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Performance of a Coal Refuse Embankment

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SYNOPSIS Continuous determinations of density, moisture content, and permeability through a 140-foot high coarse refuse embankment impounding slurry were made. The density determinations were made with nuclear moisture-density depth gauges continuously throughout 120-foot depth of the embankment. The permeability tests were made with a special packer permeability device and were conducted throughout the 120-foot depth of the embankment. Compaction density tests were made during compaction of the refuse. Comparisons were made to design, as-compacted, and in-place permeabilities, densities, and phreatic surface within the embankment. The study shows that coarse refuse embankments compacted in roughly 18-inch lifts with a special dozer and haulage equipment perform well in terms of comparisons of in-situ parameters to design parameters for seepage, density, and strength.

INTRODUCTION

Two waste products are created by coal processing plants. The first is coarse refuse consisting of the non-coal material mined along with the coal, generally defined as being the +28 mesh sieve material. The second is fine refuse or slurry which is a by-product of the washing of the coal and is generally the -28 mesh material. The usual method of disposal of these two waste products is the construction of an embankment utilizing the coarse coal refuse and pumping of the slurry or fine coal refuse behind the embankment. The laboratory measured vertical coefficient of permeability of coarse coal refuse is usually on the order of 10^{-4} cm/s and relatively large amounts of seepage from such an impoundment are generally calculated.

Typical design analyses of seepage from such an embankment usually assume the embankment impounds water and utilize the permeability of the coarse refuse to predict seepage. This procedure usually greatly over-estimates seepage as the fine coal refuse when settled generally has a coefficient of permeability on the order of 10^{-5} to 10^{-7} cm/s. In a normal disposal process the slurry is usually deposited near the face of the embankment creating a relatively low permeability material on the upstream face of the embankment and very little water is impounded on the slurry. The factor controlling seepage is, therefore, the permeability of the slurry and not that of the coarse refuse.

It is also generally thought that higher degrees of compaction of coarse refuse reduce the permeability and increase strength. Very little information relative to in-situ permeability and strength parameters for coarse refuse in actual embankments exists. This paper presents the data generated in an evaluation of the permeability, density, and strength of coarse refuse in an actual embankment. An embankment constructed of coarse refuse placed with standard in the industry compaction techniques, approximately 140 feet in height, was chosen for evaluation of the in-situ density, moisture content, and permeability.

The embankment chosen for study is a coarse refuse embankment with an earth starter dam. Construction on Stage I of the embankment was begun in 1979, with refuse placement beginning in January, 1982. At the time of this study, the embankment was approximately 140 feet high with a total of about 1.2 million cubic yards of refuse having been placed. The original specifications for the project required 90% of standard Proctor dry unit weight as a compaction specification. The method of placement of the refuse was a D-8 dozer tracking the refuse in roughly 18-inch lifts, and rubber tired scrapers hauling the refuse. No compaction equipment was used.

This evaluation was designed to compare design parameters to as-placed and in-situ parameters. Tests were performed on the coarse refuse as a part of the initial design. These tests included strength, permeability and other index testing. Subsequent to the design, the coarse refuse was placed and some 214 field density tests were performed during construction. A method was devised to determine in-situ density and moisture by nuclear depth-density and moisture gauges to obtain a continuous determination of density and moisture for about 120 feet of refuse. Moisture and density readings were made with the nuclear gauge at 1-foot intervals from elevation 829 feet to elevation 706 feet. In addition, bore hole permeability tests were performed with a special packer permeability device to obtain a continuous determination of permeability from elevation 829 feet to elevation 706 feet. Figure 1 shows the location of the test probes. In addition to this testing, conventional test borings were made and samples were obtained for triaxial and other index testing on the refuse. Pneumatic piezometers were installed to determine the in-situ phreatic surface for comparison with the design phreatic surface. This paper describes the results of the testing of the in-situ refuse and compares it to the design data and the as-compacted data.

