Large Scale Preconstruction Tests of Embankment Materials for an Earth-Rockfill Dam

Essais à grande échelle des matériaux précédant la construction d'un barrage en terre-enrochement

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Summary

Preconstruction field tests were made on two proposed embankment materials consisting of a weathered sandstone-sandy clay mixture to be used in the core and broken sandstone to be used in the shell. The purpose was to select the best methods for compaction and to determine the physical properties of these materials as they would appear in the completed dam. Two test areas were constructed using materials from the proposed borrow pits. The area for the core materials included sixteen sections, each with a different mixture of materials or method of compaction. The area for the broken sandstone fill included six sections, each with a different combination of compaction procedures. An in place permeability test was devised for the compacted core materials. A 6 ft. by 6 ft. by 3 ft. deep direct shear box was employed to test the strength of the compacted broken sandstone. The test results made it possible to check the design with greater assurance and to plan the construction more fully. The data from the preconstruction test compare favorably with results obtained from tests made during construction of the dam.

Sommaire

Des essais ont été faits sur chantier avec deux matériaux proposés pour le barrage : un mélange de grés décomposé et d'argile sableuse, à utiliser pour le noyau, aussi bien qu'un grès broyé, à utiliser pour la partie extérieure du barrage. Le but de ces essais était de choisir les meilleures méthodes de compactage et de déterminer les propriétés physiques de ces matériaux tels qu'ils apparaîtront dans le barrage achevé. Deux zones d'essai ont été construites avec des matériaux provenant des fouilles d'emprunt proposées. La zone contenant des matériaux pour le noyau a comporté seize sections, chacune avec un différent mélange ou méthode de compactage. La zone de grès broyé a comporté six sections, chacune avec une combinaison différente des procédés de compactage. Un essai in situ de perméabilité a été effectué pour le matériau compacté du noyau. Une boite de cisaillement direct, ayant comme dimensions 6 ft. × 6 ft. et 3 ft. de profondeur, a été utilisée pour l'essai de résistance au cisaillement du grès broyé compacté. Les résultats de ces essais ont permis de vérifier le projet avec beaucoup plus de sûreté et de faire un plan plus complet de la construction de l'ouvrage. Les données de ces essais sont en plein accord avec les résultats des essais faits pendant la construction du barrage.

Introduction

The design of embankment dams is commonly based on laboratory tests of the materials correlated with experience on similar materials on past projects. This procedure is adequate for soils. It is not satisfactory for materials like weathered or broken sandstones for which experience is limited and that are so coarse grained that they cannot be tested in the ordinary laboratory apparatus.

Full scale test areas were employed to determine the compaction characteristics of the materials and establish a correlation, where possible, with the ordinary laboratory compaction tests. Large scale field tests were devised to test the compacted materials in place to determine their characteristics to be used in design.

Construction Materials

The project for which the test program was employed is the Lewis Smith Dam of the Alabama Power Company. It is located in a U-shaped canyon of the Sipsey Fork of the Warrior River about 35 miles northwest of Birmingham, Alabama. It is a 300 ft. high combined earth and rockfill structure with over 5,000,000 cu. yd. of embankment.

The site is underlain by sandstones and shales of Carboniferous (Pennsylvanian) Age. The upper rock is sandstone, in level strata of varying thickness. The top of the sandstone has weathered forming a residual soil mantle 5 to 10 ft. thick and a partially weathered transition zone 10 to 20 ft. thick. A side channel spillway cuts through the sandstone and furnishes all the materials for the embankment.

The only materials available for the core are the residual soil and the more weathered sandstone. The upper three feet of soil is a sandy clay but it becomes more sandy, and the relative amount of partially weathered sandstone increases with increasing depth. The unweathered sandstone and the harder parts of the weathered sandstone are the only materials available for the shell, since the shale slakes and splits up on exposure to air. The sandstone its strong with average unconfined compressive strengths of 7 800 lb. per sq. in. unweathered, and 2 000 lb. per sq. in. partially weathered. However, it is seamy and friable and tends to break into a wide range of sizes with large amounts of fines. Therefore, while part of the rock is suitable for a dumped rock fill, much is too fine (under 12 in.) and should be compacted.

Test Area Construction

Two test areas were constructed : one of the proposed core materials and one of the broken rock finer than 12 in.

A quarry was established in the area of the spillway cut. The core materials including the sandy clay and weathered rock to a depth of about 20 ft. were excavated with a power shovel. The shell material of unweathered and slightly weathered sandstone was broken by blasting and excavated by a power shovel.

