Strength parameters of earth-rock mixtures

Paramètres de résistance des mélanges sol-roche

V. H. TORREY, PhD, Research Civil Engineer, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, USA
R. T. DONAGHE, Senior Civil Engineering Technician, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, USA

SYNOPSIS The results of a comparative investigation are presented wherein consolidated undrained and unconsolidated undrained triaxial compression tests were utilized to assess the validity of two current practices of altering prototype gradations of earth-rock mixtures to reduce maximum particle size and permit laboratory testing of smaller diameter specimens. Results of tests performed on 38.1 cm diameter by 97.8 cm tall specimens of unaltered (full-scale) gradations are compared to results of tests on 15.2 cm diameter by 35.7 cm tall specimens composed of gradations of materials obtained by scalping (removing) oversized particles from the full-scale gradations and either discarding the scalped fraction or replacing it with an equal weight of finer graded material. Both total and effective stress strength parameters are presented and compared. With respect to the prediction of strength parameters for the full-scale gradations, the scalping procedure was found unsatisfactory. The scalping/replacement procedure may be satisfactory for estimating effective stress strength parameters but not for total stress parameters.

INTRODUCTION

Over the last 40 years there has been a considerable increase in the usage of earth-rock mixtures in the fills of high dams and other embankments. Such soils are heterogeneous mixtures of particles which may range in size from as large as boulders to as small as clay. The presence of a significant fraction of particles larger than about 2.5 cm makes for extreme difficulties in the assessment of strength parameters by conventional laboratory triaxial tests. One of the major complications arises from the fact that the diameters of the triaxial specimens must exceed that of the maximum particle size of the material by a sufficient ratio to yield reliable results. In addition, a minimum specimen height to diameter ratio of about 2.5 must also be provided. Consequently, unless alternative procedures are employed, large particle sizes dictate specimen proportions which exceed the testing capabilities of most modern soil laboratories as well as making routine testing laborious and expensive for laboratories with the capabilities.

The objective of this investigation was to examine the validity of the Corps of Engineers standard practice (Engineer Manual EM 1110-2-1906, 1970) for determining strength parameters of earth-rock mixtures containing more than 10 percent by weight of particles larger than 1.90 cm (3/4-in.). That procedure specifies that the oversized fraction be scalped (removed) and replaced with an equal percentage by weight of the particle range between the U. S. Standard No. 4 sieve (4.76 mm) and 1.90 cm. Triaxial testing is then performed on 15.2 cm diameter specimens assuming that results are comparable to those that would be obtained on larger specimens of the parent full-scale material. Secondarily, it was also decided to assess the practice of determining strength parameters of earth-rock mixtures by performing tests on specimens formed by scalping the oversized fraction if it comprises less than about 40 percent by weight of the total material.

TESTING PROGRAM

The approach to achieving the objectives was to compare results of isotropically consolidated undrained (CU) and unconsolidated undrained (UU) strain-controlled triaxial tests performed on 38.1 cm diameter by 97.8 cm tall specimens of full-scale gradations with those obtained from 15.2 cm diameter by 35.7 cm tall specimens of scalped/replaced and scalped gradations derived from the full-scale gradations. Three artificial full-scale gradations (Fig. 1) were created to contain 20, 40, and 60 percent gravel (Unified Soil Classification System) by blending the appropriate percentages by weight of subrounded to rounded washed gravel (GP, 7.6 cm maximum particle size), and subangular to subrounded mortar sand (SP) with a constant percentage of clay (CL). The Atterberg Limits of the clay

