Research Article

Study on the Mixed Materials Proportion of Stratum Based on the Modelling Experiment

Yijun Zhou¹ and Tao Xu²

¹College of Architecture and Engineering, North China University of Science and Technology, Tangshan 063210, China

²School of Civil Engineering, Southeast University, Nanjing 211189, China

Correspondence should be addressed to Tao Xu; xu-tao@seu.edu.cn

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It is highly significant to select similar materials as well as the proportion of mixed materials in the model test. The mixed materials are used to simulate the stratum of the model test, including the iron ore powder, natural sands, gypsum, and lime. The stratum contains silty clay and silt soil. First of all, the symmetry coefficient of model mechanics parameters are calculated by the equation, and the symmetry ratio is 16:1. Second, calculate the proportion of compositions in mixed materials by the orthogonal test. The deviation method is used to analyze the mixed materials and how to influence the elastic modulus, cohesion, and friction angle. Finally, get the mixed materials which meet the symmetry theory and control factors.

1. Introduction

The model test is a method that uses the symmetry theory to reduce the size of the prototype. The symmetrical material is highly significant to the model test, and it usually contains some kinds of materials called mixed materials. Choosing suitable mixed materials can determine the model test whether success or not [1–3].

The mixed materials have been researched by some researchers. In abroad, Fumagalli [4] researched the model test of engineering geology initially in the 1960s. He used gypsum, powder of PbO, expansive soil, and water to simulate the stratum. Han et al. [5] researched the materials of MIB to study the rock and soil. Wang [6] selected the barite, quartz, and vaseline to study proportion of mixed materials in the model test. He found that different proportions of mixed materials lead to different results of the test. Chen and Zuo [7, 8] introduced several materials to study the influence for proportion of stratum, including PbO, gypsum, expansive soil, sands, starch, hardener, and so on.

The symmetry theory is mainly used to guide the model test to determine the proportion for the model and prototype [9–12].

The geology model test is highly complex and is affected by lots of factors, such as density of soil, cohesion of soil, friction angle of soil, elastic modulus of soil, and so on. Therefore, the much more important factor must be controlled, ignoring the less important factors [13–17].

To measure the proportion of mixed materials, some kinds of methods are introduced, including the direct shear test, orthogonal test, deviation analysis method, three axes test, and so on [18–26].

2. Materials and Methods

2.1. Determination of Symmetry Coefficient of Stratum

2.1.1. Symmetry Ratio. In the process of the model test, the symmetry ratio is a crucial step and also determines the model test whether it can correctly react to objective laws or not. The symmetry ratio is the ratio between the prototype and the model and marked C . The definitions of model test parameters are as follows: L is the length, r is the density, δ is the displacement, σ is the stress, ε is the strain, σ^t is the tensile strength, σ^c is the compressive strength, c is the cohesion, ϕ is the friction angle, μ is Poisson's ratio, and f is

the coefficient of friction. All of the parameters of symmetry ratio are given in Table 1.

2.1.2. *Establishment of Symmetry Equation.* According to the symmetry theory, establish the equation of the prototype

and model, including the equilibrium equation, geometric equation, and physical equation.

(1) Establish a symmetrical condition by the equilibrium equation:

$$\text{Equilibrium equation of prototype: } \left\{ \begin{array}{l} \left(\frac{\partial \sigma_x}{\partial x} \right)_p + \left(\frac{\partial \tau_{yx}}{\partial y} \right)_p + \left(\frac{\partial \tau_{zx}}{\partial z} \right)_p + X_p = 0 \\ \left(\frac{\partial \sigma_y}{\partial y} \right)_p + \left(\frac{\partial \tau_{zy}}{\partial z} \right)_p + \left(\frac{\partial \tau_{xy}}{\partial x} \right)_p + Y_p = 0 \\ \left(\frac{\partial \sigma_z}{\partial z} \right)_p + \left(\frac{\partial \tau_{xz}}{\partial x} \right)_p + \left(\frac{\partial \tau_{yz}}{\partial y} \right)_p + Z_p = 0 \end{array} \right\}. \quad (1)$$

