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ENGINEERING PROPERTIES OF CLAY SHALES. REPORT 1. DEVELOPMENT OF CLASSIFICATION INDEXES FOR CLAY SHALES

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Suggested Standardized Procedures

26. Currently, it is difficult to correlate classification indexes of clay shales between laboratories due to variations in preparation methods allowed by standard CE testing procedures and by further variations being introduced by the laboratories specifically for clay shales. It seems paradoxical to specify the dimensions of a liquid limit grooving tool to close tolerance if one laboratory dries and slakes all its material while another works from the natural moisture, or if one laboratory oven-dries its material for hydrometer analyses while another does not. Unless uniform procedures are followed, there can be no simple indexes for classification.

27. Investigations are showing that classification indexes are affected by air-drying and slaking, by oven-drying and slaking, by the type and duration of mechanical dispersing, and by other variations in procedure. While the methods for preparing clay shale material for testing should cover a sufficient range of disaggregation efforts to assess the strength of interparticle bonds, the number of variables allowed to influence the indexes must be minimized by standardized procedures to prevent the classification of each material becoming a minor research project in itself. Therefore, it is recommended that only three methods of processing clay shale material be considered for standardization. First, to provide a reference value, the material should be tested without any drying. Second, a single cycle of air-drying and slaking should be used to disaggregate the material, similar to the MRD standard procedure for clay shales. Finally, to provide an essentially complete disaggregation, the material should be subjected to high-speed blenderizing. Oven-drying and cyclic air-drying and slaking merit additional investigation, but the value of these two methods does not appear as great as that of the three recommended methods. Cyclic air drying and slaking, of course, require several weeks to complete and appear too cumbersome for normal usage.

28. Suggested standardized procedures for preparing clay shale

material are as follows:

a. Undried. Material at essentially natural water content should be shaved or shredded, immediately placed in distilled water, and allowed to soak for at least 48 hr. After removing excess water by decanting, the wet material should be ground in a mortar with a rubber-tipped pestle and washed through the No. 40 sieve. Excess water should be removed using a plaster-of-paris dish lined with filter paper. The sieved material, at a water content above the liquid limit, should be worked in a thin layer on a glass plate with a steel spatula until no further reduction in the size of lumps can be achieved.

b. Air-dried. Material at essentially natural water content should be shaved or shredded and dried to a constant weight in an atmosphere with a temperature less than 50 C (120 F) and a relative humidity less than 30 percent. (The drying atmosphere may be produced by a low-temperature oven, a dessicator, or a controlled-humidity room.) After a constant weight is attained (and after a drying period of at least 48 hr), the material should be soaked in distilled water for at least 48 hr. After removing excess water by decanting, the wet material should be ground in a mortar with a rubber-tipped pestle and washed through the No. 40 sieve. Excess water should be removed using a plaster-of-paris dish lined with filter paper. The sieved material, at a water content above the liquid limit, should be worked in a thin layer on a glass plate with a steel spatula until no further reduction in the size of lumps can be achieved.

c. Blenderized. Material at essentially natural water content should be shaved or shredded and dried to a constant weight in an atmosphere with a temperature lessthan 50 C and a relative humidity less than 30 percent. After a constant weight is attained (and after a drying period of at least 48 hr), the material should be soaked in distilled water for at least 48 hr. The slurry should be placed in a high-speed food blender having a no-load speed of 15,000 to 20,000 rpm. The material should be blenderized without interruption for a period of 10 min and then washed through the No. 40 sieve. Material retained on the sieve should be discarded. Excess water should be removed using a plaster-of-paris dish lined with filter paper. The sieved material, at a water content above the liquid limit, should be worked in a thin layer on a glass plate with a steel spatula until no further reduction in the size of lumps can be achieved.

29. When material is to be prepared by all three methods, care should be exercised that the parent material for the batches is similar.

The piece of sample selected should be divided by a vertical cut into two parts with one piece about twice as large as the other. The smaller piece should be shaved into distilled water to produce the undried batch, and the larger piece used to produce the other two batches. Figure A4 shows a flow diagram of the three preparation methods and indicates when separation of batches is required.

30. Material may be taken from each of the three batches and used for Atterberg limits determinations without further processing. Dry strength and gloss determinations should be made on material taken for Atterberg limits determinations. Material for a hydrometer analysis should be removed from each batch and soaked overnight in distilled water containing a sufficient amount of a suitable chemical dispersant (such as sodium tripolyphosphate or sodium hexametaphosphate) to prevent flocculation. Dispersion should be made in a milk shake stirrer or with an air jet, but not with a high-speed food blender.

31. The use of a high-speed blender for soil dispersion introduces a large number of variables which have not yet been evaluated. However, most of the variables (size and shape of container, size and shape of blades, no-load speed, variation of speed with load, etc.) can be avoided by specifying a single make and model of blender. Most blenders on the market are household appliances, and the operating characteristics of models being sold at different times could very well change. The only blender really intended for laboratory use, and available from every laboratory supply company, is the Waring "Blendor." It is recommended that the standardized procedure for disaggregating clay shale material by blenderizing should utilize the standard one-speed Waring Blendor with the 1000-ml glass container. Specifying this make of blender would give the manufacturer no significant economic advantage since only a few CE laboratories would require one and the unit price is modest, about $35.

