Comparison of Soil-Aggregate Mixture Strength by Two Methods

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This investigation compares strength values of soil-aggregate road materials as determined in-place by the Burggraf Shear Apparatus and by the triaxial compression test in the laboratory. A large number of soil-aggregate surface course materials, including both pit-run gravel and crushed stone materials, were tested.

The in-place strength of these materials was determined essentially according to ASTM Designation D-916-47T. The triaxial compression tests were performed on samples taken directly from the field test points and remolded to the same moisture content and density as existed during the field test.

The results of these tests indicated that, within the scope of the types and conditions of the materials studied, a definite relationship exists between the strength values determined by the two different methods.

•THE RESISTANCE of soil-aggregate road materials to deformation by traffic loads is largely governed by their shear strength. The measurement of this property is necessary, not only in the understanding of the service behavior of these materials but also in the formulation of working principles for mixture design.

There are several strength tests that may be applied to soil-aggregate materials. In the laboratory, the triaxial compression test is probably the most useful. In this well-known test, a cylindrical specimen is subjected to a confining pressure on all sides, and a vertical axial stress is applied to the end until the specimen fails in shear. The stresses may be applied under conditions closely parallel with actual field conditions; hence, the results may have a more direct application to practical problems than those from other laboratory tests. However, the test has to be performed on laboratory molded specimens, as it is impossible to obtain soil-aggregate specimens from the road without appreciable disturbance. The test is of particular value in the laboratory evaluation of the relative importance and quantitative effect of the various material factors on the strength characteristics of soil-aggregate materials, which is an important procedure in mixture design.

For the evaluation of the in-place strength of soil-aggregate road materials, the Burggraf Shear Apparatus can be most effectively used. In this procedure, a horizontal thrust is applied, by means of a screw-propelled plunger-type pump, through a compression plate, to an exposed vertical section of a soil-aggregate layer until the material ahead of the plate fails in shear. The method was developed by Fred Burggraf and has been adopted by ASTM as Designation D-916-47T (1). By means of this apparatus, various road surface materials can be tested under actual environmental conditions, and the criteria for their strength and performance can be deter-

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mined (2, 3, 4). Although the portable mechanical device may be adapted to laboratory testing, its use thus far has been confined to the field evaluation of road materials.

Whereas the methods of procedure for these two tests are different, both are concerned with the resistance of soil-aggregate materials to shearing. From the point of view of mechanics a main difference between the two tests appears to be the manner in which the materials are loaded to failure. As shown in Figure 1, the major principal stress in the triaxial compression test is the applied vertical stress, and the lateral stress applied all around is the minor principal stress. In the in-place shear test by the Burggraf Shear Apparatus, the applied horizontal stress is the major principal stress and the minor principal stress is that due to the weight of the wedge of soil-aggregate material or any vertical loads applied as a surcharge to the surface of the wedge adjacent to the compression plate (5). Because of the differences in the general setup of these tests, the behavior of soil-aggregate materials under the loading conditions in each of these tests at the time of failing also becomes separately distinct. In the triaxial compression test, a soil-aggregate material is failed under the condition of triaxial loading. In the Burggraf shear test, however, it is failed in a plane strain condition. Consequently, the strength values as obtained from these two tests may be expected to be characteristically different.

OBJECTIVE AND SCOPE OF INVESTIGATION

The investigation described here was made to provide data for comparing the strength values of soil-aggregate road materials as determined in-place by the Burggraf Shear Apparatus and those as determined by the triaxial compression test in the laboratory. It was hoped that a correlation between these values might be established by

