Effect of gravel fractions on direct shear strength of sand

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ABSTRACT - Naturally occurring and reconstituted granular soils consisting of a matrix of large and small particles i.e. quarry sand, backfills and saprolithic sands are encountered very often in construction. 100mm square shear box was used to determine the shear strength of 0.425mm – 9.5mm granular particles. The results reveal that for the size of shear box used, shear strength increases with average particles size up to 4.25mm and erratic for higher particle size. Addition of gravel results in decrease in dry density of the mixture and a decrease in mobilized strength. The Guth (1945) [1] Model is linear and predicted an increase in shear strength with gravel content in contrast with the laboratory values. The difference is due to the effect of rough textured gravel on the on the mobilized strength of the lower dry density matrix.

1. INTRODUCTION

Materials forming part of engineered or reconstituted backfills, glacial tills, mudflows, debris flows, residual and saprolithic soils, have a distinct structure which consists of a mixture of a base soil matrix (sand, silt, or clay or a combination of these soils) and large particles of gravel. In order to obtain the shear strength of these mixtures in the laboratory, large representative samples need to be tested in either the triaxial or the direct shear apparatuses. These large samples require large direct shear or triaxial cells and large loading systems in order to simulate field stress conditions. The use of large triaxial or direct shear equipment makes the tests very time consuming and expensive. Direct shear and triaxial compression tests on granular materials with oversized particles conducted by ([2]; [3]; [4]; [5]; [6]; and [7]) have indicated that that the shear strength of the mixtures depends upon the relative concentration by volume (or weight) of the oversized particles in the mixtures. These researchers found that if the concentration by volume was greater than 45% (>70% by weight), the shear strength of the mixtures was basically that of the large particles alone. If the concentration by volume of the large particles in the mixtures was between 45% and 31 % (70% and 48% by weight), the shear strength of the mixtures was partially controlled by the friction between the large particles. If the concentration by volume of the large particles was less than 31% (<48% by weight), the shear strength of the mixtures was basically that of the matrix of the smaller particles alone.

The aim of the study is to determine the shear strength of granular specimens of uniform particle sizes of 0.425mm with different percentages of 9.5mm, gravel in a 100mm x 100mm shear box apparatus. It is thus intended to obtain the shear strength of larger granular soils from that of the mixtures with dispersed oversized particles from the strength of the smaller granular matrix which will be easily obtained using conventional laboratory tests and the concentration by volume of the dispersed oversized particles. If the proposed methodologies are found to be feasible for soils with non-contiguous or dispersed oversized particles, it will be highly beneficial to the geotechnical engineering community in terms of time and money saved since large conventional equipment would not be required to measure the shear strength of soil-rock mixtures since the property of the soil matrix, can easily be measured with conventional geotechnical equipment and the value of concentration can be easily estimated.

2. MATERIALS AND METHODS

It is also important to examine the stress strain behavior for specimens of gravel particles that are contiguous i.e. the gravel particles touch each other. In the sand-gravel mixtures the particles of gravel will touch when their concentration increases in the sand-gravel mixtures. For the determination of the shear strength of granular soils [1] proposed Equa. 1 in terms of peak stress or stress ratio thus

$$\tau_c = \tau_m (1 + 2.5 C) \tag{1}$$

In Eq. (1), τ_c is the shear strength of a granular material with dispersed oversized particles; τ_m is the shear strength of the granular matrix in which the large particles are dispersed, and C is the concentration by volume of the oversized particles. The square shear box had a width of 100 mm and a depth of 40 mm aspect ratio, H/L=0.40. The samples were sheared at a constant rate of 0.25 mm/min, which is consistent with the standard rate for drained tests on sands. Tests were conducted in a water bath with the sample completely submerged in water to assure that the samples had no cohesion. The thickness of the 100 mm shear box did not meet the [8] minimum criteria of six times the maximum particle diameter for some specimens. Three set of specimens were tested (1) T1; 0.425-2.36mm, T2; 2.36-4.75mm, T3; 4.75-9.5mm, T4; 9.5-13.2mm, T5; 13.2-19.0mm, (2) Type 1+2, Type (1+2) + (20%T4), Type 1+2 + (40%T4), Type 1+2+ (70%T4), where Type (1 +2) = 50/50 mix of 0.425-2.36mm and 2.36-4.75mm; Type 4 = 13.2-19.0mm and (3) Interface direct shear tests

