proportions of the model's particular elements were chosen so that the essential part with a vertical reinforcement in the zone 1 be subject to the limiting condition created by the load q_f .

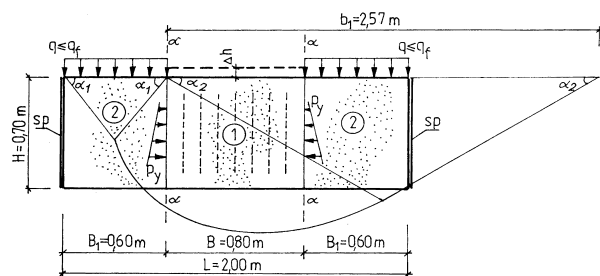


Fig. 4 Model diagram (vertical profile): 1 - model of subsoil with vertical reinforcement; 2 - zones of active pressure of the model 1; 3 - measuring wall of the lateral pressure p_y

The length of the zone b_1 in the limiting condition created was calculated according to [1]:

$$b_1 = B_1 \operatorname{tg} (0.25 \pi + 0.5 \varphi) e^{0.5 \pi \operatorname{tg} \varphi} \quad (23)$$

where: $B_1 = 0.60$ m - width of the surface on which the load q is transferred,
 $\varphi = 30^\circ$ - initially assumed internal friction angles of sand.
 After inserting this data, formula (23) yielded
 $b_1 = 2.57$ m.

7.2. Calculation of the limiting load in the zones 2

The value of the limiting load q_f of the soil medium in the zones 2 (Fig. 4) surrounding the essential part of the model was calculated from the Terzaghi-Schulze formula according to [3]:

$$q_f = [1 + 0.3 B_1 (L')^{-1}] c N_c + \gamma_D D N_q + [1 - 0.2 B_1 (L')^{-1}] \gamma_B B_1 N_\gamma \quad (24)$$

where: $c = 0$ - cohesion of soil medium,

γ_D, γ_B - soil volumetric weight (for the erratic subsoil it should be precised: γ_D till depth D and γ_B below the bottom of foundation on the depth from D to $D + B$);
 $\gamma_D = \gamma_B = \gamma = 19.0$ kN/m³ - initially accepted soil volumetric weight,

$B_1 = 0.60$ m - loading surface width,

$L' = 1.20$ m - loading surface length - measured perpendicular to the $L = (B + 2B_1)$ dimension,

$D = 0.0$ m - founding depth,

$N_c = 37.0$; $N_q = 23$; $N_\gamma = 10.0$ - load capacity coefficients according to Terzaghi, adopted from table 9-2 [3] for $\varphi = 30^\circ$.

Having inserted the above data into formula (24), we obtained $q_f = 0.103$ MPa. We assume that the size of the loading surface is 0.60 m x 1.20 m = 0.72 m² and then the vertical force P , necessary to exert the load $q_f = 0.103$ MPa, equals 74.16 kN.

8. Summary

In order to calculate the strength parameters of a reinforced soil medium, the following data obtained from model studies are indispensable:

$q \leq q_f$ - vertical loads in the range up to the limiting condition (Fig. 3),

p_y - horizontal pressure due to the action of the load q ,

Δh - vertical displacement (measure of soil displacement) of the model's zone 1 due to a bilateral horizontal thrust of the zone 2.

The suggested physical model allows a measurement of these values for both non-reinforced and reinforced media with not only horizontal, but also vertical inserts. Following the test so performed, it will be possible to determine the increase in the resistance of a reinforced medium to horizontal pressure and the decrease in soil vertical displacement h , which is a consequence of horizontal loads.

Reviewed by: E. Krličková, F. Schlosser

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