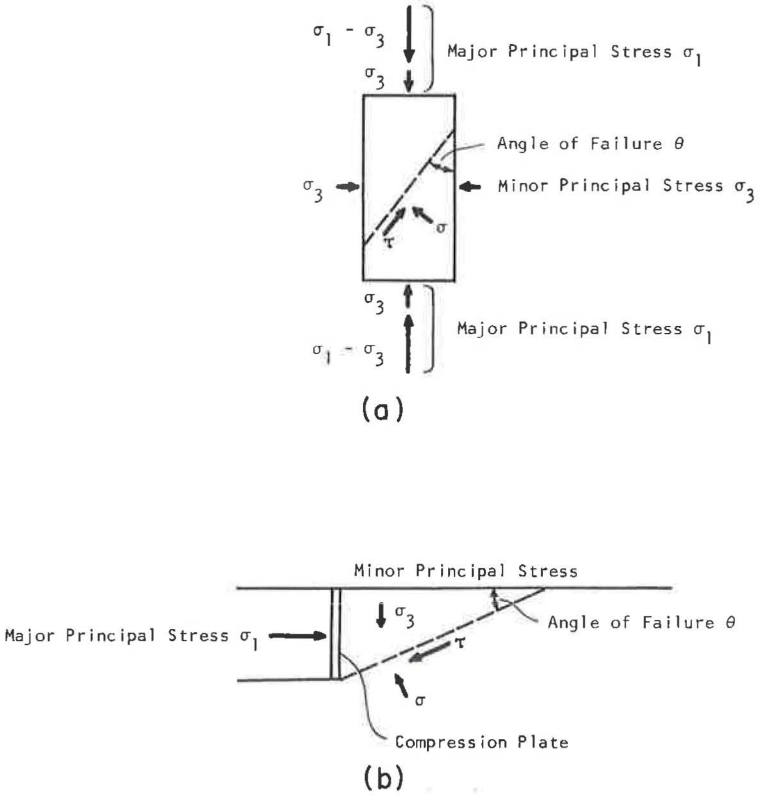

Figure 1. Stress conditions in (a) triaxial compression test and (b) Burggraf shear test.

which the laboratory test results might be used for estimating the possible in-place strength of soil-aggregate materials and, in turn, for predicting those behavior characteristics associated with their in-place strength. For instance, field investigations on the service conditions of soil-aggregate road surfaces conducted at the University of Illinois have shown that potholes and washboard formations seldom occur in materials with high Burggraf shear values.

Included in the study was a total of 65 soil-aggregate surface course materials from secondary and local roads in all parts of Illinois. The in-place strength of these materials was determined essentially according to ASTM Designation D-916-47T. The triaxial compression tests were performed on specimens prepared in the laboratory from materials taken directly from the field test points. These specimens were remolded to the same moisture content and density as existed during the field test. The relationship between the strength values determined by the two tests is indicated by a correlation-regression analysis.

TESTING PROGRAM

All materials involved in this study had been placed for at least 2 yr, and a few for as many as 5 or 6 yr, before the field tests were performed. Both pit-run gravel and crushed stone, typical surfacing materials for soil-aggregate roads, were represented in this investigation. In the selection of test sites, those materials with a history of high stability were included as well as those exhibiting poor service. The tests were conducted during various seasons of the year, but most were performed in summer and fall. The moisture content of these materials was, in general, quite low, ranging from 1.0 to 5.4 percent with an average value of 2.5 percent.

With the Burggraf Shear Apparatus a hole about 10 by 10 in. is dug in the layer to be tested to a sufficient depth, and a vertical face against which the test is to be made is carefully cut to receive a standard compression plate connected to the thrust cylinder. The horizontal thrust is then applied by turning a hand wheel operating the screw-propelled plunger-type pump at a uniform rate to force the compression plate against the soil-aggregate layer until the material ahead of the plate fails. The area of the surface on which the failure occurs is measured, and the strength value is determined by dividing the maximum horizontal thrust by the sheared area. The angle of failure, θ (Fig. 1 (b)), is determined by measuring its tangent, which consists of one measurement from the top of the compression plate to the bottom of the cavity divided by the distance from the face of the compression plate to the most remote edge of the sheared surface.