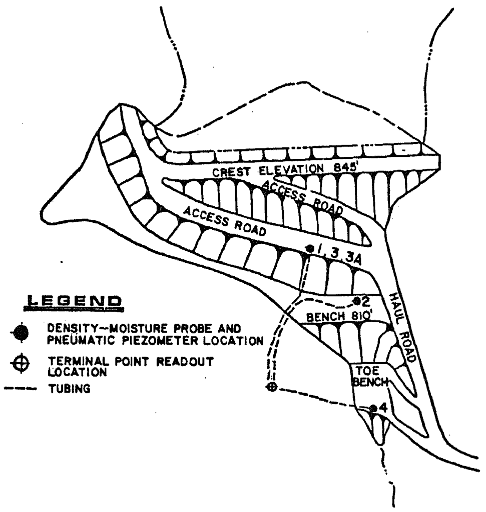

Fig. 1 Stage III Construction of the Embankment, at the Time of the Study

EMBANKMENT DESCRIPTION

The Muskingum refuse embankment for American Electric Power Service Corporation is located at Central Ohio Coal Company in Morgan County, Ohio. The project was initially designed and permitted in 1979 as a coarse refuse embankment impounding slurry. The starter embankment for the project was an earthfill embankment to elevation 805 feet. The starter embankment contained approximately 75,000 cubic yards and was completed in 1979. The remainder of the embankment is constructed of coarse refuse placed as downstream construction. The final planned embankment has several stages of coarse refuse with a top elevation of 885 feet. At the time of this study, the embankment was in Stage III with the configuration being approximately as shown on Figure 2. The top elevaticn of the embankment was about 845 feet and the embankment contained approximately 1.2 million cubic yards.

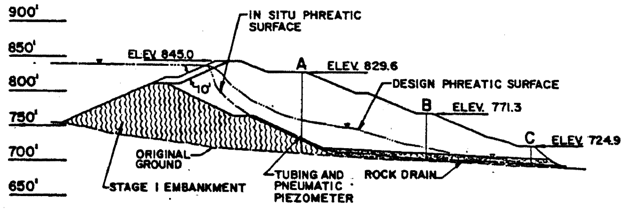

Fig. 2 Cross-Section of the Embankment at the Time of the Study

INITIAL DESIGN DATA

Samples of the various materials to be utilized in the embankment construction were obtained in an original exploration during 1979 and appropriate testing was performed. Samples of the coarse refuse from which the embankment would be constructed were obtained from the preparation plant. Shear, permeability, and index testing were performed as a part of the design report. Table I details the initial design data.

Table I. Initial Design Data for Coarse Refuse

Parameter	Value
Classification	"GP-GM" to "GM"
Maximum Standard Proctor Dry Unit Weight	129.4 pcf
Optimum Moisture Content	5.8%
Vertical Permeability	1.1×10^{-4} cm/s
Approximate Gradation	
Gravel	48% to 66%
Sand	27% to 38%
Silt and Clay	7% to 14%
Specified Degree of Compaction	90%
ϕ' at 90% Compaction	36.4°
C' at 90% Compaction	0.0

Figure 3 shows the gradation range (a) of the coarse refuse as initially tested.

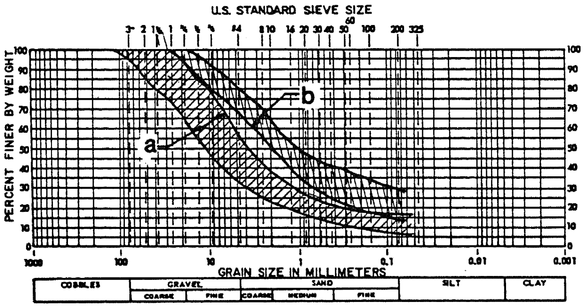

Fig. 3 Gradation Range for Refuse: a. Design; b. In-Situ

A phreatic surface was calculated using a standard Casagrande construction. The phreatic surface for the design is as shown on Figure 2. An assumption was made in this calculation that the permeability of the coarse refuse was 100 times that of the slurry and that the horizontal permeability of the coarse refuse was equal to four times the vertical permeability. A 10-foot thick cohesive cover and a rock drain were designed to control seepage.