The core test area included sixteen sections approximately 20 ft. square, Fig. 1a. Four different variations of the core materials (moisture, thickness, and relative amounts of partially weathered rock) were placed in uniform strips across the area. Four different compaction procedures were employed in equal lanes the length of the area so each all the different core materials. The compaction methods were (1), disc harrow followed by a 50 ton rubber tired roller (2) 50 ton rubber tired roller alone (3) 700 psi sheeps-foot followed by a 50 ton rubber tired roller, and (4) a 700 psi sheepsfoot roller alone.

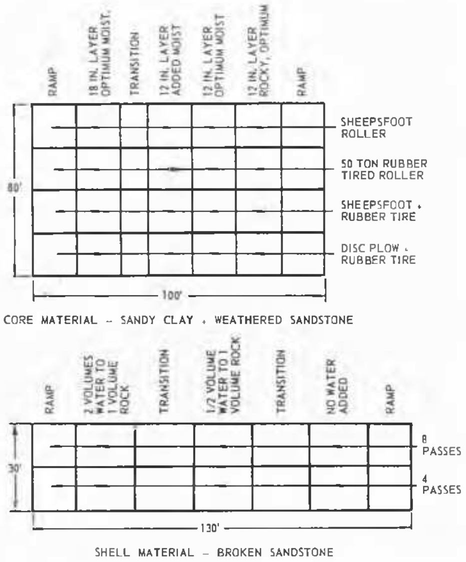


Fig. 1 Arrangement of test areas.
Disposition des zones d'essai.

The compacted shell test area, Fig. 1b included six sections. The same broken sandstone was use throughout. Three different amounts of moisture were employed in strips across the area : (1) field moisture; (2) 1/2 volume of water to 1 volume of rock; and (3) 2 volumes of water to 1 volume of rock. A 50 ton, 4 wheel rubber tired roller with a 100 psi tire pressure was used for compaction : 4 passes in one strip and 8 passes in the other, the length of the area.

Test Area Compaction

Both areas were constructed in three lifts. Tests of the density of the materials were made in the top two lifts after compaction was complete and in some cases at intervals during the work. Standard laboratory compaction tests were performed on the fraction of the placed but uncompacted core material finer than 3/4 in. for comparison.

Dry densities of from 109 lb. per cu. ft. to 116 lb. per cu. ft. were produced in the core test area. According to the Modified Proctor Test (ASTM D-1557-58 T Method C) the maximum density was 121 lb. per cu. ft. and the optimum moisture 13 per cent. The degree of compaction was therefore 90 per cent to 96 per cent of the maximum.

Tests of an 18 in. thick lift compared to a 12 in. lift (after compaction) indicated about 2 per cent less compaction for the thicker lift and less uniformity of compaction. Comparison of the test areas compacted at optimum moisture with those at two per cent over showed about one per cent more density for the optimum.

The sheepsfoot roller alone, and the sheepsfoot roller teamed with a disc plow to break up the weathered rock, produced the least compaction. The highest compaction was with the 50 ton rubber tired roller. In a full face mixture of the sandy clay and weathered rock it produced that best compaction by itself. When the proportion of weathered rock was increased, the combination of sheepsfoot and rubber tired rollers was best. The sheepsfoot helped pulverize the irregular weathered rock lumps and produced compaction at the bottom of the lift, while the rubber tire compressed the entire layer. Since the combination was only slightly less effective when the proportion of weathered rock was less, this procedure was specified for all the core compaction.

Density, tests in the compacted shell test area were complicated by the rock up to 12 inches. Pits 3 ft. by 3 ft. were excavated and all the materials (nearly 3 000 lb.) weighed. The pit volume was found by lining the hole with thin sheet plastic and filling it with water. The moisture content of the rock was found by drying several 100 lb. samples. Dry densities of from 128 to 135 lb. per cu. were obtained. This is 83 to 88 per cent of the weight of the solid rock. As was expected 8 passes of the roller produced greater densities than 4; the average difference was 3 lb. per cu. ft. Little increase was produced by rolling more than 8 passes, however. The greatest density was obtained by washing the surface of the area with 1/2 volume of water for each volume of rock. This was applied by a 1 1/4 in. nozzle at a pressure of 50 lb. per sq. in. or more. Half of the water was applied before compaction by working the jet back and forth across the fill to wet the rock and wash the fines into the voids. The remainder was applied after half the rolling was complete. With no water, the fines tended to hold the coarser pieces apart and prevent compaction while with two volumes of water the surface would flood in areas of abundant fines.

The typical grain size distribution for both the core and the shell materials are shown in Fig. 2. These show the irregular gradation caused by the breakdown of the sandstone into its original grains of fine sand. It is much more evident in the weathered sandstone — sandy clay mixture where the intergranular bonds have been weakened, than in the unweathered sandstone.