In the present investigation, the parabolic compression plate, having a height of $2\frac{15}{32}$ in., a width of $7\frac{1}{2}$ in., and an area of 12.2 sq in., was used to adapt to the limited thickness of the surface courses. To provide a uniform bearing area, a fast setting plaster, Hydrocal White, approximately $\frac{1}{4}$ in. in thickness, was applied between the compression plate and the vertical face to be tested. The horizontal thrust was applied at a uniform rate of 10 lb/sec, until the point of maximum pressure was noted. A typical failure at the end of the test is shown in Figure 2.

The triaxial compression test was performed on the soil-aggregate materials taken directly from each field test point. The cylindrical specimens were 4 in. in diameter and 8 in. in height. The materials were compacted to in-place density with the field moisture content. The in-place density and

Figure 2. Typical failure of soil-aggregate surface course in Burggraf shear test.

moisture content of the surface course materials were determined according to AASHO Designation T-147-54; the volume of the density hole was measured by means of the sand-density cone using standard Ottawa sand. Confining pressures of 5, 15 and 30 psi were applied by compressed air and maintained constant throughout the test. The axial load was applied to produce a constant rate of vertical deflection of 0.1 ipm until the specimen failed. The apparatus for this test is shown in Figure 3.

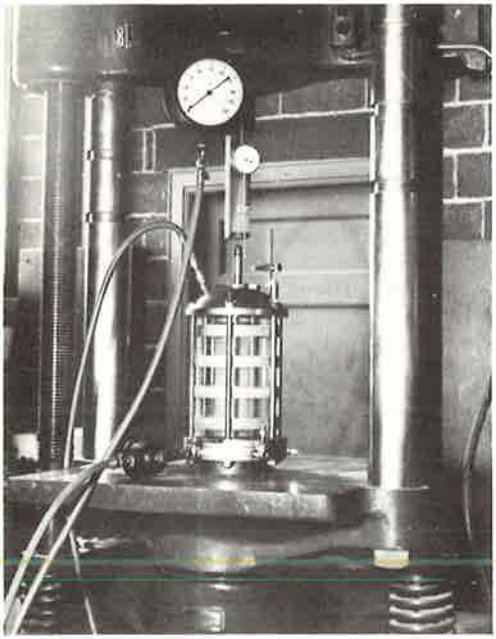

Figure 3. Apparatus setup for triaxial compression test.

RESULTS AND DISCUSSIONS

The results of the in-place and laboratory strength tests conducted on the soil-aggregate surface course materials are summarized in Table 1. The in-place shear strength was calculated by dividing the maximum horizontal thrust by the sheared area. The sheared area was determined, after the sheared-out material had been removed, by placing a piece of paper in the cavity and outlining the edge of the sheared surface. The numerical value was found by means of a planimeter. The laboratory strength value for the comparable loading condition was taken from the Mohr diagram plotted from the data of triaxial compression tests for the three different confining pressures. Because only the weight of the wedge of soil-aggregate material acted as a confining load during the in-place strength test, which was negligible in magnitude, the laboratory strength value was determined in the Mohr diagram from a failure circle representing zero confining pressure. The ordinate of the point of tangency of the circle with the failure envelope was taken as the shear strength of the material.

Also given in Table 1 are the major principal stresses, σ_1, at failure and the angles of failure, θ, of various materials as determined by the two strength tests. The major principal stress at failure in the in-place strength test was determined by dividing the maximum horizontal thrust by the area of the parabolic compression plate. For the triaxial compression test, this value was obtained in the Mohr diagram from the failure circle for zero confining pressure. For the triaxial compression test, the angle θ was computed from the angle of shearing resistance, ϕ, as indicated in the Mohr diagram, according to the expression

$$\theta = 45^\circ - \phi/2 \qquad (1)$$

The three sets of data in Table 1 are also plotted in Figures 4, 5, and 6, with the in-place test value as ordinate and the corresponding laboratory value as abscissa.