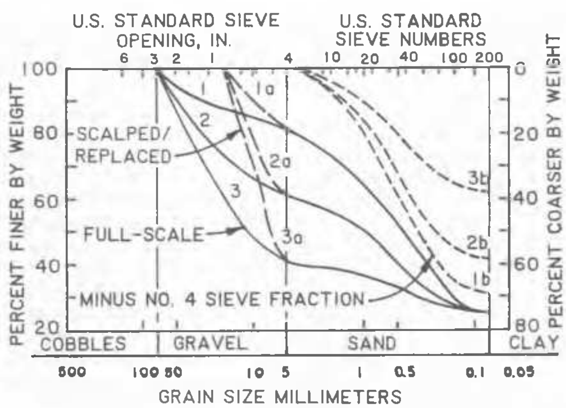

Fig. 1 Test Gradations

were w_l = 43 and w_p = 22. The range of full-scale gradations was chosen to be representative of materials used in the construction of many earthen dams. The three scalped gradations tested (Fig. 1) represented the minus U. S. Standard No. 4 sieve (4.76 mm) fraction of the full-scale gradations. All test specimens were compacted to 95 percent of the standard effort maximum dry density for the particular gradation being tested at a water content achieved by combining saturated-surface-dry gravel with the minus No. 4 sieve fractions prepared at their optimum water contents plus one percentage point. Specimens were tested under confining pressures of 413.7 kPa and 1379.0 kPa. The 3-year testing program also included comparative tests to assess any equipment and specimen size effects and a series of CU tests on a natural earth-rock mixture placed as fill in a major Corps of Engineers dam. Within the length restrictions on this paper, only the results relative to the artificial gradations can be addressed and partially discussed. Emphasis is placed on the behaviors of full-scale versus scalped/replaced specimens. Results of the scalped test series are presented but not discussed. This is because the absence of gravel and the variable clay fraction of scalped materials (see Fig. 1) complicates comparative discussion beyond the space available. The reader is referred to the formal report of the work (Donaghe and Torrey, 1984) for comprehensive information. However, the authors presume the privilege of stating some conclusions drawn from the research but not specifically treated herein. Additional investigations of moisture-density and strength testing techniques for earth-rock mixtures are in progress at the Waterways Experiment Station (WES).

TEST RESULTS

CU Tests, Effective Stress Parameters.

Effective stress paths yielded by the CU tests are shown in Fig. 2 and reveal considerable excess pore pressures generated during shear for all the gradations tested. The stress paths for scalped/replaced and scalped specimens were characterized by immediate, strong development of excess pore pressure while the full-scale gradations containing 20 and 40 percent gravel tended to be somewhat less contractive. Overall, it is clear that compaction to 95 percent of standard effort maximum density yielded relatively loose structures. The stress paths also indicate no effective cohesion intercepts for any of the gradations.

The effective angle of internal friction $\bar{\phi}'$, based on maximum principal effective stress ratio, is plotted versus gravel content in Fig. 3. The data for scalped materials are plotted according to the gravel content of their parent full-scale gradations. Since there were no observed tendencies toward curvature of the strength envelopes, an average value of ϕ' was taken for each gravel content based on $\bar{c}'$ = 0. The curves of Fig. 3 show that for both the full-scale and scalped/replaced specimens, ϕ' increased with increasing gravel content. Values for full-scale gradations ranged from 35 to 42 degrees and were consistently about two degrees higher than those for the scalped/replaced cases. It is interesting to note that the curve for the scalped materials lies close to that for the scalped/replaced gradations although generally lower.