32. If the make of the blender were specified, the remaining variables would be (a) the amount of wear to be permitted on the blades, (b) the quantity of the soil-water slurry to be placed in the container, and (c) the water content of the slurry. To provide a starting point for

the specification of these variables, the following restrictions are suggested. First, a blade should be replaced when the overall length becomes 3 mm (1/8 in.) less than the original length. Second, blenderizing should be started with the container approximately half filled with slurry; that is, about 500 ml should be placed in the container. Third, the initial water content of the slurry should be above 300 percent or more than twice the liquid limit, whichever is the greater. The value of the liquid limit to serve as a basis for the initial water content should be the highest value obtained, that is, the value determined after blenderizing the material. Typically, the weight of dry soil in the blender at any one time should not exceed 150 g.

33. It is definitely not suggested herein that the introduction of three standardized methods for disaggregating clay shale material will solve the problem and that no further work need be done. The three methods only will ensure that comparable values are produced by different laboratories. CE division laboratories should be encouraged, during investigations for Civil Works projects, to try other methods as well as variations in the three standardized methods.

normal stress (less than 2 kg per sq cm), a specimen of clay shale may tend to swell, causing an increase in the gap between the two halves of the shear box, or irregularities on the shearing surfaces may cause the upper half of the specimen to be lifted or tilted, permitting water from the reservoir to enter between the halves. Also, with a low normal stress, the accuracy of the shear stress measurement must be greater and any friction in the system is more critical. Under a high normal stress (more than 15 kg per sq cm), the extrusion of remolded material from the gap between the two halves of the shear box is greatly accelerated. Extrusion may have two possible effects on the measured residual friction angle. First, as described by LaGatta,[25] extrusion will cause a redistribution of normal stress over the shearing surfaces so that the residual friction angle computed on the assumption of a uniformly distributed normal stress may be too low, especially in a rotational shear apparatus. Second, extrusion may produce gross irregularities on the shearing surfaces, especially in a direct shear apparatus where the front and rear portions of both surfaces are unsupported at the ends of each stroke. Also, extrusion will continuously remove the disaggregated, well-oriented clay particles from between the surfaces, and a condition of equilibrium will not be possible. Because of these effects, the computed residual friction angle may be too high. MRD found that repeated direct shear tests under normal stresses of 15 and 30 kg per sq cm resulted in significantly higher computed residual friction angles than tests under 4 and 8 kg per sq cm.[22]

39. Because of practical considerations in the performance of residual shear strength tests for classification purposes, it is recommended that both low and high normal stresses be avoided. The most satisfactory results would probably be obtained using a normal stress between 4 and 8 kg per sq cm.

Effect of Rate of Displacement

40. A definite decrease in residual friction angle with decreasing rate of shear displacement has been observed in tests at MRD,[22] Harvard,[25] and others. However, the variation appears to be small except when the

rate is increased to the order of, say, 10 cm per day. The results shown in fig. B16 indicate a decrease of about 15 percent in the shear stress (1 deg change in the friction angle) with a hundred-fold decrease in displacement rate, though there was insufficient displacement under each of the different rates to be sure that equilibrium had been obtained. Contrary results were obtained at the Belgian Geotechnical Institute where a five-fold decrease in displacement rate caused an increase of about 25 percent in the shear stress (4 to 5 deg change in the friction angle).[43]

41. Several laboratories use relatively high rates of displacement to accumulate large shear displacements within a reasonable period and then reduce the rate for a valid measure of shear stress. In these instances, the shear stresses measured initially in tests with high rates may be affected by incomplete dissipation of excess pore water pressures (as shown by the initial portions of the curves in fig. B16) in addition to a rate-dependent viscosity of remolded clay. Measurements of shear stresses at low rates (0.1 cm per day) are seldom feasible because of the great length of time needed to obtain sufficient displacement at such rates to ensure an equilibrium condition.

42. While further investigation of the effect of displacement rate is warranted, it is not believed that this effect would be significant in determinations of residual friction angles as long as the rate was sufficiently slow (less than 1 cm per day) to provide essentially complete dissipation of excess pore water pressures. Also, if much lower rates of displacements were to be used, the durations of tests would become excessive for determinations of classification indexes.

Suggested Standardized Procedure

43. Until more comparative residual shear strength tests have been performed, it is suggested that either a direct shear or an annular shear apparatus be used in a standard method for determining the residual friction angle. Furthermore, it is recommended that a precut specimen of intact material at natural water content should be used in the standard method.

Details of the procedure for a standardized test are suggested in the following paragraphs.