In studying the data, it may be immediately noted that, regardless of the type of surface material, the shear strength from the in-place test is consistently of higher value than that obtained from the triaxial compression test. Because the shearing stress in the soil-aggregate materials at zero confining pressure is a function of the major principal stress, this trend is also indicated between the major principal stresses at failure for the two tests. On the other hand, the angle of failure is, as a rule, smaller in the in-place test than in the triaxial compression test under comparable conditions.

TABLE 1

SUMMARY OF TEST DATA

Sample	Shearing Value, τ (psi)		Major Principal Stress, σ_1 (psi)		Angle of Failure, θ (deg)	
	Burggraf	Triaxial	Burggraf	Triaxial	Burggraf	Triaxial
			(a) Gravel			
1	30.4	17.5	123	46	20.7	25.5
2	24.3	12.5	121	36	18.4	23.5
3	40.6	21.0	162	56	23.3	24.0
4	69.3	27.5	328	86	19.6	20.0
5	23.9	12.5	127	32	20.7	24.5
6	10.6	10.5	44	22	22.6	24.7
7	24.8	10.5	153	28	19.6	24.5
8	14.3	11.0	39	30	28.0	24.0
9	38.2	20.0	213	52	18.4	25.2
10	38.6	17.0	141	46	25.7	23.2
11	18.1	12.0	121	31	17.4	24.5
12	56.1	26.0	242	72	22.6	22.5
13	26.0	17.0	114	46	18.4	24.2
14	34.4	18.0	197	48	19.2	25.0
15	9.2	9.5	58	26	16.8	24.2
16	29.6	13.2	213	36	22.0	24.0
17	15.8	16.0	96	46	16.4	22.5
18	31.6	20.0	140	60	20.5	21.2
19	35.5	20.7	202	54	19.0	25.0
20	32.7	14.0	139	38	21.7	23.5
21	22.8	16.5	148	48	16.4	25.5
22	23.5	12.2	184	32	14.0	25.0
23	38.3	19.0	187	50	19.6	24.5
24	32.8	14.5	130	40	22.6	24.0
25	38.6	23.0	126	70	24.4	21.0
26	36.4	19.0	142	60	22.0	20.0
27	30.8	13.5	117	44	23.3	19.5
28	36.3	17.0	148	50	21.2	21.2
29	26.8	17.0	148	46	19.4	23.2
30	32.1	9.5	170	24	19.6	25.5
31	47.4	21.3	265	59	18.0	23.0
32	58.7	19.0	221	52	24.0	23.5
33	58.4	20.0	185	53	25.7	24.7
34	40.0	18.5	201	54	18.9	21.7
			(b) Crushed Stone			
1	44.3	17.5	224	50	20.7	21.7
2	34.4	13.0	188	35	18.4	24.0
3	21.5	19.0	120	53	21.7	23.5
4	58.8	30.5	316	82	21.1	23.7
5	34.4	16.5	208	46	16.4	23.7
6	36.9	14.0	184	40	20.2	24.0
7	40.8	20.0	239	58	18.9	22.5
8	44.4	28.7	260	78	17.8	24.5
9	42.4	21.0	258	66	16.4	20.0
10	24.3	19.3	156	58	16.6	20.5
11	28.4	14.0	111	38	24.5	23.7
12	37.5	24.0	135	66	23.3	22.7
13	35.5	19.3	272	54	16.4	20.7
14	50.7	17.3	312	46	16.4	24.7
15	49.1	22.0	275	62	19.9	22.7
16	53.0	20.0	348	58	16.6	22.0
17	46.7	17.0	224	50	21.1	22.0
18	62.8	26.5	242	74	22.3	23.5
19	52.1	20.5	219	60	21.1	21.7
20	47.5	22.5	238	60	19.4	24.5
21	64.5	25.0	279	70	21.4	24.5
22	78.3	28.5	284	84	23.3	23.5
23	64.3	27.5	344	84	18.2	19.5
24	63.9	24.5	277	70	21.6	22.2
25	54.0	20.5	234	54	18.2	25.2
26	41.6	13.5	133	38	23.7	22.7
27	37.6	12.5	165	34	21.4	24.5
28	38.6	25.5	221	70	17.4	24.0
29	32.8	17.5	201	46	16.4	25.0
30	48.3	22.5	254	66	19.6	21.5
31	16.0	8.7	78	24	17.4	23.2