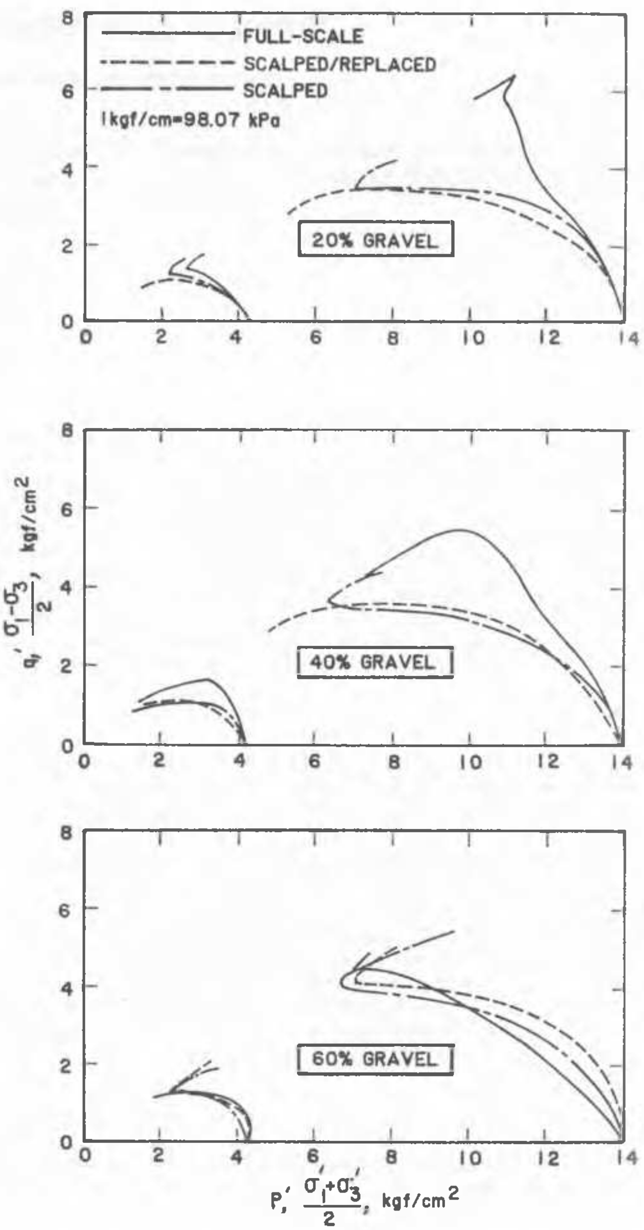

Fig. 2 Effective Stress Paths

CU Tests, Total Stress Parameters.

Total stress strength envelopes based on maximum principal stress difference were linear and exhibited no cohesion intercepts. Best fit curves for the total stress angle of internal friction, Øu, versus gravel content are given in Fig. 3. The curves show that Øu for the full-scale gradations ranged up to 7 degrees higher than those for corresponding scalped/replaced gradations. The greatest difference in Øu values occurred at the lowest gravel content and diminished with increasing gravel content. On the basis of earlier work by WES (Donaghe and Townsend, 1975), this