44. The specimen should consist of two pieces of intact material trimmed to fill the inside of the shear box or confining ring. The two pieces should be of approximately equal height and have a total height not in excess of 1 in. (preferably, the total height should be 0.5 in., but this is often not practical for stiff, fissured materials). The top and bottom surfaces of each piece should be plane and parallel. Only a reasonably close fit of each piece to the inside of the shear box* is necessary for stiff-to-hard materials which must be cut to shape with a bandsaw or, in the case of very hard materials, with a diamond wheel. The lower half of the specimen should be firmly seated against the porous plate in the lower half of the shear box. A slight (0.010 to 0.020 in.) projection of the lower half of the specimen above the lip of the box is desirable; certainly the top of this half of the specimen should not initially be below the lip. Then the upper half of the specimen should be placed in the shear box, the upper porous plate added, and the remainder of the shear apparatus assembled.

45. Alternatively, a specimen of softer material may be precut inside the shear box. In this case, an intact specimen is firmly seated between saturated porous plates in the apparatus and, then, a plane should be cut with a small-diameter (0.008- to 0.014-in.-diam) steel wire through the specimen at the separation between the upper and lower halves of the box. After cutting, the two halves of the specimen should be separated and the cut surfaces inspected for planeness. Any irregularities should be removed with a straightedge.

46. Once the apparatus is completely assembled around the precut specimen, the normal stress should be applied and, then, the specimen should be inundated with distilled water. For a standardized method of determining the residual friction angle, it is suggested that a single value of normal stress should be used. A standard value of about 6 tons per sq ft is recommended as being high enough to prevent the swelling of most clay shales, yet low enough to minimize the problem of material

* In the following paragraphs, the term "shear box" should be considered to include the specimen-confining rings of an annular shear apparatus.

extruding from between the two halves of the box during shear. The specimen should be allowed to consolidate or swell to essentially an equilibrium condition under the normal stress; a minimum period of 16 hr should be allowed before shear.

47. When the consolidation phase is completed, a gap should be formed between the two halves of the box to ensure that normal and shear stresses are borne only by the specimen. This gap should be kept rather small (0.015 to 0.025 in.) to minimize extrusion of remolded material from the shearing surface. Periodically during the test, the gap can be checked by inserting thickness gages, and adjustments can be made. Closure of the gap is quite critical in an annular shear test since friction between the two outer confining rings acts with a large moment akin to increasing the measurement of torque disproportionately.

48. Horizontal displacement of one half of the specimen relative to the other should be initiated at a controlled rate not in excess of 0.5 in. per day (about 0.0003 in. per min). Shear movement under constant normal stress should be continued, either by uninterrupted movement in a rotational apparatus or by repeatedly reversed movement (with about 0.25 in. displacement to each side of the initial, center position) in a translational apparatus, until a minimum shearing resistance is attained. A semilogarithmic plot of shear stress (arithmetic scale) versus cumulative shear displacement (logarithmic scale) should be maintained during the test to show when a minimum value has been reached. When a direct shear apparatus is used for the test, only the shear stress measured when the two halves of the shear box are vertically aligned (at the midpoint of each stroke) should be plotted.

49. If, after completing the standard test, the effects of increased normal stress and decreased displacement rate are to be determined, this additional information should also be obtained according to standardized procedures. First, the effect of increased normal stress should be determined as follows. After the minimum resistance has been attained under a normal of about 6 tons per sq ft and at a displacement rate less than 0.5 in. per day, the normal stress should be approximately doubled

while the two halves of the shear box are vertically aligned and the specimen allowed to consolidate for at least 16 hr. Then, shear displacement should be resumed at the previous rate and be continued until a minimum shearing resistance corresponding to the increased normal stress is reached, as previously described.

50. Next, the effect of decreased rate of displacement should be determined as follows. After the minimum shearing resistance has been reached under the high normal stress (approximately 12 tons per sq ft) and at a displacement rate less than 0.5 in. per day, the rate of displacement should be reduced to a tenth of the standard rate (that is, to less than 0.05 in. per day) without any change in the normal stress, and shear displacement should be resumed until the minimum shearing resistance is developed. When a direct shear apparatus is used for the test, the rate of displacement should be reduced soon after the upper half of the shear box has passed through the initial, vertically aligned position. Movement at the reduced rate should continue to the end of the stroke and then, on the return stroke, pass through the initial position again. The shear stress measured when the two halves of the box are vertically aligned this second time should be used to compute the residual friction angle for the decreased displacement rate.

51. At the end of the test, after the shear force has been removed, the water reservoir should be emptied and all free water removed from the specimen. Then, the normal stress should be removed and the two halves of the specimen separated. The shear surfaces should be carefully inspected, and the condition of the surfaces (texture, gloss, irregularities, etc.) should be described. Two final water contents should be determined: one on material scraped from both shear surfaces and another on the remainder of the specimen.

52. While not yet believed appropriate for a standard classification procedure, the residual friction angle could be determined using remolded material prepared by the same three methods (initial, air-dried, and blended) applied to determinations of particle-size distributions and Atterberg limits. Results of this type are being produced; the typical

method used at Harvard University to prepare residual shear test specimens is to reconsolidate material that has been air-dried and slaked. Some study of the effects of air-drying and of blending on the residual friction angle may be needed to assist in establishing correlations between residual friction angle and Atterberg limits.