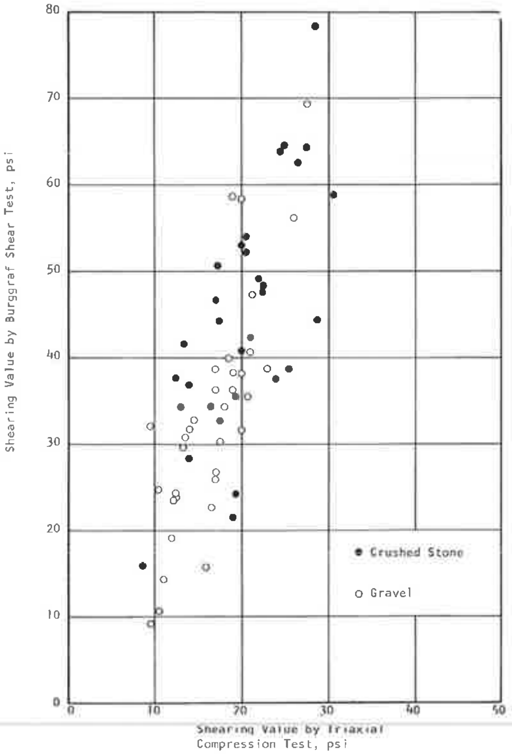

Figure 4. Relation between shearing strength values of soil-aggregate mixtures by Burggraf shear test and triaxial compression test.

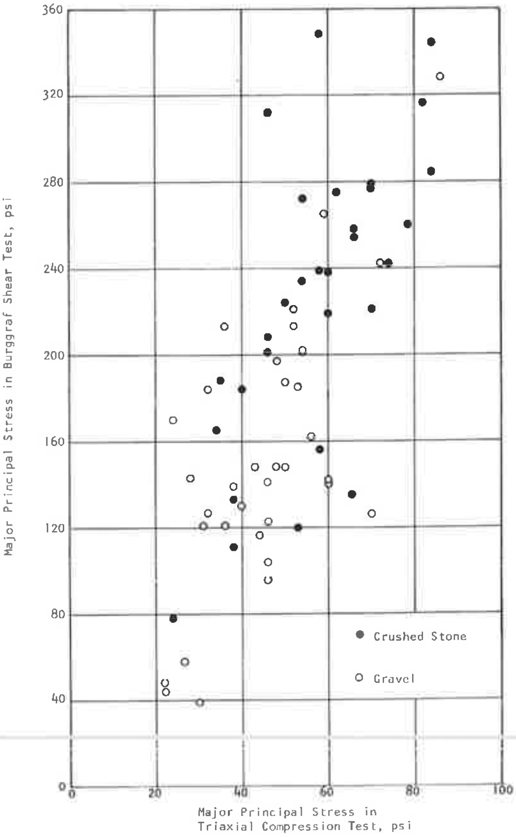

Figure 5. Relation between major principal stresses by Burggraf shear test and triaxial compression test.