PLACEMENT TECHNIQUE AND ORIGINAL COMPACTION DATA

It was decided to place the coarse refuse in approximate 18-inch to 2-foot lifts as experience had shown that equipment tracking the material could compact an 18-inch lift to 90% of the maximum standard Proctor dry unit weight. The equipment hauling the refuse to the site was rubber tired scraper equipment. Compaction was accomplished by a D-8 dozer spreading and tracking the material and by the haulage equipment. This technique proved satisfactory to achieve greater than the required 90% standard Proctor dry unit weight and has been used throughout the placement of the refuse.

Approximately 214 density tests have been performed as a part of the inspection program to date. The average of those tests for each 5-foot lift of refuse are plotted on Figure 4.

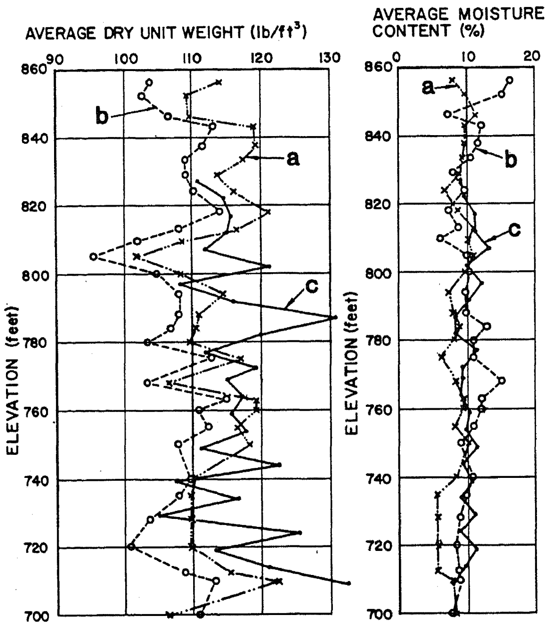

Fig. 4 Results of Measurements: a. Laboratory Standard Proctor; b. As-Compacted Values; c. In-Situ Measurements After Completion of the Embankment

As the refuse was being placed the character changed from time to time and standard Proctor tests were periodically performed to achieved proper control of the placement. A total of thirty-five standard Proctor tests have been performed. The average values for 5-foot lifts are shown in Figure 4.

The overall average degree of compaction of the refuse embankment from date of starting to the time of study was 95%. The construction specifications required 90%. Overall compaction moisture content varied between 6.2% and 16.4% with the average moisture content at compaction being 10.5%. The optimum moisture content of the coarse refuse from the various standard Proctor tests varied between 5.7% and 11.3%. A weighted average shows that the embankment was compacted at an average moisture content approximately 1.9% over the optimum moisture content as achieved by the standard Proctor tests. The original strength testing was performed at approximately 1% over optimum. Table II presents the average of the various parameters after compaction from 1982 through October of 1984, which represents some 1.2 million cubic yards of refuse placed.

CONDITIONS AT THE TIME OF STUDY

A testing program was devised to determine the in-situ density, moisture content, permeability, gradation, strength, and phreatic surface. This program was designed to provide continuous determinations of density, moisture, and permeability throughout the depth of the embankment.

Table II. As Compacted Average Parameters

Parameter	Average Value
Average Percent Compaction	95%
Overall Average Dry Unit Weight of Embankment	107.8 pcf
Average Moisture Content of Embankment	10.5%
Percentage Moisture Above Average Optimum	1.9%
Average Standard Proctor Dry Unit Weight	113.4 pcf
Average Optimum Moisture Content	8.6%

1) In-Situ Density and Moisture Content

The density and moisture content from elevation 829 feet down to elevation 706 feet were determined in 1-foot intervals utilizing depth nuclear gauge. The gauges used were Troxler depth-density and moisture gauges. The depth gauge is equipped with an 8 millicurie source of Cesium 137. The moisture gauge is equipped with a 3.5 AM-241/BE source. The density gauge works by emitting gamma rays into the soil. Some of these gamma rays are absorbed by the soil and some are reflected back to a detector. The denser the soil the more gamma rays are absorbed and the fewer are returned. It is possible to calibrate the gauge to density and this technique has been in use for determining density of materials since about 1950. The moisture gauge works on the principle of emitting fast neutrons into the soil. The fast neutrons are "slowed" by hydrogen atoms and counted as "slow" neutrons. The moisture content can, therefore, be determined from the nuclear readings. This technique has also been in use for about 35 years.

