

Study on Mechanical Properties of Expand Polystyrene

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Abstract: Expand Polystyrene is simply written as EPS, and it is newly used as a kind of embankment filler. Based on abroad studies to EPS mechanical properties, a further research on EPS has been done in this paper. The triaxial test is used for the study. Duncan-Chang parameters of EPS are studied in the test. EPS block bearing test is studied by means of finite element method, and the Duncan-Chang parameters obtained from EPS triaxial test are proved to be right. The application value and the application extent are pointed out in conclusion, as is of valuable reference to real geotechnical engineering projects.

Keywords: EPS, Traxial Test, Duncan-Chang Parameters, Finite Element Method

1. Introduction

EPS is the simplified writing of “Expand Polystyrene”. Different densities and block sizes of this material can be produced according to different demands. Its common density in embankment engineering project is 0.2 KN/m³. This new kind of chemical production is now widely used abroad (Germany, Norway, Japan, Sweden etc) in the practice of geotechnical engineering, especially in the embankment engineering project in soft ground. Geotechnical engineers in Germany and Japan have done some research for EPS, on the points of its physical, chemical and mechanical properties. In the aspects of its physical and chemical properties, special attentions have been paid to the physical and chemical features of EPS itself and its proper water soil media environment. In the mechanical aspects, studies have been done on the compressive deformation. Figure 1 shows the triaxial test results done by Japanese geotechnical researchers on EPS (density $\rho=0.2$ KN/m³). Based on EPS engineering practice

and its present status of research, further researches on EPS (density $\rho=0.2$ KN/m³) have been done by means of triaxial test and big block bearing test respectively, on the purpose of finding its interior mechanical properties.

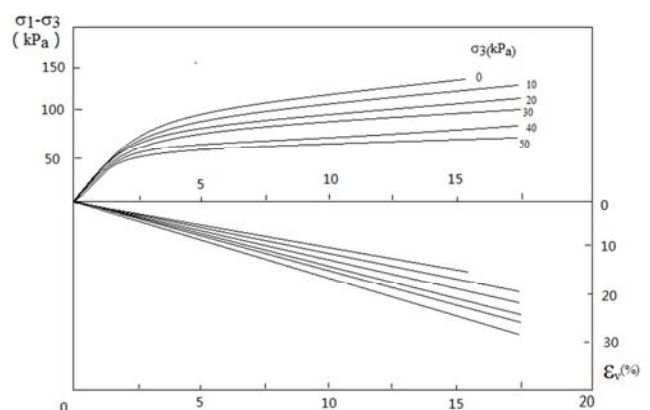


Figure 1. EPS Triaxial Test Results in Japan.

2. EPS Triaxial Test Results Analysis

2.1. Relation Between Stress ~ Strain Under Different Confining Pressures

In this test, the confining pressures of $\sigma_3 = 0, 10, 30, 50, 100, 150, 200, 300$ kPa are put on different samples respectively. The relationship between its deviation stress $q = \sigma_1 - \sigma_3$ and its axial strain ϵ_a , and the relationship between its volume strain ϵ_v and its axial strain ϵ_a are shown in Figure 2.

The curves in Figure 2 shows that during the process of the increase of the confining pressure σ_3 from 0 kPa to 100 kPa, the damage stress $(\sigma_1 - \sigma_3)_f$ (when $\epsilon_a = 15\%$) decreases, that means the structure strength decreases, which is contrary to the results of the soil triaxial test. But during the process of the increase of σ_3 from 100 kPa to 300 kPa, the derivation stress $(\sigma_1 - \sigma_3)_f$ reducing to the damage of EPS sample structure increases, which conforms to results of the triaxial test. The process of the increase of the confining pressure σ_3 from 0 to 100 kPa can be regarded as the process of structure damage of EPS. The process of the increase of σ_3 from 100 kPa to more can be regarded as the completion of structure damage, and EPS has been compressed completely. When the completely compressed EPS is compressed again, it shows the strength increasing. Under low confining pressure condition, when $\sigma_3 = 0 \sim 100$ kPa, the test results are similar to that of Japan.