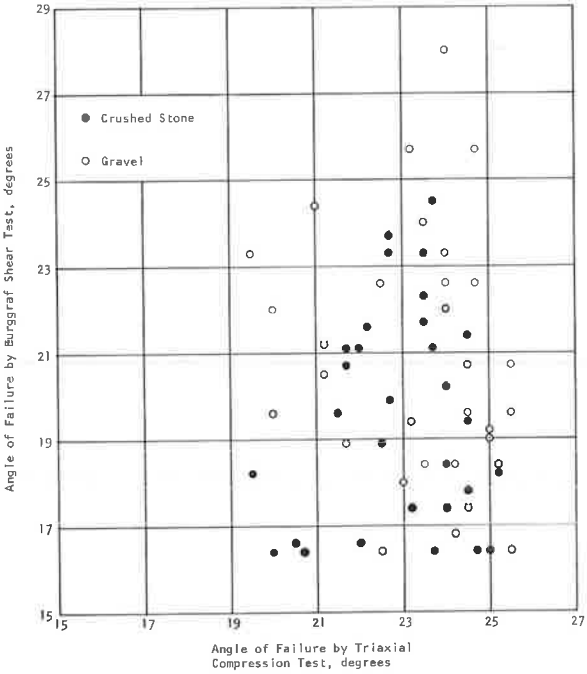

Figure 6. Relation between angles of failure by Burggraf shear test and triaxial compression test.

There are at least two major factors which seem to account for the aforementioned differences. Although the soil-aggregate samples for the laboratory tests were taken from the in-place test points, it is speculated that the laboratory tests were not conducted on exactly the same materials as those in the in-place tests. The in-place strength tests were performed on the soil-aggregate surface materials which had been in service for a considerable length of time; it is conceivable that the continued traffic action on these materials had established a keying, a mechanical friction bond, and a shear strength (6) which could not be accomplished or reproduced in the laboratory within a short period of time by controlling the moisture and density conditions alone when these materials were remolded for the triaxial compression tests. In other words, the higher strength value for the in-place test was attributable, at least partly, to those strength characteristics of soil-aggregate materials associated with field conditioning and absent in the remolded materials in the triaxial compression test.

Another major, or perhaps even more significant, factor seemingly attributable to the different strength values by the two tests is that related to the state of stress at failure in these two tests. In the triaxial compression test, the material is loaded initially with an all-around stress, σ_3, and subsequently subjected to a uniaxial stress difference, $\sigma_1 - \sigma_3$. When the uniaxial stress difference approaches the ultimate value, the material fails along a plane on which obliquity is a maximum. Because under this loading condition there are no kinematic restrictions, the material is free to fail on the weakest surface. In the in-place strength test by the Burggraf Shear Apparatus, the material is stressed in a plane strain condition. In this test, the major principal stress, σ_1, with which the soil-aggregate material is loaded to failure is acting in the horizontal direction, and the minor principal stress, σ_3, due to the weight of the wedge is acting downward. In the direction of the axis perpendicular to these two stresses and coinciding with that of the intermediate principal stress, σ_2, deformation of the material is prohibited, and movement is only possible in the plane in which σ_1 and σ_3 act. Because the stress difference at failure is governed by the boundary restrictions on displacements (7), the change in kinematically possible displacements imposed by the conditions of plane strain in the Burggraf shear test accounts for the increased shearing resistance and the increased angle of shearing resistance, ϕ, and, in turn, the decreased angle of failure, θ, as observed in this investigation. This phenomenon has been investigated, both mathematically and experimentally, and reported by Wittke and his associates in connection with their studies concerning the shearing strength of cohesionless soils (8, 9).

In view of the consistent relation between the in-place strength values as determined by the Burggraf Shear Apparatus and the shear strength values as determined by the triaxial compression test (Fig. 4), an attempt was made to correlate the results of these two tests. Such a correlation, offering the possibility of estimating the in-place strength values of soil-aggregate materials on the basis of the results of their triaxial compression tests, would be of value in the determination of the laboratory criteria for estimating the strength and performance of soil-aggregate materials in-place.

The equation expressing the relationship between the two strength values for all soil-aggregate materials included in this study, calculated from the data in Table 1, is

$$B = 2.21\ T - 2.0 \qquad (2)$$

in which B represents the in-place strength value as determined by the Burggraf Shear Apparatus and T denotes the shear strength value as determined by the triaxial compression test. The standard error of estimate for Eq. 2 is 9.4; the correlation coefficient is 0.78.