The density and moisture gauges were calibrated to the refuse. The purpose of calibrating the nuclear gauge is to establish a calibration curve relating nuclear gauge counts to total unit weight values. This calibration procedure was conducted in the field utilizing coal refuse from the site being studied by obtaining nuclear density readings at different density states. Coal refuse was collected in sufficient quantity to fill a calibrated barrel (approximately 8 cubic feet) and three density states were used. A metal tube was placed in the calibration barrel, the barrel was filled with coal refuse, and nuclear readings recorded. After each density state was evaluated in this manner the calibration curve was developed.

The nuclear moisture gauge calibration was made in conjunction with the density calibration. Nuclear moisture gauge readings were recorded for each density state. The moisture content was determined and the calibration curve developed.

The density and moisture content were determined with the nuclear gauge every foot throughout the embankment. A total of 120 density and moisture content determinations of the in-situ material were made during this study. Figure 4 shows the average density and moisture contents for each 5-foot increment throughout the depth of the embankment. The percentages for compaction shown in Figure 5 were calculated by utilizing appropriate standard Proctor curves for the various elevations of refuse from the initial inspection data. It can be calculated from Figure 5 that the following average conditions exist in the embankment to date (Table III).

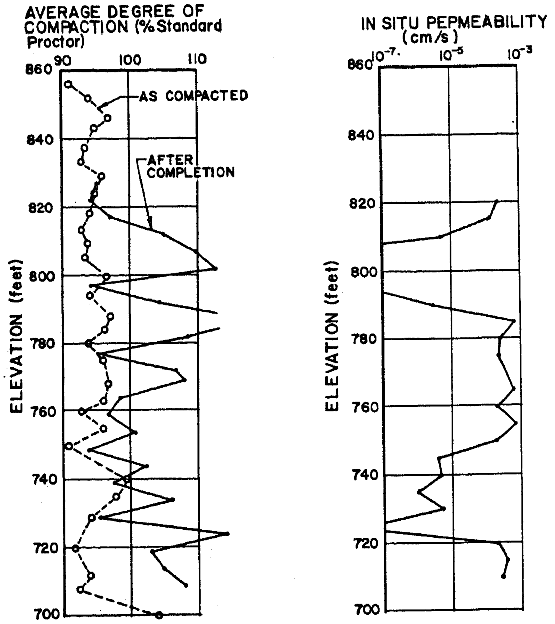

Fig. 5 Results of In-Situ Measurements

Table III. In-Situ Average Parameters

Parameter	Average Value
Average Percent Compaction	102.2%
Overall Average Dry Unit Weight of Embankment	116.0 pcf
Average Moisture Content of Embankment	10.1%
Percentage Moisture Above Average Optimum	1.5%
Average Standard Proctor Dry Unit Weight	113.4 pcf
Average Optimum Moisture Content	8.6%

2) In-Situ Permeability Testing

Permeability testing was performed by a double end packer permeability device inserted below the casing as the casing for the nuclear density and moisture meters was being removed. The casing was removed in 5-foot increments and 5-feet of coarse refuse tested at one time. The flow of water through the 5-foot perforated packer pipe was calculated over a 10 minute period of time. Utilizing the flow, the area being tested at any given time, and the total head being applied, the permeability for each 5-foot section was calculated. The permeabilities are plotted on Figure 5. The above-referenced values obviously represent horizontal permeabilities. In most areas the horizontal permeability varies between about 10^{-4} cm/s and 10^{-6} cm/s. Some areas were found in which no water was taken indicating that there are zones in which the embankment is relatively impermeable. The overall average permeability of the embankment discarding those areas of zero permeability is 2.31×10^{-4} cm/s. The average horizontal permeability used in the design was 1.6×10^{-4} cm/s.