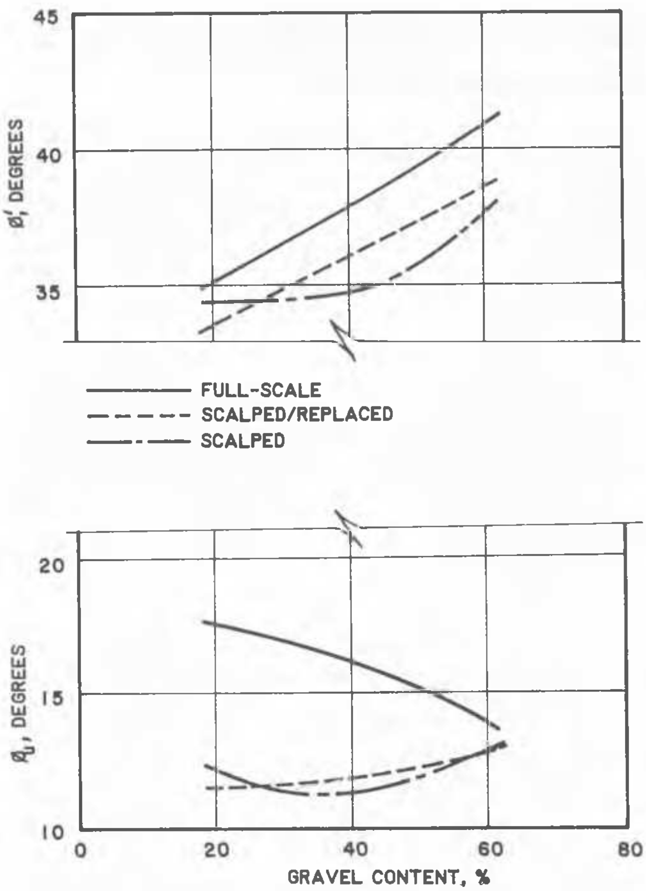

Fig. 3 Angles of Internal Friction Versus Gravel Content, CU Tests

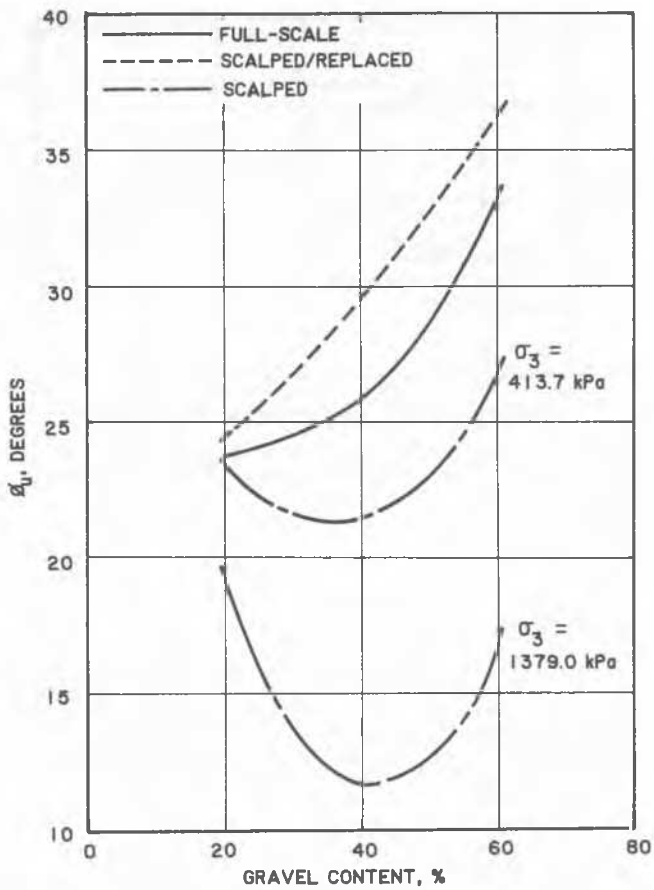

Fig. 4 Angle of Internal Friction Versus Gravel Content, UU Tests

trend is attributed to increasing interference of the plus 1.9 cm (3/4-in.) fraction of the full-scale gradation with increasing gravel content upon the compaction of the minus 1.9 cm fraction. In other words, in specimens having larger particle sizes, a skeletal structure is formed which increasingly shields the "matrix" material from the effects of the applied compactive effort as gravel content is increased. This is borne out by the effective stress paths of Fig. 2 for which it was pointed out previously that the full-scale gradations become more contractive with increasing gravel content. At the highest gravel content tested there is the least difference between the stress paths for the full-scale and scalped/replaced materials. The values of Øu are quite low overall, reflecting the considerable excess pore pressures during shear. The range in Øu values was from 14 to 18 degrees for the full-scale specimens and from 11 to 13 degrees for the scalped/replaced specimens. The trend in results for the scalped gradations again was similar to that for the scalped/replaced series.

UU Tests.

Relationships between Øu and gravel content for the UU tests are given in Fig. 4. Average curves are shown to represent the trends for full-scale and scalped/replaced materials although Øu values for the 413.7 kPa confining pressure were consistently slightly higher (approximately one degree) than those for tests at 1379.0 kPa. This indicates the higher degrees of saturation prior to shear at higher confining pressure, and, therefore, higher induced pore pressures during shear. Since Øu values for the scalped materials tested at 1379.0 kPa were significantly lower than those tested at 413.7 kPa, separate curves are drawn for each confining pressure. Based on differences in Øu at equal confining pressures, scalped/replaced specimens exhibited the greater loss in strength with increasing confining pressure compared to that of full-scale specimens. The curves of Fig. 4 show that average Øu values for full-scale specimens increased from 24 to 33 degrees as gravel contents increased and were 0.5 to 4 degrees lower than those of corresponding scalped/replaced specimens. The smallest difference was at the lowest gravel content. The Øu value for the scalped gradations was as much as 14 degrees lower than that for the corresponding full-scale gradations at the higher confining pressure. Since there was more variation in Øu for the UU tests than for the CU tests, the degree of saturation was an important factor influencing strength. This is illustrated in Fig. 5 where a roughly linear relationship is seen between Øu and degree of saturation prior to shear.