$$\text{Equilibrium equation of model: } \left\{ \begin{array}{l} \left(\frac{\partial \sigma_x}{\partial x} \right)_m + \left(\frac{\partial \tau_{yx}}{\partial y} \right)_m + \left(\frac{\partial \tau_{zx}}{\partial z} \right)_m + X_m = 0 \\ \left(\frac{\partial \sigma_y}{\partial y} \right)_m + \left(\frac{\partial \tau_{zy}}{\partial z} \right)_m + \left(\frac{\partial \tau_{xy}}{\partial x} \right)_m + Y_m = 0 \\ \left(\frac{\partial \sigma_z}{\partial z} \right)_m + \left(\frac{\partial \tau_{xz}}{\partial x} \right)_m + \left(\frac{\partial \tau_{yz}}{\partial y} \right)_m + Z_m = 0 \end{array} \right\}. \quad (2)$$

Substitute the symmetry coefficient c_σ, c_L, c_X into formula (1), and the following formula is obtained:

$$\left\{ \begin{array}{l} \left(\frac{\partial \sigma_x}{\partial x} \right)_m + \left(\frac{\partial \tau_{yx}}{\partial y} \right)_m + \left(\frac{\partial \tau_{zx}}{\partial z} \right)_m + \frac{c_\gamma c_L}{c_\sigma} X_m = 0 \\ \left(\frac{\partial \sigma_y}{\partial y} \right)_m + \left(\frac{\partial \tau_{zy}}{\partial z} \right)_m + \left(\frac{\partial \tau_{xy}}{\partial x} \right)_m + \frac{c_\gamma c_L}{c_\sigma} Y_m = 0 \\ \left(\frac{\partial \sigma_z}{\partial z} \right)_m + \left(\frac{\partial \tau_{xz}}{\partial x} \right)_m + \left(\frac{\partial \tau_{yz}}{\partial y} \right)_m + \frac{c_\gamma c_L}{c_\sigma} Z_m = 0 \end{array} \right\}. \quad (3)$$

According to formulas (2) and (3), we can get the equation for c_γ, c_L, c_σ .

$$\frac{c_\gamma c_L}{c_\sigma} = 1. \quad (4)$$

(2) Establish a symmetrical condition by the geometry equation:

TABLE 1: Symmetry coefficient calculation formula.

Parameter	Length	Strain	Density	Volume force	Displacement	Stress	Elastic modulus	Poisson's ratio	Friction angle	Cohesion
Symmetry ratio	$C_L = (L_p/L_m)$	$C_\epsilon = (\epsilon_p/\epsilon_m)$	$C_\gamma = (\gamma_p/\gamma_m)$	$C_X = (X_p/X_m)$	$C_\delta = (\delta_p/\delta_m)$	$C_\sigma = ((\sigma^t)_p/(\sigma^t)_m) = ((\sigma^c)_p/(\sigma^c)_m)$	$C_E = (E_p/E_m)$	$C_\mu = (\mu_p/\mu_m)$	$C_\phi = (\phi_p/\phi_m)$	$C_c = (c_p/c_m)$

$$\text{Geometry equation of prototype: } \left\{ \begin{array}{l} (\varepsilon_x)_p = \left(\frac{\partial u}{\partial x} \right)_p \\ (\varepsilon_y)_p = \left(\frac{\partial v}{\partial y} \right)_p \\ (\varepsilon_z)_p = \left(\frac{\partial w}{\partial z} \right)_p \\ (\gamma_{xy})_p = \left(\frac{\partial u}{\partial y} \right)_p + \left(\frac{\partial v}{\partial x} \right)_p \\ (\gamma_{yz})_p = \left(\frac{\partial v}{\partial z} \right)_p + \left(\frac{\partial w}{\partial y} \right)_p \\ (\gamma_{zx})_p = \left(\frac{\partial u}{\partial z} \right)_p + \left(\frac{\partial w}{\partial x} \right)_p \end{array} \right\}. \quad (5)$$