3. RESULTS AND DISCUSSION

The results of shear strength parameters of granular soils derived from shear tests in a 100mm x 100mm shear box was presented in Table 1. The frictional angle increased with particle size up to 4.75 - 9.5mm and remained constant afterwards. Larger particle mobilize shear stress within a large shear band. The maximum particle size to specimen thickness ratio did not meet the ASTM criterion and thus restrained particle displacement may have resulted in limited mobilization of direct shear stress. Also in Table 1, the addition of large gravel particles up to 70% to a sand specimen resulted in a decrease in mobilized strength. Addition of rough textured gravel up to 70 % resulted in reduced dry density and thus a slight decrease in mobilized strength. Very few tests designed to obtain the shear strength of granular materials with dispersed oversized particles have been conducted to date. The reason for the lack of test results in these materials was to do with the fact that large representative samples need to be tested in either the triaxial or the direct shear apparatuses. The results of the effect of particle crushing on shear strength and dilation characteristics of Sand-Gravel Mixtures by [9] is shown in Table 2. The results were derived from series of tests on sand containing different percentages of 15mm and 25mm particle size gravels. The results show that irrespective of the size of the gravel, the shear strength remain constants up to 40% and increased significantly afterwards, it is thus implied that the 40% is the boundary between the near field and the far field behaviour.

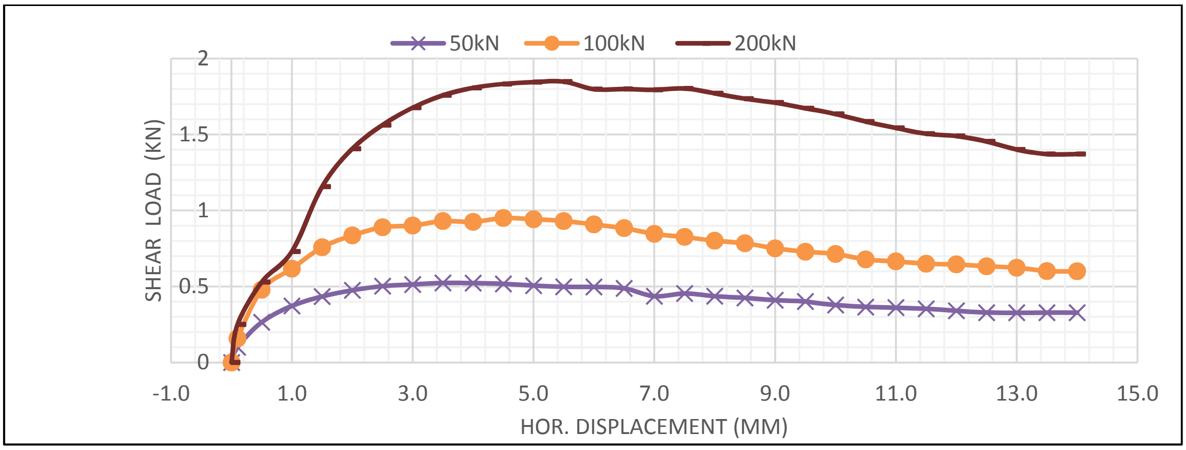
Fig 1 and Fig 2 illustrates the incompatibility of stress and dilatants deformation in relation to large particle size. The large granular soils exhibited residual stress state at increasing dilatants deformation. [10] conducted some conventional direct shear tests using a 65 mm shear box on mixtures of sand and gravel. The sand had an average diameter of 0.3 mm and the gravel with an angular shape had a diameter equal to 5 mm. The result is shown in Table 3. Using the values of the shear strength of the sand alone, τ_m, as well as the concentration by volume, C, of the gravel in the mixtures, the values of the shear strengths of the mixtures, τ_c, were evaluated using the Guth's model represented by Eq. 1 [1]. The values of the shear strength, τ_c, of the sand-clay mixture obtained using the Guth's model was superimposed on the values obtained by [10]. Fig. 3 shows that the Guth's model predicts very well the shear strength of the mixtures. Thus, Eq. 2 seems to predict reasonably well the shear strength of granular material with oversized particles. In this case the gravel content is limited to 30% and an icrease in shear stress with gravel content was indicated. Fig 4 showed that the Guth model could not predict the shear stress of granular soils in a 100mm x 100mm shear box both in the near field region (C = 30%) and the far field region (C > 30%). There was a slight reduction in mobilized shear stress at gravel contents of 20% - 40%. This may be due to reduced dry density, as was also indicated in Table 1. The major differences between the test conditions of Fig 3 and Fig 4 are specimen thickness to maximum particle size ratio, the surface texture of the particle.