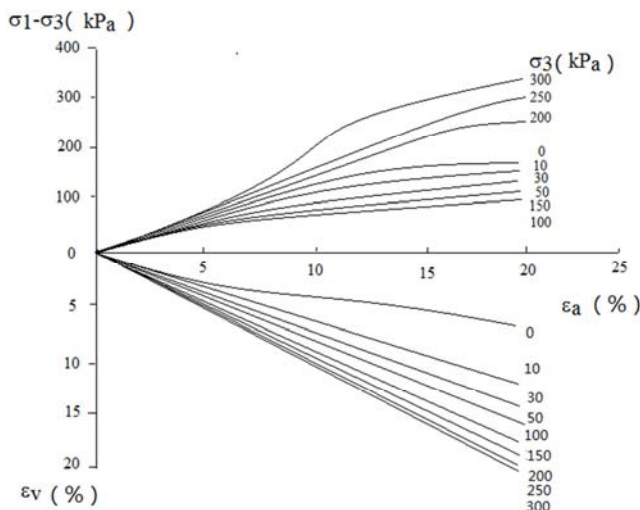


Figure 2. Relationship: between $q = \sigma_1 - \sigma_3$ and ϵ_a ; between ϵ_v and ϵ_a .

2.2. Relation Between Volume Strain ϵ_v and Axial Strain ϵ_a

As is shown in Figure 2, when axial strain $\epsilon_a < 5\%$, the relation between ϵ_v and ϵ_a shows that the volume strain approaches axial strain, that means lateral strain is small, or we can say the Poisson's ratio of EPS is small. When $\epsilon_a > 5\%$ and $\sigma_3 = 0$, the straight line deviates to curve. The reason is the lack of restriction of lateral pressure loads for lateral deformation. Although the other straight lines curved more or less, the former straight line relationship is still maintained. The above characteristics are quite different from the mechanical properties of soil.

3. Determination of Duncan-Chang Parameters of EPS

3.1. Brief Introduction to Duncan-Chang Model

Duncan-Chang Model was raised by James M. Duncan and Chin-Yung Chang in 1970. It is nonlinear—elasticity model for soil and widely used in Nonlinear Analysis of Stress and Strain in Soils. Based on the curve of strain~stress relationship from normal triaxial test, in the model, the curve of $(\sigma_1 - \sigma_3) \sim \epsilon_a$ relationship got from soil normal triaxial test is regarded as a hyperbola, and the elastic parameters E and ν are substituted by tangent line elastic module E_t and tangent line Poisson's ratio ν_t . The important formulas of Duncan-Chang model are as follows:

$$E_t = \left[1 - \frac{R_f (1 - \sin \phi) (\sigma_1 - \sigma_3)}{2c \cos \phi + 2\sigma_3 \sin \phi} \right]^2 K P_a \left(\frac{\sigma_3}{P_a} \right)^n$$

$$\nu_t = \frac{G - F \lg \left(\frac{\sigma_3}{P_a} \right)}{(1 - A)^2}$$

$$A = \frac{D (\sigma_1 - \sigma_3)}{K P_a \left(\frac{\sigma_3}{P_a} \right)^n \left[1 - \frac{R_f (1 - \sin \phi) (\sigma_1 - \sigma_3)}{2c \cos \phi + 2\sigma_3 \sin \phi} \right]}$$

In the above formulas, there are eight parameters in Duncan-Chang model: $C, \phi, K, n, R_f, G, F, D$, and they are measured by triaxial test.

Where:

E = tangent modulus as a function of confining stress σ_3

K = loading modulus number

P_a = atmospheric pressure (used as normalizing parameter)

σ_3 = confining stress

n = exponent for defining the influence of the confining pressure on modulus

3.2. C and ϕ Values

As it is shown in Figure 2, EPS triaxial test results illustrate that when $\sigma_3 = 0 \sim 100$ kPa, $(\sigma_1 - \sigma_3) \sim \epsilon_a$ relationship curves are hyperbolas. Thus, when the surrounding pressure σ_3 is less than 100 kPa ($\sigma_3 \leq 100$ kPa), Duncce model is suitable for EPS. Duncan-Chang parameters of EPS can be determined by triaxial test. The Duncan-Chang parameters of EPS discussed below are only under the condition of low σ_3 pressures.