$$\text{Geometry equation of model: } \left\{ \begin{array}{l} (\varepsilon_x)_m = \left(\frac{\partial u}{\partial x} \right)_m \\ (\varepsilon_y)_m = \left(\frac{\partial v}{\partial y} \right)_m \\ (\varepsilon_z)_m = \left(\frac{\partial w}{\partial z} \right)_m \\ (\gamma_{xy})_m = \left(\frac{\partial u}{\partial y} \right)_m + \left(\frac{\partial v}{\partial x} \right)_m \\ (\gamma_{yz})_m = \left(\frac{\partial v}{\partial z} \right)_m + \left(\frac{\partial w}{\partial y} \right)_m \\ (\gamma_{zx})_m = \left(\frac{\partial u}{\partial z} \right)_m + \left(\frac{\partial w}{\partial x} \right)_m \end{array} \right\}. \quad (6)$$

Substitute the symmetry coefficient $c_\varepsilon, c_\delta, c_L$ into formula (5), and the following formula is obtained:

$$\left\{ \begin{array}{l} (\varepsilon_x)_m \left(\frac{c_\xi c_L}{c_\delta} \right) = \left(\frac{\partial u}{\partial x} \right)_m \\ (\varepsilon_y)_m \left(\frac{c_\xi c_L}{c_\delta} \right) = \left(\frac{\partial v}{\partial y} \right)_m \\ (\varepsilon_z)_m \left(\frac{c_\xi c_L}{c_\delta} \right) = \left(\frac{\partial w}{\partial z} \right)_m \\ (\gamma_{xy})_m \left(\frac{c_\xi c_L}{c_\delta} \right) = \left(\frac{\partial u}{\partial y} \right)_m + \left(\frac{\partial v}{\partial x} \right)_m \\ (\gamma_{yz})_m \left(\frac{c_\xi c_L}{c_\delta} \right) = \left(\frac{\partial v}{\partial z} \right)_m + \left(\frac{\partial w}{\partial y} \right)_m \\ (\gamma_{zx})_m \left(\frac{c_\xi c_L}{c_\delta} \right) = \left(\frac{\partial u}{\partial z} \right)_m + \left(\frac{\partial w}{\partial x} \right)_m \end{array} \right\}. \quad (7)$$

According to formulas (6) and (7), we can get the equation for c_ξ, c_δ, c_L .

$$\frac{c_\xi c_L}{c_\delta} = 1. \quad (8)$$

(3) Establish a symmetrical condition by the physical equation:

$$\text{Physical equation of prototype : } \left\{ \begin{array}{l} (\varepsilon_x)_p = \frac{1}{E_p} [\sigma_x - \mu(\sigma_y + \sigma_z)]_p \\ (\varepsilon_y)_p = \frac{1}{E_p} [\sigma_y - \mu(\sigma_x + \sigma_z)]_p \\ (\varepsilon_z)_p = \frac{1}{E_p} [\sigma_z - \mu(\sigma_x + \sigma_y)]_p \\ (\gamma_{xy})_p = \left[\frac{2(1+\mu)}{E_p} \tau_{xy} \right]_p \\ (\gamma_{xz})_p = \left[\frac{2(1+\mu)}{E_p} \tau_{xz} \right]_p \\ (\gamma_{yz})_p = \left[\frac{2(1+\mu)}{E_p} \tau_{yz} \right]_p \end{array} \right. \quad (9)$$

$$\text{Physical equation of model : } \left\{ \begin{array}{l} (\varepsilon_x)_m = \frac{1}{E_p} [\sigma_x - \mu(\sigma_y + \sigma_z)]_m \\ (\varepsilon_y)_m = \frac{1}{E_p} [\sigma_y - \mu(\sigma_x + \sigma_z)]_m \\ (\varepsilon_z)_m = \frac{1}{E_p} [\sigma_z - \mu(\sigma_x + \sigma_y)]_m \\ (\gamma_{xy})_m = \left[\frac{2(1+\mu)}{E_p} \tau_{xy} \right]_m \\ (\gamma_{xz})_m = \left[\frac{2(1+\mu)}{E_p} \tau_{xz} \right]_m \\ (\gamma_{yz})_m = \left[\frac{2(1+\mu)}{E_p} \tau_{yz} \right]_m \end{array} \right. \quad (10)$$