3) In-Situ Gradation

In addition to the above testing, samples were obtained for various parameter testing. The samples between elevations of different permeabilities were combined and an overall gradation test was performed on those samples. These areas were chosen to coincide with the higher and lower permeability zones. Table IV lists the pertinent factors relative to the grain size of the material in these zones.

Table IV. In-Situ Gradation Data

Elevation Range (ft)	Classification	% Gravel	% Sand	% Silt & Clay	D_{30} (mm)	D_{60} (mm)
820.0-824.0	SM	27	56	17	0.23	2.52
794.0-805.5	SM	25	46	29	0.09	2.00
786.5-787.5	SM	29	55	16	0.85	3.59
779.0-786.5	SM	22	54	24	0.18	2.15
760.0-765.0	SM	33	53	14	0.69	3.74
734.5-745.5	SM	30	47	23	0.17	2.79

Figure 3 shows the gradation range (b) for the samples tested.

4) In-Situ Strength Parameters

Strength tests performed on undisturbed samples of the coarse refuse material yield the following values in comparison with design values.

Table V. Comparison of Design Strength to Actual Achieved Strength

Samples	Type of Material	Effective Strength Parameters ϕ' (°)	C' (psi)	Avg. Dry Unit Weight (pcf)	Avg. Moisture Content (%)
Laboratory Compacted (Design)	Black Coal Refuse	36.4	0.0	117.8	6.3
Undisturbed (Actual)	Black Coal Refuse	39.3	0.0	102.1	10.8

Table V shows that the in-situ samples tested were at lower densities than the design tests (as well as the overall average for the embankment) and that the strength values are higher.

5) In-Situ Phreatic Surface

In order to establish the current phreatic surface three pneumatic piezometers were installed. The piezometer works by applying pressure through a 3/16-inch polyethylene tubing to the piezometer point and reading the pressure which is equivalent to the head of water in the boring. These piezometers were installed at the juncture of refuse and original soil. The depth and elevation of the three piezometers are shown in Figure 2.

After the piezometers were installed they were backfilled with 5 to 10 feet of sand to provide a filter around the piezometers. The boring was then closed off with 5 to 10 feet of bentonite pellets and the remainder of the hole filled with on-site material. The leads for the piezometers were buried in a trench and covered with refuse. They were then trenched into a manhole on the left abutment for a permanent installation. These piezometers were read at various times after the installation. Table VI shows the piezometer readings along with the elevations of the water level in each piezometer.

Table VI. In-Situ Phreatic Levels

Piezometer	Elevation of Piezometer (ft)	Elevation of Water Surface (ft)
A	732.6	733.5
B	707.4	711.0
C	686.9	690.0

The above information was used to plot the actual phreatic surface in-situ. It can be seen from Figure 2 that the actual phreatic conditions within the embankment are much lower than those assumed during design. This is partially because the design conditions considered the embankment to be retaining water when in actual fact the embankment retains fine refuse which in itself has a relatively low permeability. There is very little water actually perched on top of the slurry and the actual flow conditions are considerably less than those calculated by assuming the embankment to be retaining water.

CONCLUSIONS

1) Permeability and Seepage

Very little correlation between permeability and percent compaction within the coarse refuse embankment was noted. The permeabilities were performed continuously from top to bottom and coincided with various different densities. Figure 5 shows the plots of degree of compaction and permeability. It will be noted from Figure 5 that higher permeabilities do not necessarily coincide with lower densities, nor do lower permeabilities coincide with higher densities. The greater effect on permeability for coarse refuse is the grain size distribution, not the degree of compaction. Coarse refuse is basically a sand and gravel with a percentage of fines. The data shows percentage of fines in relationship to the percentage of the other size fractions within the total mix is what controls the permeability of the coarse refuse. Table VII shows the average permeability versus density and percentage of each fraction for each 5-foot level throughout the embankment.