In Figure 3, the strength envelope line of EPS between point A and point B is a straight line, at which the confining pressure $\sigma_3 = 0 \sim 100$ kPa and the cohesive force $C = 122$ kPa and the friction angle $\phi = -23^\circ$. Because the damaged degree of EPS becomes more and more heavier with the increasing of confining pressure σ_3 ($0 \sim 100$ kPa) so the friction angle is of minus value, as differs from that of soil. The strength envelop line between point B and point D is a curve, at which the confining pressure σ_3 increases from 100 kPa, and the compaction density of EPS getting greater and greater, so the

strength envelop curve appears. The above phenomenon can be explained as follows: AB straight line is the damage process of EPS structure; BD curve line is the repress stage

of EPS after enough EPS compaction degree has been gotten. The c, ϕ value to the AB envelop line are suitable for $\sigma_3 \leq 100 \text{Kpa}$

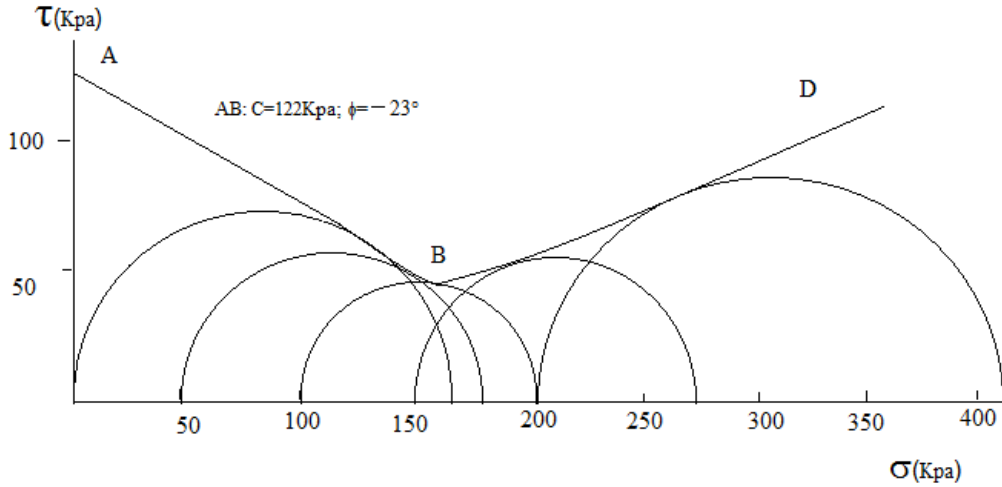


Figure 3. Limiting Mohr's Circle and Strength Envelope.

3.3. K and n Values

According to the $\frac{\epsilon_a}{\sigma_1 - \sigma_3} \sim \epsilon_a$ straight line relationship figures under different surrounding pressures, the initial elastic modulus E_i corresponding to different surrounding pressures can be determined. The relationship of $l_g \frac{E_i}{P_a} \sim l_g \frac{\sigma_3 + P_a}{P_a}$ is shown in Figure 4. The figure shows A→B is a straight line. From the straight line of AB, $\frac{\sigma_3 + P_a}{P_a} \leq 2.0$, i.e. $\sigma_3 \leq P_a \approx 100 \text{Kpa}$, the K and n value can be fixed, $K=37.87, n=-0.21$. The values of K and n are suitable to $\sigma_3 \leq 100 \text{kPa}$.

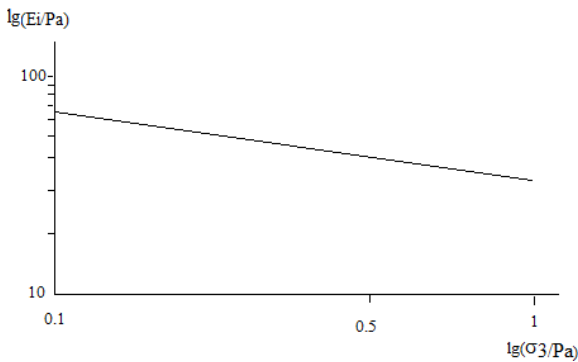


Figure 4. Relationship Of $l_g \left(\frac{E_i}{P_a} \right) \sim l_g \left(\frac{\sigma_3 + P_a}{P_a} \right)$

3.4. G and F Values

According to the relationship line of $-\frac{\epsilon_r}{\epsilon_a} \sim -\epsilon_r$. Under

different surrounding pressures, the initial tangent line Poisson's ratio $\nu_i \sim l_g \frac{\sigma_3 + P_a}{P_a}$ in Figure 5, $\frac{\sigma_3 + P_a}{P_a} \leq 2$, i.e. $\sigma_3 \leq P_a \approx 100 \text{kPa}$, G and F value can be calculated, $G=0.095, F=0.00$. The G and F value is suitable for $\sigma_3 \leq 100 \text{kPa}$.