Substitute the symmetrical coefficient $c_\varepsilon, c_\sigma, c_\mu, c_E$ into formula (9), and the following formula is obtained.

$$\left\{ \begin{array}{l} (\varepsilon_x)_m = \frac{c_\sigma}{c_\varepsilon c_E} \frac{1}{E_m} [\sigma_x - c_\mu \mu (\sigma_y + \sigma_z)]_m \\ (\varepsilon_y)_m = \frac{c_\sigma}{c_\varepsilon c_E} \frac{1}{E_m} [\sigma_y - c_\mu \mu (\sigma_x + \sigma_z)]_m \\ (\varepsilon_z)_m = \frac{c_\sigma}{c_\varepsilon c_E} \frac{1}{E_m} [\sigma_z - c_\mu \mu (\sigma_x + \sigma_y)]_m \\ (\gamma_{xy})_m = \frac{c_\sigma}{c_\varepsilon c_E} \left[\frac{2(1+\mu)}{E_p} \tau_{xy} \right]_m \\ (\gamma_{xz})_m = \frac{c_\sigma}{c_\varepsilon c_E} \left[\frac{2(1+\mu)}{E_p} \tau_{xz} \right]_m \\ (\gamma_{yz})_m = \frac{c_\sigma}{c_\varepsilon c_E} \left[\frac{2(1+\mu)}{E_p} \tau_{yz} \right]_m \end{array} \right\}. \quad (11)$$

According to formulas (10) and (11), we get the equation for $c_\sigma, c_\varepsilon, c_E$. The symmetry coefficient of Poisson's is $c_\mu = 1$.

$$\frac{c_\sigma}{c_\varepsilon c_E} = 1. \quad (12)$$

2.1.3. Symmetry Ratio Determination. According to the symmetry theory and the size of model box, finally the symmetry ratio in the model test is $C_L = 16:1$. It is assumed that the symmetry ratio of density is $1:1$, and the dimensionless parameter is $1:1$. Therefore, all of the parameters of symmetry ratio in the model test are given in Table 2.

3. Testing

3.1. Selecting of Stratum Symmetry Materials

3.1.1. Prototype Stratum Parameters. In the model test, selecting the soil of Shanghai is considered as the prototype stratum. The information of prototype stratum in Shanghai is given in Table 3. According to formula (13), the relationship between compression modulus and elastic modulus is

$$E = E_s \left(1 - \frac{2\mu^2}{1-\mu} \right), \quad (13)$$

where E is the elastic modulus of soil, kPa; E_s is the compression modulus of soil, kPa; μ is Poisson's ratio of soil.

Based on the exiting conclusion of research, finally, it selected mixed materials to research stratum in the model test, including iron ore powder, natural sands, gypsum, and lime. The iron ore powder and natural sands are aggregate, which have a great density. The gypsum and lime is the adhesive, which has better sticky property and great tension. In addition, the mixed materials are no harm for beings, easily available, low cost, and so on.

3.1.2. Determination of Mixed Materials Ratio Initially. According to the direct shear test for many times, rely on the density of symmetry ratio. The mixed materials ratio is obtained initially, as given in Table 4. The mixed materials are made to simulate each stratum, as given in Table 5.

From what has been researched above, it just studies about the mixed materials ratio for silty clay and silt soil.

3.2. Determination of Mechanics Parameters for Stratum Symmetry Materials

3.2.1. Design of the Orthogonal Test. The orthogonal test is used to research the proportion of mixed materials, design three factors and three levels, a total of nine tests, according to the purpose of the test, considering the density, cohesion, friction angle, elastic modulus, and Poisson's ratio as the control index, as given in Table 6.

3.2.2. Parameters of the Orthogonal Test. In order to get the five parameters, that is, density, cohesion, friction angle, elastic modulus, and Poisson's ratio, the research adopts, respectively, the density test, the direct shear test, elastic modulus test, and Poisson's ratio test.