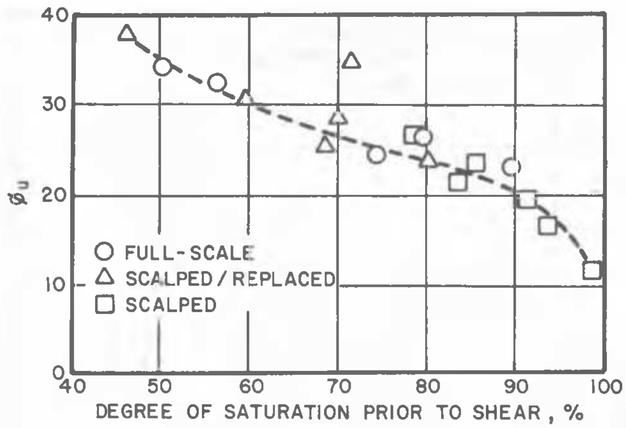

Fig. 5 Angle of Internal Friction Versus Degree of Saturation Prior to Shear, UU Tests

Conclusions

The conclusions stated below have been drawn from among those for the total testing program partially presented herein. Until additional research is complete, they must be considered restricted to the general test material characteristics and test procedures reported.

Consolidated Undrained Triaxial Tests (CU).

(i) The scalping/replacement procedure provides a satisfactorily conservative means of estimating effective stress strength parameters for full-scale earth-rock mixtures.

(ii) The scalping procedure in which tests are performed on the minus U. S. Standard No. 4 sieve (4.76 mm) fractions of full-scale gradations yields effective stress parameters which may be conservative by as much as 5 degrees in Ø'.

(iii) Earth-rock mixtures compacted to approximately 95 percent of standard effort maximum dry density may develop considerable pore pressures during undrained shear. As a result, Øu may be as low as 11 degrees.

(iv) There were no trends in results to indicate that either Ø' or Øu decreased with increasing confining pressure because of particle breakage. This is attributed to reduced effective stresses resulting from considerable excess pore pressure during undrained shear.

(v) There were no significant differences in test results due to differences in sizes of specimens or testing equipment.

(vi) Neither the scalping/replacing or scalping procedure provides a satisfactory means of estimating strength parameters of full-scale gradations based on total stresses.

Unconsolidated-Undrained Triaxial Tests (UU).

(i) Neither the scalping/replacing nor scalping procedure provides a satisfactory means of estimating UU strength parameters for full-scale gradations. Øu from scalped/replaced materials may be up to 4 degrees higher and from scalped materials up to 14 degrees lower than Øu for corresponding full-scale materials.

(ii) The value of Øu obtained from UU tests on full-scale, scalped/replaced, and scalped materials is a function of the degree of saturation prior to shear which is, in turn, a function of the confining pressure. The degree of saturation increases with increasing confining pressure and Øu decreases. Scalped gradations exhibit the greatest decrease in strength while full-scale materials exhibit the least.

(iii) Because of the specimen preparation procedures used in this study, initial degree of saturation was an inverse function of gravel content. Therefore, Øu increased with gravel content. For the full-scale gradations, Øu was as low as 24 degrees at 20 percent gravel content and between 35 and 40 degrees at 60 percent gravel content.

REFERENCES

Donaghe, R. T. and Torrey, V. H. (1984). Strength and deformation properties of earth-rock mixtures. Technical Report, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Donaghe, R. T. and Townsend, F. C. (1975). Compaction characteristics of earth-rock mixtures. Miscellaneous Paper S-73-25, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Army Corps of Engineers (1970). Laboratory soils testing. Engineer Manual EM 1110-2-1906, Headquarters, Department of the Army, Office of the Chief of Engineers, Washington, DC.

ACKNOWLEDGEMENTS

The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research conducted under the Civil Works Program of the United States Army Corps of Engineers by the Waterways Experiment Station. Permission was granted by the Chief of Engineers to publish this information.