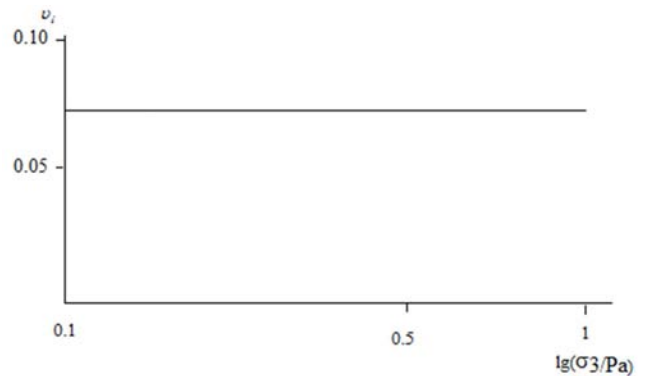


Figure 5. Relationship Between ν_i and $l_g \frac{\sigma_3 + P_a}{P_a}$.

3.5. Rf and D Values

The value of Rf and D are determined from the average values of Rf and D under different surrounding pressures. The formula of Rf indicator is: $Rf = \frac{(\sigma_1 - \sigma_3)_f}{(\sigma_1 - \sigma_3)_n}$, in which $(\sigma_1 - \sigma_3)_n$ indicates the value of $(\sigma_1 - \sigma_3)$ when $\epsilon_a \rightarrow \infty$, i.e., the gradually increased value of $(\sigma_1 - \sigma_3)$ in the $(\sigma_1 - \sigma_3) \sim \epsilon_a$ hyperbola. In the straight line of $\frac{\epsilon_a}{\sigma_1 - \sigma_3} \sim \epsilon_a$ relationship, the physical meaning of the slope

b in the straight line is the reciprocal of $(\sigma_1 - \sigma_3)_n$ in hyperbola. So $Rf = b(\sigma_1 - \sigma_3)_f$, the Rf value in different surrounding pressures is averaged to be: $Rf = 0.85$.

In the straight line relationship of $\frac{-\varepsilon}{\varepsilon_a} \sim -\varepsilon_r$, D is the line slope. In the hyperbola of $\varepsilon_a \sim \varepsilon_r$, D is the reciprocal of gradually advancing value of ε_a , $D = \left(\frac{1}{\varepsilon_a}\right)_{(-\varepsilon_r) \rightarrow \infty}$. The

value of D indicates the shape of the hyperbola of $\varepsilon_a \sim \varepsilon_r$. The curving degree increases with the increasing of D value. D values are different in different hyperbolas, but the differences are not great, they can be averaged as $D = -0.01$.

The F and D values are suitable to the confining pressure $\sigma_3 \leq 100kPa$.

4. Block bearing test to EPS and Finite Element Analysis

4.1. Introduction to the Test

The size of the tested EPS block is: length \times width \times height = $3 \times 2 \times 1.8m^3$, shown in Figure 7. The EPS block based in concrete ground, and nine pressure boxes are fixed on its one side. At the two opposite sides, two concrete retaining walls are formed. The EPS block end faces, the pressure boxes and the concrete retaining walls are combined tightly. In the test, the loads are put in the top surface of the EPS block, and the pressure boxes indicate the pressure in the interface of EPS block side and retaining wall. There are four stages of vertical load to the test. In the four loading stages, the vertical pressures of the EPS block top surface are as follows: 2kPa, 22kPa, 44kPa and 50.33kPa.

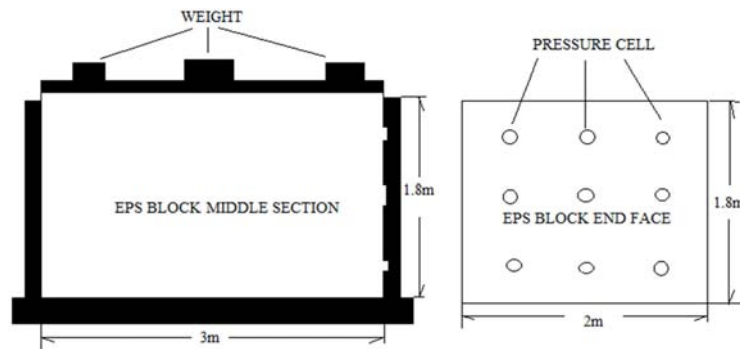


Figure 6. Test Installation Indicator.

4.2. Finite Analysis to the EPS Block Bearing Test

The test can be simplified as a plane strain problem for finite analysis. According to the symmetry, only half of the middle section is needed for the finite analysis. Rectangle elements are used in the finite element mesh. There are pressure boxes at the node 33, node 77 and node 121, shown in Figure 7.