(1) Density test

In the density test, the formula of density is given in the following equation, and the instruments are given in Table 7.

$$\rho = \frac{m_1 - m_2}{V_2}, \quad (14)$$

ρ is the density of soil, g/cm³; m_1 is the total quality of soil and ring knife, g; m_2 is the quality of ring knife, g; V_2 is the volume of ring knife, cm³.

(2) Direct shear test

The direct shear test is a common method to measure the shear strength of soil. There is about four times to measure the shear strength in one direct shear test, under different vertical pressures, measuring the shear stress when soil is destroyed. The formula is given as follows:

$$\tau_f = c + \sigma \tan \phi, \quad (15)$$

τ_f is the shear strength of soil, kPa; c is the cohesion of soil, kPa; ϕ is the friction angle of soil; σ is the vertical stress, kPa.

(3) Poisson's ratio and the elastic modulus test

The value of Poisson's ratio is measured by two steps:

- The lateral pressure coefficient K_0 of soil samples is obtained by the static pressure coefficient test
- Getting the value of Poisson's ratio according to the generalized Hooker's law

The elastic modulus is measured from the lateral compression test of similar materials, as shown in Figure 1, and the formula is derived as follows:

TABLE 2: Each of parameter for symmetry ratio.

Parameter	Geometry	Displacement	Stress	Strain	Cohesion	Friction angle	Elastic modulus	Poisson's ratio	Bending moment
Prototype	16	16	16	1	16	1	16	1	16 ⁴
Model	1	1	1	1	1	1	1	1	1

TABLE 3: The physical quantity of prototype stratum in Shanghai.

Stratum	Density (kN/m ³)	Cohesion (kPa)	Friction angle (°)	Elastic modulus (MPa)	Poisson's ratio	Thickness of stratum (m)
Fill the soil	18.5	0	15	11	0.33	0.64
Silty clay	19.2	20	17	38	0.36	1.92
Silt soil	17.5	13	11	10	0.31	17.6
Silty clay	18.4	27	14	42	0.34	6.24

TABLE 4: Mixed materials finished initially.

Proportion of iron and sand in mixture (%)	Quality ratio between iron and sand	Quality ratio between gypsum and lime	Volume ratio between water and gypsum
85	1.5 : 3.5	1 : 1	2 : 8

TABLE 5: Simulation materials of each stratigraphic.

Stratum	Thickness of prototype (m)	Thickness of the model (cm)	Mixed materials
Fill the soil	0.64	4	Natural sands
Silty clay	1.92	12	Iron ore powder, natural sands, gypsum, and lime
Silt soil	17.6	110	Iron ore powder, natural sands, gypsum, and lime
Silty clay	6.24	39	Iron ore powder, natural sands, gypsum, and lime

TABLE 6: Value of control index.

Factors	Proportion of iron and sand in mixture (%)	Quality ratio between iron and sand	Quality ratio between gypsum and lime
Level 1	80	2 : 3	2 : 1
Level 2	85	1.5 : 3.5	1 : 1
Level 3	90	1 : 4	1 : 2

TABLE 7: Instrument of the density test.

Name	Ring knife	Balance	Vernier caliper	Compaction meter
Parameters	Internal diameter, 6–8 cm; height 2 cm	Accuracy, 0.1 g	Accuracy, 0.02 mm	Diameter, 100 mm; height, 127 mm; volume, 997 cm ³

According to generalized Hooke's law,

$$\varepsilon_x + \varepsilon_y = 0, \quad (16)$$

$$\varepsilon_x = \frac{\sigma_x}{E} - \frac{\mu(\sigma_y + \sigma_z)}{E}, \quad (17)$$

$$\varepsilon_y = \frac{\sigma_y}{E} - \frac{\mu(\sigma_x + \sigma_z)}{E}. \quad (18)$$

Substituting formulas (17) and (18) into formula (16), the following equation is obtained:

$$K_0 = \frac{\sigma_x}{\sigma_z} = \frac{\mu}{1 - \mu}, \quad (19)$$

where μ is Poisson's ratio; K_0 is the side pressure coefficient; E is the elastic modulus, kPa.