Field Permeability Test

Laboratory tests of the permeability of compacted soils can be misleading because the irregulatities in field compaction and the large rock fragments in the embankment cannot be reproduced in the small test samples. Therefore, a new procedure was developed to secure a realistic measure of the permeability of the materials as they will be found in the dam core.

The test arrangement is shown in Fig. 3. A sheet of polyethylene 8 ft. by 10 ft. was placed on the top of the previous layer. This formed an impervious surface that prevented downward seepage out of the layer being tested. The test layer was then compacted by the rollers over the plastic base. Three parallel trenches 6 feet long and 12 inches wide

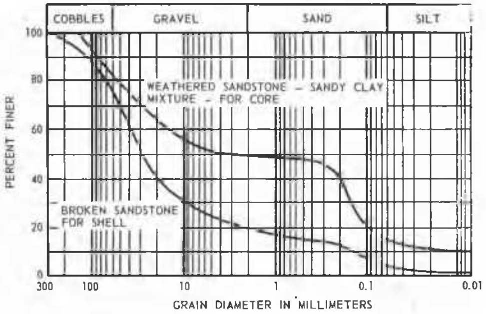


Fig. 2 Gradation of compacted weathered sandstone-sandy clay core material and broken sandstone shell materials.
Granulométrie du grès décomposé-argile sableuse pour le noyau et du grès broyé pour la partie extérieure du barrage.

were dug as shown in Fig. 3. The center trench was shallow while the side trenches penetrated the full depth of the fill. The center trench was kept full of water and the water in the side trenches maintained so that the difference in water levels was always 9 inches. The rate at which water was added to the center trench was measured at intervals until steady flow was reached (one day for these materials). The permeability of the soil was then computed from the equilibrium rate using a two dimensional flow net with correction for seepage around the ends. If Q is the seepage rate the permeability can be computed approximately by

$K = 0{\cdot}04\,Q$ (K in ft. per min., Q in U.S. gal. per min.).

$K = 0{\cdot}005\,Q$ (K in cm. per sec., Q in liters per min.).

The tests is not precise since the volume of water seeping through the ends of the trench cannot be evaluated and since some water will be lost by evaporation. It was found, however, that the test results were consistent from day to day and from test area to test area, so the errors did not appear serious.

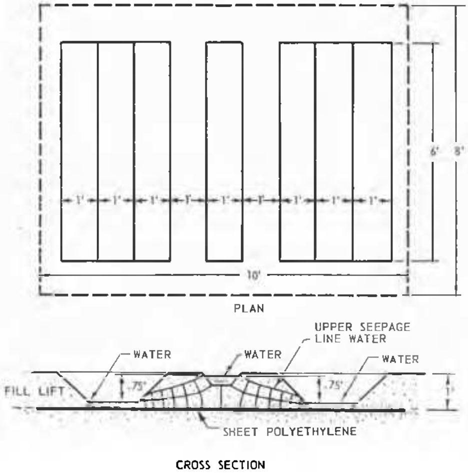


Fig. 3 Field permeability test.
Essai de perméabilité sur chantier.

The permeability coefficient for the test areas ranged from 2×10^{-4} cm per sec. to $2{\cdot}5 \times 10^{-4}$ cm per sec for the areas compacted by the sheepsfoot — rubber tire combination and the sheepsfoot roller alone. Laboratory tests of large undisturbed samples cut from the same test areas gave from $2{\cdot}2 \times 10^{-4}$ to $3{\cdot}3 \times 10^{-4}$ cm per sec (slightly higher than the field values). The cause of the difference appeared to be small cracks in the laboratory specimens produced by the sampling process. By comparison the permeability of samples compacted in the laboratory to the same density as in the field had permeabilities of 1×10^{-5} cm per sec or 1/10 the field values. The reason is the lack of rock fragments in the laboratory sample and the larger voids which form when the fragments touch one another.

The field test is a simple and inexpensive method for checking the inplace permeability of a compacted fill. While it requires time and blocks further work in that area it can be installed rapidly and the measurements made on weekends so that the work obstruction will be minimized.

Large Scale Shear Test

Because it is impossible to determine the strength of compacted broken rock in the usual laboratory test a large direct shear test box was constructed to test the rock in place in the compacted shell material test area.

The device consisted of two boxes 6 ft. by 6 ft. square and 1·5 ft. deep as shown in Fig. 4. The lower box with a reinforced steel bottom was placed on top of the first fill lift and then the second 1·5 ft. lift of broken rock was dumped arount it and in it, in the same way the other shell test sections were constructed. The rock surface was then rolled and sluiced. The upper half of the box was then placed on the lower half; the next 18 in. lift was placed in and around the box and compacted as before.