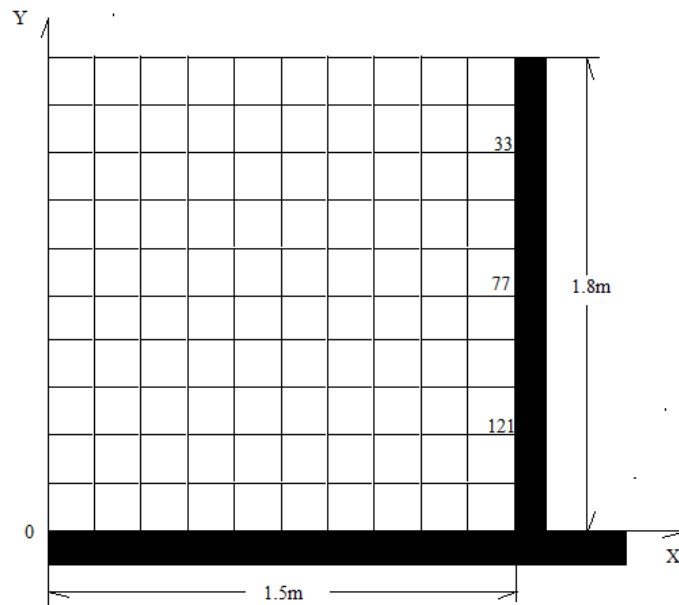


Figure 7. Finite Element Mesh of EPS Block in Bearing Test.

Duncan model is used in the finite element analysis, all the Duncan parameters are the results discussed above. The horizontal stress σ_x on the interference of EPS block and

retaining wall can be calculated values of σ_x at the node 33, 77 and 121 are shown in table 1, in which there are measured values of node 33, 77 and 121 for contrast.

Table 1. The Contrast of Calculated Value and Measured Value.

| load | | 2kPa | | | 22kPa | | | 42kPa | | | 50.33 | | |
|---------------------|------------------|------|------|------|-------|------|------|-------|------|------|-------|------|------|
| node | | 33 | 77 | 121 | 33 | 77 | 121 | 33 | 77 | 121 | 33 | 77 | 121 |
| σ_x (kPa) | calculated value | 0.15 | 0.21 | 0.29 | 1.46 | 1.52 | 1.58 | 2.77 | 2.83 | 2.89 | 3.35 | 3.72 | 3.63 |
| | measured value | 0.13 | 0.13 | 0.13 | 1.47 | 1.46 | 1.43 | 2.93 | 2.92 | 2.91 | 3.61 | 3.60 | 3.58 |

In table 1, the results of finite elements analysis are very close to the measured values, as shows Duncan-Chang can be used for the nonlinear elastic analysis of EPS block. The Duncan parameters are obtained from the triaxial test under low confining pressure ($\sigma_3 \leq 100kPa$). The geotechnical embankment engineering projects are of low confining pressure.

5. Conclusion

Through the triaxial test research on EPS samples and the finite elements analysis on ESP block bearing test, the conclusions can be drawn as follows:

The relationship curve of $(\sigma_1 - \sigma_3) \sim \varepsilon_a$ shows: the structure strength of EPS decreases with the increasing of confining pressure σ_3 (under the condition of $\sigma_3 \leq 100kPa$). It shows that EPS blocks used in geotechnical embankment should under low confining pressure.

Under the condition of low confining pressure σ_3 , the Poisson's ratio is small ($\nu < 0.1$). The volume density of EPS is small ($\rho = 0.2kN/m^3$). EPS is of valuable reference in the shallow soft ground embankment. When EPS blocks are used as fillers in road embankment, the upper load on EPS block should be small ($\sigma_1 - \sigma_3 < 50kPa$), the triaxial strain is small ($\varepsilon_a \leq 3\%$). Not only the compressed vertical deformation of EPS blocks is small, but also the settlement of roadbed is small, so the total settlement of road surface can be decreased.

The relationship of $\sigma_1 - \sigma_3 \sim \varepsilon_a$ obtained from the triaxial test of EPS shows: when $\sigma_3 < 150kPa$, it is a hyperbola, and Duncan-Chang model is suitable, and Duncan parameters exist. Through the EPS block bearing test, the measured results are very close to the results calculated, as indicates that the Duncan-Chang parameters obtained from the triaxial tests are confirmed.

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