According to generalized Hooke's law, the strain of Z axis is given in the following formula:

$$\varepsilon_z = \frac{\sigma_z}{E} - \frac{\mu(\sigma_x + \sigma_y)}{E}. \quad (20)$$

Substituting $\sigma_z = p$, $\sigma_x = \sigma_y = (\mu/(1 - \mu))p$ into formula (20), the following equation is obtained:

$$E = \frac{P}{\varepsilon_z} \left(1 - \frac{2\mu^2}{1 - \mu} \right), \quad (21)$$

$$\varepsilon_z = \frac{\Delta H}{H} = \frac{(e_0 - e_1)}{(1 + e_0)}. \quad (22)$$

Compression coefficient under confinement conditions is

FIGURE 1: Stress condition of the confined compress test.

$$a = \frac{\Delta e}{\Delta \sigma} = \frac{(e_0 - e_1)}{P}. \quad (23)$$

Finally, formula (21) is given as follows:

$$E = \frac{1 + e_0}{a} \left(1 - \frac{2\mu^2}{1 - \mu} \right). \quad (24)$$

Compression modulus under confinement conditions is

$$E_s = \frac{1 + e_0}{a}, \quad (25)$$

$$E = E_s \left(1 - \frac{2\mu^2}{1 - \mu} \right),$$

where E_s is the compression modulus under confinement conditions, kPa; e_0 is the porosity ratio; a is the compression coefficient under confinement conditions, kPa^{-1} ; Δe is the change of the amount porosity ratio; $\Delta \sigma$ is the change of the amount vertical stress, kPa.

4. Results and Analysis

According to design and the performed orthogonal test, the results of the orthogonal test obtained are given in Table 8.

Because the value of density almost has no change, as well as Poisson's ratio, they are out of consideration in the following test.

First of all, to produce the mixed materials, select the cohesive force, the friction angle, and the elastic modulus as the control factor.

4.1. Analysis of Cohesive Force as the Control Factor. According to the results of the orthogonal test for nine group data, calculate the relative error of nine group cohesive data. The smaller the value of relative error, the more accurate the results, as given in Table 9.

According to the orthogonal test and relative error of cohesive, the dispersion of factors for A, B, and C is

$$\begin{aligned} A: (I_A - \delta)^2 + (II_A - \delta)^2 + (III_A - \delta)^2 &= 112.92, \\ B: (I_B - \delta)^2 + (II_B - \delta)^2 + (III_B - \delta)^2 &= 14.82, \\ C: (I_C - \delta)^2 + (II_C - \delta)^2 + (III_C - \delta)^2 &= 35.25. \end{aligned} \quad (26)$$

From the test results analysis and Figure 2, we can see that

- (a) The relationship between the A, B, and C is $A > C > B$
- (b) The factor 2 point is inflection point, and the line changes suddenly when through the factor 2 point.
- (c) A1, B2, C2 is the closest value, respectively, in each factor compared with the prototype cohesion value

4.2. Analysis of Friction Angle as the Control Factor. According to the results of the orthogonal test for nine group data, calculate the relative error of nine group friction angle data. The smaller the value of relative error, the more accurate the results, as given in Table 10.

According to the orthogonal test and relative error of friction angle, the dispersion of factors for A, B, and C is

$$\begin{aligned} A: (I_A - \delta)^2 + (II_A - \delta)^2 + (III_A - \delta)^2 &= 0.0481, \\ B: (I_B - \delta)^2 + (II_B - \delta)^2 + (III_B - \delta)^2 &= 0.0065, \\ C: (I_C - \delta)^2 + (II_C - \delta)^2 + (III_C - \delta)^2 &= 0.0099. \end{aligned} \quad (27)$$

From the test results analysis and Figure 3, we can see that

- (a) The relationship between the A, B, and C is $A > B > C$
- (b) The factor 2 point is inflection point, and the line changes suddenly when through the factor 2 point.
- (c) A2, B3, C1 is the closest value, respectively, in each factor for the prototype friction angle value

4.3. Analysis of Elastic Modulus as the Control Factor. According to the results of the orthogonal test for nine group data, calculate the relative error of nine group elastic modulus data. The smaller the value of relative error, the more accurate the results, as given in Table 11.