Table 1. Shear strength parameters of granular soils derived from shear tests in a 100mm x 100mm shear box.

Soil Type	Phi	Soil Type	Phi
0.425 – 2.36	25.4	Type 1 + 2	42.1
2.36 – 4.75	40.8	Type 1 + 2 (20%T4)	42.3
4.75 – 9.5	44.1	Type 1 + 2 (40%T4)	41.2
9.5 – 13.2	38	Type 1+2(70%T4)	41.8

Table 2. Shear results in a 65 mm square shear box on mixtures of sand with average diameter of 0.3 mm and gravel with an angular shape and diameter of 5 mm [10]

% of Large Particles	Normal Stress (158kPa)	Normal Stress (237kPa)	Normal Stress (316kPa)
0	106	135	210
6	115	160	220
12	140	165	240
18	160	210	280
32	201	308	340



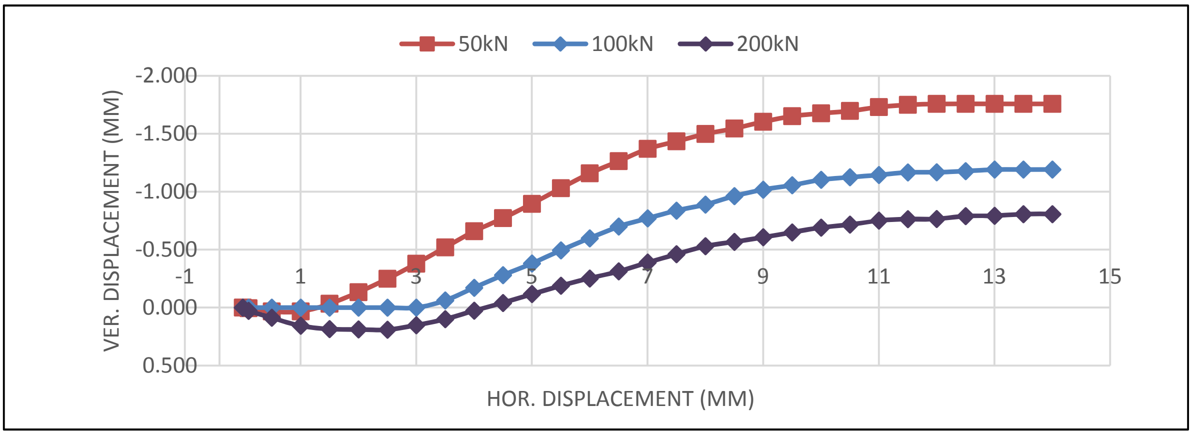


Fig. 1. Stress deformation curves of Type 1+2

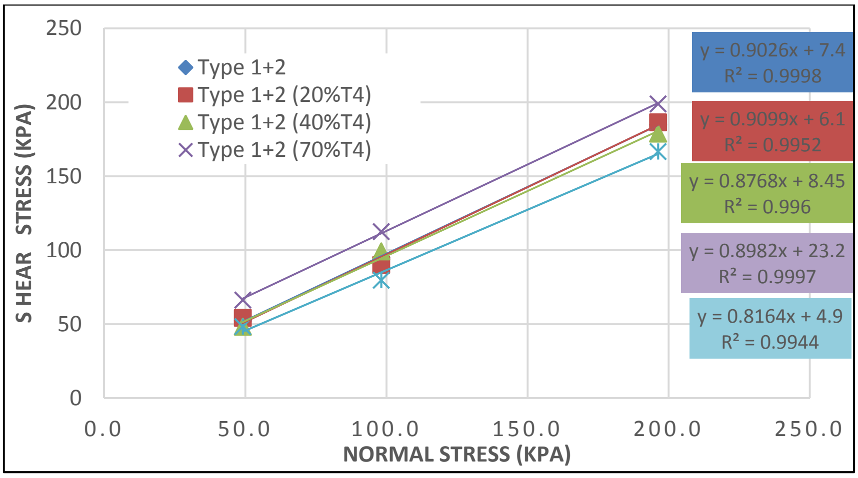


Fig 2. Strength Envelope of Mixtures of T1 +T2 and T4

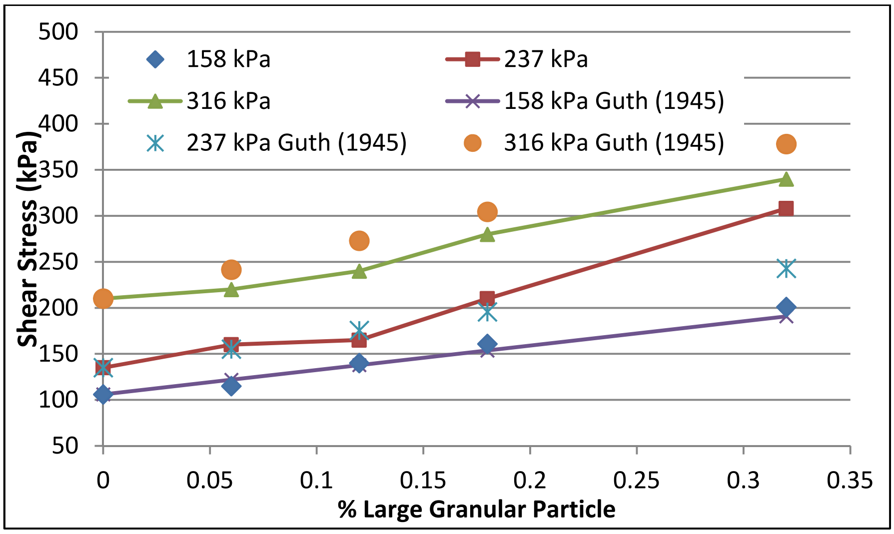


Fig. 3. Prediction of [10] shear stress by [1] model.