Table VII. Comparison of Permeability to Percent Compaction and Grain Size

Elevation Range (ft)	Permeability (cm/s)	% Compaction	Average Dry Unit Weight (pcf)	% Gravel	% Sand	% Silt & Clay	D_{30} (mm)
827.6-822.6	0	95.3	110.7				
822.6-817.6	2.46×10^{-4}	94.5	114.5	26	57	17	0.23
817.6-812.6	1.43×10^{-4}	97.3	115.6				
812.6-807.6	4.83×10^{-6}	105.0	115.0				
807.6-802.6	0	109.8	111.9	25	46	29	0.09
802.6-797.6	0	112.9	122.2	25	46	29	0.09
797.6-792.6	0	94.4	108.2	25	46	29	0.09
792.6-787.6	2.90×10^{-6}	104.4	115.9	29	55	16	0.85
787.6-782.6	7.22×10^{-4}	118.2	130.7	22	54	24	0.18
782.6-777.6	2.59×10^{-4}	108.7	119.9	22	54	24	0.18
777.6-772.6	2.41×10^{-4}	95.5	111.7				
768.4-763.4	4.38×10^{-4}	107.3	117.7	33	53	14	0.69
763.4-758.4	2.29×10^{-4}	96.9	115.6	33	53	14	0.69
758.4-753.4	7.54×10^{-4}	101.0	117.8				
753.4-748.4	2.04×10^{-4}	94.1	111.3				
748.4-743.4	3.87×10^{-6}	102.6	122.4	30	47	23	0.17
743.4-738.4	4.83×10^{-6}	97.7	107.7	30	47	23	0.17
738.4-733.4	9.67×10^{-7}	106.3	116.7	30	47	23	0.17
733.4-728.4	5.80×10^{-6}	95.6	105.0				
728.4-723.4	0	114.2	125.4				
723.4-718.4	1.95×10^{-4}	103.2	113.3				
718.4-713.4	3.84×10^{-4}	104.9	121.1				
713.4-708.4	3.33×10^{-4}	108.2	132.5				

It can be seen from Table VII that there is no correlation between percent compaction and permeability of the coarse refuse. The percent compaction for the 10^{-4} cm/s permeability varied between 94.1% and 118.2%, while the percent compaction corresponding to the "zero" permeability material varied between 94.4% and 114.2%.

There is a rough correlation between D_{30} and permeability. The 10^{-4} cm/s permeability refuse has a D_{30} ranging between about 0.18 mm and 0.85 mm. The "zero" permeability material has a D_{30} of 0.09 mm. The permeability of coarse refuse is, therefore, much more dependent on grain size; and in particular, the amount of fines than it is on percent compaction. The compaction of coarse refuse at 95% instead of 90% standard Proctor, therefore, has no appreciable effect on permeability or seepage. Specifying a higher degree of compaction for coarse refuse will not substantially decrease seepage through the embankment. Cohesive facings and subdrains should be used to control seepage through coarse refuse embankments as it is unproductive to try to control seepage by increased compaction of coarse refuse.

2) Density

The method of placing coarse refuse in 18-inch to 2-foot lifts and tracking with a dozer and hauling equipment produces a well compacted fill that achieves the desired results. This method produced an average percentage of compaction of 95% of the standard Proctor value with no additional compaction equipment being utilized. The embankment as it consolidated over a period of time increased in density. Thus, the density in coarse refuse embankments can be expected to increase somewhat with time as the embankment is consolidated under its own weight.

3) Stability

The in-situ stability was found to be greater than the design stability of the structure. The strength parameters in-situ were higher than the design strength parameters and the factor of safety comparably higher. This conclusion indicates that the design criteria for coarse refuse embankments are conservative and that a compaction specification of 90% standard Proctor is adequate to produce the required stability at slopes of 2.5:1.

CONCLUSIONS

Design assumptions relative to permeability and seepage in coarse refuse embankments compare favorably with actual observed values. The design assumptiontions are shown to be conservative in this study. Coarse refuse can be compacted in 18-inch lifts by dozers and haulage equipment to provide a satisfactory embankment. Correlations of permeability to percent compaction indicate that it is not effective to try to reduce the permeability by increasing compaction for coarse refuse.