According to the orthogonal test and relative error of elastic modulus, the dispersion of factors for A, B, and C is

$$\begin{aligned} A: (I_A - \delta)^2 + (II_A - \delta)^2 + (III_A - \delta)^2 &= 50.27, \\ B: (I_B - \delta)^2 + (II_B - \delta)^2 + (III_B - \delta)^2 &= 9.14, \\ C: (I_C - \delta)^2 + (II_C - \delta)^2 + (III_C - \delta)^2 &= 207.40. \end{aligned} \quad (28)$$

From the test results analysis and Figure 4, we can see that

- (a) The relationship between the A, B, and C is $C > A > B$
- (b) The factor 2 point is inflection point, and the line changes suddenly when through the factor 2 point.
- (c) A3, B2, C1 is the closest value, respectively, in each factor for the prototype elastic modulus value

As shown in Figures 5 and 6, according to the standard, the samples are damaged when the displacement of

TABLE 8: Orthogonal test conclusion.

Serial number	Proportion of iron and sand in mixture (%)	Quality ratio between iron and sand	Quality ratio between gypsum and lime	Elastic modulus (MPa)	Cohesion (kPa)	Friction angle (°)	Density (g/cm ³)	Poisson's ratio
1	80	2:3	2:1	9.76	16	29	2.24	0.30
2	80	1.5:3.5	1:1	17.95	2.8	31.28	2.16	0.35
3	80	1:4	1:2	23.78	16.05	28.80	2.11	0.37
4	85	2:3	1:1	19.94	29.69	26.60	2.28	0.34
5	85	1.5:3.5	1:2	21.56	22.87	27.19	2.17	0.36
6	85	1:4	2:1	8.43	27.29	25.11	2.05	0.31
7	90	2:3	1:2	16.37	20.06	27.91	2.25	0.35
8	90	1.5:3.5	2:1	2.48	24.48	27.58	2.15	0.30
9	90	1:4	1:1	13.68	10.43	28.48	2.09	0.33

TABLE 9: Cohesive force of relative error analysis.

Serial number	Proportion of iron and sand in mixture (%)	Quality ratio between iron and sand	Quality ratio between gypsum and lime	Relative error
1	80	2:3	2:1	15
2	80	1.5:3.5	1:1	1.8
3	80	1:4	1:2	15.05
4	85	2:3	1:1	28.69
5	85	1.5:3.5	1:2	21.87
6	85	1:4	2:1	26.29
7	90	2:3	1:2	19.06
8	90	1.5:3.5	2:1	23.48
9	90	1:4	1:1	9.43
I	10.62	20.92	21.59	$P = 160.68$
II	25.62	15.72	13.31	$\delta = P/9 = 17.85$
III	17.32	16.92	18.66	

P , the sum of the data for every factor; δ , the average of the data for every factor; I, the average of relative error for factor 1; II, the average of relative error for factor 2; III, the average of relative error for factor 3.

FIGURE 2: Cohesive force of trend diagram.

TABLE 10: Friction angle of relative error analysis.

Serial number	Proportion of iron and sand in mixture (%)	Quality ratio between iron and sand	Quality ratio between gypsum and lime	Relative error
1	80	2 : 3	2 : 1	1.64
2	80	1.5 : 3.5	1 : 1	1.84
3	80	1 : 4	1 : 2	1.62
4	85	2 : 3	1 : 1	1.42
5	85	1.5 : 3.5	1 : 2	1.47
6	85	1 : 4	2 : 1	1.28
7	90	2 : 3	1 : 2	1.54
8	90	1.5 : 3.5	2 : 1	1.51
9	90	1 : 4	1 : 1	1.59
I	1.7	1.53	1.48	$P = 13.92$
II	1.39	1.61	1.62	$\delta = P/9 = 1.55$
III	1.55	1.50	1.54	

P , the sum of the data for every factor; δ , the average of the data for every factor; I, the average of relative error for factor 1; II, the average of relative error for factor 2; III, the average of relative error for factor 3.