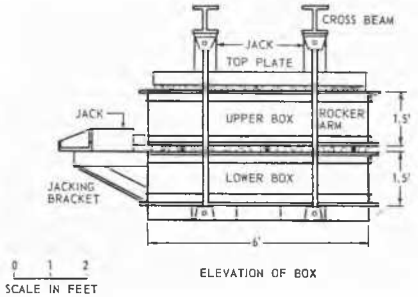


Fig. 4 Direct shear box.
Boîte de cisaillement direct.

After compaction the buried box was uncovered by digging around it. The top plate was placed on the box and four hydraulic jacks mounted on it. Two cross beams were placed across the jacks and fastened to the bottom of the box by hinged rocker arms. Two horizontal jacks were mounted on a bracket at the rear of the box so as to force the top half across the bottom. The complete test arrangement is shown in Fig. 5. A normal stress was applied to the compacted rock by the four vertical jacks and was maintained constant throughout each test. The horizontal load was increased in increments and the deformation measured by micrometer dial gages installed between the top and bottom boxes.

The test results for normal loads of 2 100 lb. per sq. ft. and 4 100 lb. per sq. ft. are shown on Fig. 6. The stress strain curves indicate nearly elastic behavior up to loads of 1/3

Fig. 5 Direct shear box test in progress.
Exécution d'un essai dans la boîte de cisaillement direct.

and 2/3 the failure load respectively. As might be expected the strains were much smaller for the higher normal stress loading than for the lower. The Mohr diagram shows an angle of internal friction of 45 deg. and an intercept of about 100 lb. per sq. ft. on the vertical axis. The angle of internal friction is what might be expected for a well graded angular material. Triaxial shear tests were made in the laboratory using samples of the shell material from which all particles larger than 5 mm. were removed. The angle of internal friction at the same density as in the field was found to be 42 deg. The difference is probably caused by the lack of the larger angular particles in the laboratory test samples.

Comparison of Test Results with Construction

Construction of the embankment was completed in 1960. Records of the compaction of the core show an average density of 97 per cent of the Modified Proctor maximum with a standard deviation of 2·4 per cent using the 50 ton rubber tired roller. When the material contained an excessive amount of weathered rock it was pre-rolled with the sheepsfoot. A limited number of density tests in the rolled rock shell indicate that the compaction is essentially the same as in the test area.

Cost of Field Test Program

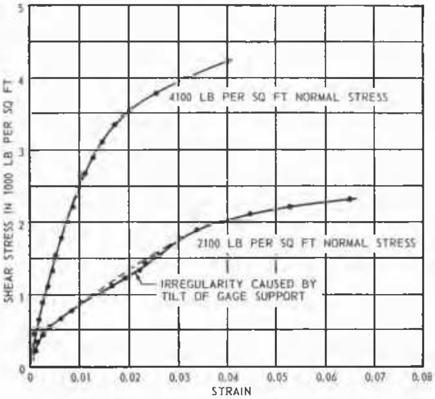
The shear box was built by a structural steel fabricator at a contract cost of $5 000. The construction of the pilot quarry and the test areas by a local road contractor cost approximately $18,000. Engineering and soil testing costs were estimated to be $7 000 bringing the total for the program to $30,000. The construction and testing required approximately one month.

Conclusions

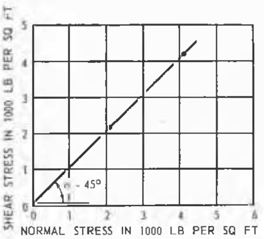
A number of conclusions were reached as a result of the investigation.

(1) The weathered sandstone and sandy clay mixture could be used as a core for the dam.

(2) The broken sandstone could be compacted and would provide a high strength shell.



STRESS STRAIN CURVES



MOHR DIAGRAM

Fig. 6 Results of direct shear test on broken sandstone up to 12 in. diameter.
Résultats d'un essai de cisaillement direct sur le grès broyé, jusqu'à 12 in. de diamètre.

(3) The 50 ton rubber tired roller is effective in compacting the sandy core and the broken rock.

(4) The sheepsfoot roller is an effective pulverizing device in weathered rock.

(5) Laboratory tests alone of the physical properties of the weathered rock and of the broken rock materials would be misleading.

(6) The fill testing program determined the construction procedures that would be necessary in the structure and eliminated uncertainties in the choice of compaction equipment and methods.

Acknowledgements

The program was conducted by the Alabama Power Company under the direction of the late F.C. Weiss, Vice-President, Mr. D. F. Elliott, Construction Manager and Mr. E.R. Coulbourn, Engineering Manager.