To determine whether the association between the two strength values is separately distinct for pit-run gravel and crushed stone, the regression equations for the two individual materials were also determined. For the pit-run gravel, the equation is

$$B = 2.41\ T - 7.0 \qquad (3)$$

with a standard error of estimate of 8.2, and a correlation coefficient of 0.80 For the crushed stone materials, the equation is

$$B = 1.82\ T + 7.8 \tag{4}$$

with a standard error of estimate of 10.1, and a correlation coefficient of 0.70.

To test the hypothesis that the correlation coefficients for the pit-run gravel and the crushed stone materials were drawn at random from the same population, a z-value of -0.95 was calculated from the correlation coefficients for both materials. Because this value is less than that indicated in the standard table for z values at the 5 percent level of significance, the hypothesis is not rejected, and it is concluded that the two coefficient values were drawn at random essentially from the same population.

The two-tailed F-test was also performed using the variance ratio, calculated by dividing the deviation mean square from regression for each of the two materials by that for the combined materials. The calculated ratio for the pit-run gravel is 0.87, and that for the crushed stone is 1.26. Both values are insignificant at the 5 percent level, indicating that there are fewer than 5 chances in 100 that the disparity between the calculated values is due to chance.

On the basis of the preceding tests, it is concluded that the relationship between the two strength values is not separately distinct for the two different soil-aggregate materials, and that the regression equation (Eq. 2) is applicable to both materials in this investigation.

CONCLUSIONS

From the results of the testing, the following conclusions have been drawn:

1. The shear strength of a soil-aggregate surface material as determined in-place by the Burggraf Shear Apparatus is consistently of higher value than that determined in the laboratory by the triaxial compression test. This trend is also indicated between the major principal stresses at failure for the two tests. The angle of failure is consistently smaller in the in-place test than in the triaxial compression test under comparable conditions. It is believed that the above differences are due in part to the different strength characteristics between the field conditioned material and the laboratory remolded material and, particularly, to the different state of stress at failure in these two tests.

2. Within the scope of the types and conditions of the materials studied, there is a definite relationship between the in-place strength value of a soil-aggregate material as determined by the Burggraf Shear Apparatus and that as determined by triaxial compression tests in the laboratory. The correlation between the two strength values appears to be not separately distinct for the two types of materials involved in this investigation. A regression equation has been established for estimating the in-place strength of soil-aggregate materials on the basis of the results of their triaxial compression tests.

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REFERENCES

1. "Tentative Methods of Test for Shear Strength of Flexible Road Surfaces, Subgrades, and Fills by the Burggraf Shear Apparatus." 1961 Book of ASTM Standards, Part 4, pp. 1368-1372 (1961).
2. Burggraf, F., "Use of Calcium Chloride in Road Stabilization." Proc. HRB, 18, Part II, pp. 249-253 (1938).
3. Burggraf, F., "Field Test on Shearing Resistance." Proc. HRB, 19: 484-489 (1939).
4. Burggraf, F., "Field Tests and Their Application to the Design of Stabilized Soil Roads." Proc. Amer. Road Builders' Assoc., pp. 324-335 (1940).
5. Burmister, D. M., "General Discussion on Triaxial Testing of Soils and Bituminous Mixtures." ASTM Spec. Tech. Publ. 106, p. 301.
6. Burmister, D. M., "Discussion on Road Tests, Field Studies, and Performance Criteria." Internat. Conf. on the Structural Design of Asphalt Pavements Proc., Univ. of Michigan, p. 108 (1963).
7. Hendron, A. J., "The Behavior of Sand in One-Dimensional Compression." Ph.D. Diss., Univ. of Illinois, Dept. of Civil Eng., p. 34 (1963).
8. Wittke, W., "Über die Scherfestigkeit rollinger Erdstaffe, Rechnerische und Experimentelle Untersuchung von Kugelschüttunger." Veröffent. des Inst. für Bodenmechanik und Grundbau der T. H. Fridericiana in Karlsruhe, 11 (1962).
9. Leussink, H., and Wittke, W., "Difference in Triaxial and Plane Strain Shear Strength Theoretical and Experimental Investigations." Presented at ASTM Sym. on Lab. Shear Testing of Soils (1963).