FIGURE 3: Friction angle of trend diagram.

TABLE 11: Elastic modulus of relative error analysis.

Serial number	Proportion of iron and sand in mixture (%)	Quality ratio between iron and sand	Quality ratio between gypsum and lime	Relative error
1	80	2 : 3	2 : 1	12.94
2	80	1.5 : 3.5	1 : 1	24.64
3	80	1 : 4	1 : 2	32.97
4	85	2 : 3	1 : 1	27.49
5	85	1.5 : 3.5	1 : 2	29.8
6	85	1 : 4	2 : 1	11.04
7	90	2 : 3	1 : 2	22.39
8	90	1.5 : 3.5	2 : 1	2.54
9	90	1 : 4	1 : 1	18.54
I	23.52	20.94	8.84	$P = 182.36$
II	22.78	18.99	23.56	$\delta = P/9 = 20.26$
III	14.49	20.85	28.39	

P , the sum of the data for every factor; δ , the average of the data for every factor; I, the average of relative error for factor 1; II, the average of relative error for factor 2; III, the average of relative error for factor 3.

FIGURE 4: Elastic modulus of trend diagram.

FIGURE 5: Action cycle of direct shear apparatus.

FIGURE 6: Failure model of test piece.

samples has no change obviously in the direct shear test. Finally, the proportion of mixed materials is shown in Figure 7. Based on the above three control factors, use the direct shear test to get the proportion of mixed materials, as given in Table 12.

Use the parameters of mixed materials to compare with the parameters of the prototype and model. It is proved that the proportion of mixed materials is reasonable and meets the requirements of symmetry ratio, as given in Tables 13 and 14.

FIGURE 7: Proportion of mixed materials.

TABLE 12: Mixed material proportion table.

Mixed materials	Proportion of iron and sand in mixture (%)	Quality ratio between iron and sand	Quality ratio between gypsum and lime
Silt soil	80	2 : 3	2 : 1
Silty clay	90	1.5 : 3.5	1 : 2

TABLE 13: Comparison of physical mechanical parameters for silty clay.

Materials	Elastic modulus (MPa)	Density (kN/m ³)	Cohesion (kPa)	Friction angle (°)	Poisson's ratio
Prototype	30.8	19.8	29	15	0.36
Model	1.92	19.8	1.81	15	0.36
Test	2.08	21.03	1.98	20.36	0.33

TABLE 14: Comparison of physical mechanical parameters for silt soil.

Materials	Elastic modulus (MPa)	Density (kN/m ³)	Cohesion (kPa)	Friction angle (°)	Poisson's ratio
Prototype	10	17.5	13	11	0.31
Model	0.7	17.5	1	11	0.31
Test	0.95	18.7	2.11	12.21	0.34

5. Conclusion

- (1) According to the symmetry theory, establish the equilibrium equation, geometric equation, and physical equation for the prototype and model. The symmetry ration of mixed materials is 16 : 1.
- (2) Select the iron ore powder, natural sands, gypsum, and lime to be the mixed materials for model stratum. Use the orthogonal tests to get the proportion of compositions in mixed materials and analyze the results by the deviation.
- (3) The proportion of compositions in mixed materials of silt soil is that the proportion of iron and sand in mixture is 80%, the quality ratio between iron and sand is 2 : 3, and the quality ratio between gypsum and lime is 2 : 1.

The proportion of compositions in mixed materials of silty clay is that the proportion of iron and sand in mixture is 90%, the quality ratio between iron and sand is 1.5 : 3.5, and the quality ratio between gypsum and lime is 1 : 2.

It is proved that the proportion of compositions in mixed materials is reasonable and meets the requirements of symmetry ratio compared with the parameters of the prototype and model.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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