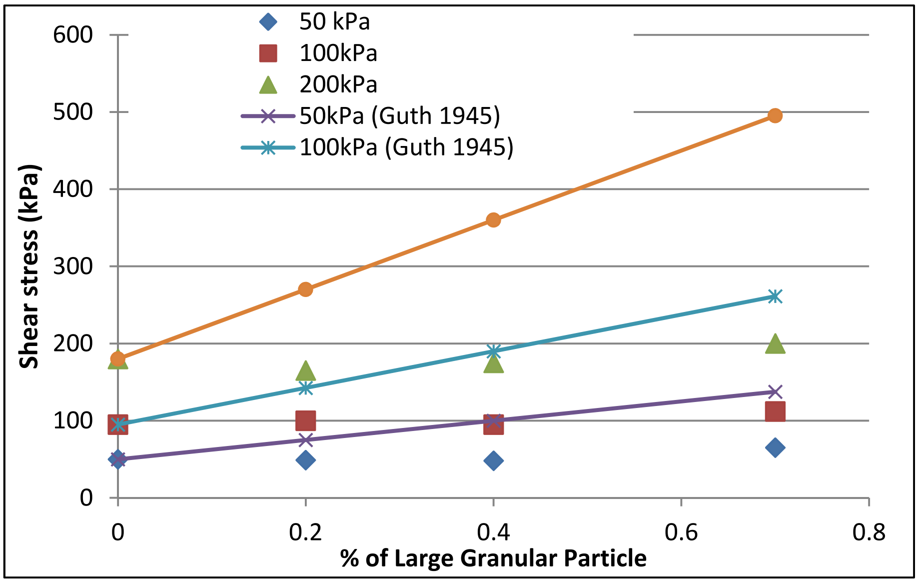


Fig. 4: Prediction of direst shear stress by [1] model.

4. CONCLUSIONS

The use of Guth model for the estimation of the shear strength of non-dispersed and dispersed sand-gravel mixtures is sensitive to the test conditions. Based on the limited tests in literature and tests conducted in a 100mm x 100mm shear box, comparisons of the shear strength predicted by Guth (1945)[1] model and the values determine with the aid of the 100mm square box revealed that the strength of gap graded sand and gravel soil matrix is dependent on the size of the shear box and that of the particles tested, (b) the degree of roughness of the oversized particles, (c) dry density and magnitude and range of applied normal stress. The addition of rough textured granular materials up to 60 – 70% may result in decrease in dry density and the mobilized strength cannot be predicted by a linear version of the Guth Model but a modified model.

5. REFERENCE

[1] Guth, E. (1945). Theory of filler reinforcement. *J. of Applied Physics,* Vol. 16, pp. 20-25.43

[2] Doddiah, D., Bhat, H.S., Somasekhar, P.V., Sosalegowda, H.B., and Ranganath, K.N., (1969). Shear strength charactyeristics of soil-gravel mixtures. *J. of the Indian Nat. Soc. of Soil Mech. and Found. Eng.,* Vol. 8, No. 1, pp. 57-66.

[3] Fragaszy, R.J., Su, J., Sidiqqi, F.H., and Ho, C.L. (1992). Modeling strength of sandy gravel. *ASCE Journal of Geotechnical Engineering*, Vol. 118(6), 920-935.

[4] Holtz, W.G., and Gibbs, H.S. (1956). Triaxial shear tests on pervious gravelly soils. *J. of the Soil Mech. and Found. Div.,* ASCE, Vol. 82 (1), pp. 1-22.

[5] Marsal, R.J., and Fuentes de la Rosa, A. (1976). Mechanical properties of rockfill-soil mixtures. *Transactions of the 12th Int. Congress on Large Dams,* Mexico City, Vol. 1, pp. 179-209.

[6] Vallejo, L.E. (2001). Interpretation of the limits in shear strength in binary granular mixtures. *Canadian Geotechnical Journal*, 38, 1097-1104

[7] Vasileva, A.A., Mikheev, V.V., and Lobanova, G.L. (1971). How the strength of gravelly soils depend on the type of state of the sand filling the pores. *Soil Mechanics and Foundation Engineering,* Vol. 8, No. 3, pp. 167-171.

[8] American Society for Testing and Materials (1990). Standard test methods for direct shear test of soils underconsolidated drained condition, D-3080-90, ASTM, Philadelphia.

[9] Hamidi, A., Alizadeh, M., Soleimani, S.M., (2009). Effect of Particle Crushing on Shear Strength and Dilation Characteristics of Sand-Gravel Mixtures *International Journal of Civil Engineering.* Vol. 7, No. 1,

[10] Yagiz, S. (2001). Brief note on the influence of shape and percentage of gravel on the shear strength of sand and gravel mixtures. *Bulletin of Engineering Geology and the Env.* 60 (4), 321-323.