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Grouting Evaluation Program of the Best Methods for Use of Microfine and Portland Cements During Treatment of the Rock Foundation at the Portugues Dam

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GROUTING EVALUATION PROGRAM OF THE BEST METHODS FOR USE OF MICROFINE AND PORTLAND CEMENTS DURING TREATMENT OF THE ROCK FOUNDATION AT THE PORTUGUES DAM

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ABSTRACT

The U.S. Army Corps of Engineers, Jacksonville District, recently completed a grouting program in Ponce. Puerto Rico, for the Portugues Dam. The program compared microfine cement to Portland cement and helped determine the most efficient and economical method to construct the grout curtain.

The foundation rock consists of volcanic sediments. A diorite stock upstream of the site altered the volcanic sediments by low grade metamorphism to metasediments. cause numerous radiating dikes and shears and a highly fractured foundation. Most of the fractures are relatively tight or healed.

A bore hole video camera recorded in-situ fracture frequency, orientation and aperture thickness before and after grouting. The camera logs revealed that 58% of all the fractures were less than 0.02 inches thickness, the groutable limit for Portland cement.

In addition to standard Corps of Engineer water pressure tests. Modified Lugeon Pressure tests were conducted in exploratory core holes drilled after grouting. All of the pressure test data was then reduced to determine the rock mass permeability and compared with corresponding grout data.

Various mix designs and pressures using both Portland and three microfine cements were experimented with. The standard injection refusal criteria time was adjusted and a "Duration Grouting" procedure, has been developed for the Portugues Dam.

KEYWORDS

1. Grout
2. Water pressure test
3. Microfine cement
4. Portland cement
5. Permeability
6. Duration Grouting

INTRODUCTION

The Portugues Dam will be a double curvature three centered elliptical thin arch concrete structure built across the Portugues River, in Ponce Puerto Rico. The Jacksonville District of the U.S. Army Corps of Engineers designed the structure and will oversee it's construction. As designed the Portugues Dam will have a length of 1,505 ft, a maximum height 271 ft and widths of 40 ft and 12 ft at the bottom and top of the structure respectively. A test grouting program was carried out on the dam foundation in order to evaluate and design the best and most cost effective method to grout such a sensitive foundation to meet design requirements for the dam structure. The term "permeability" used herein will be equivalent to hydraulic conductivity.

The Portugues Dam site foundation rock has been evaluated by extensive geotechnical investigations. This detailed investigation was due to the complex geology at the site and the necessity of a foundation which will withstand the projected stresses. The geology at the site consists of conglomerate, siltstone and sandstone altered to metasediments. The controlling geologic feature for the region is an diorite stock located upstream of the dam site. The volcanic sediments, which were deposited in a marine environment, were altered by low grade metamorphism. There are also a number of dikes and shears radiating from this upstream stock. See Fig. 1 below for geologic profile of the dam site.

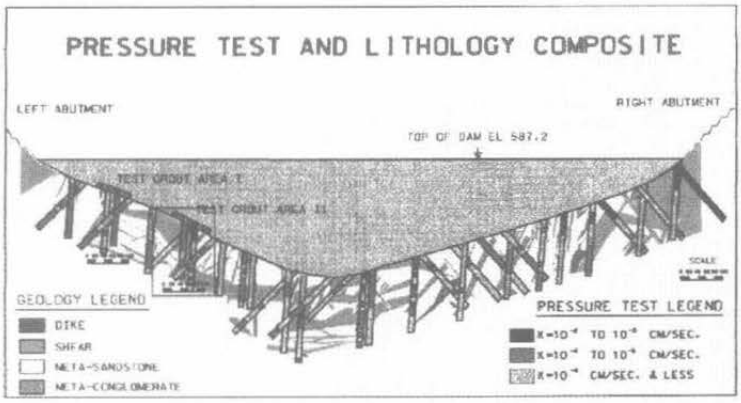

Fig. 1 Pressure Test and Lithology Composite

The rock units are moderately to more commonly highly fractured. The majority of these fractures appear to be tight to almost closed, and many are healed by mineralization. Areas of high water takes were identified early on during the exploration and initial geotechnical investigations. Design Memorandum 22, Portugues Dam Foundation Investigation, dated February 1988 contains all the details of this early geotechnical investigations including the use of a borehole video camera.

The borehole video camera recording was performed in addition to the usual logging of the foundation rock core borings taken along the dam alignment. This in-situ approach provided supplementary information to the actual joint fracture, frequency, orientation, aperture thickness and condition. Measurements taken utilizing the in-situ rock video confirmed the tight condition of the rock joints and fractures. The resulting analysis of 18 core borings for a total of 2,888 linear feet revealed that 58 % of the fracture openings were 0.02 inches or less. The fineness of the fracture apertures raised some concern as to whether the foundation rock mass could be effectively grouted with Portland cement grout. According to the industry consensus, apertures of 0.02 inch or less would not allow for effective grout penetration with Portland cement. The distribution of the aperture width for the composite data from both abutments is indicated in Fig. 2. The aperture distribution is near log-normal. Aperture width measurements varied from 0.0 to 6.0 inches, however, measurements exceeding 0.10 inches constituted less than 1.0% of the data.

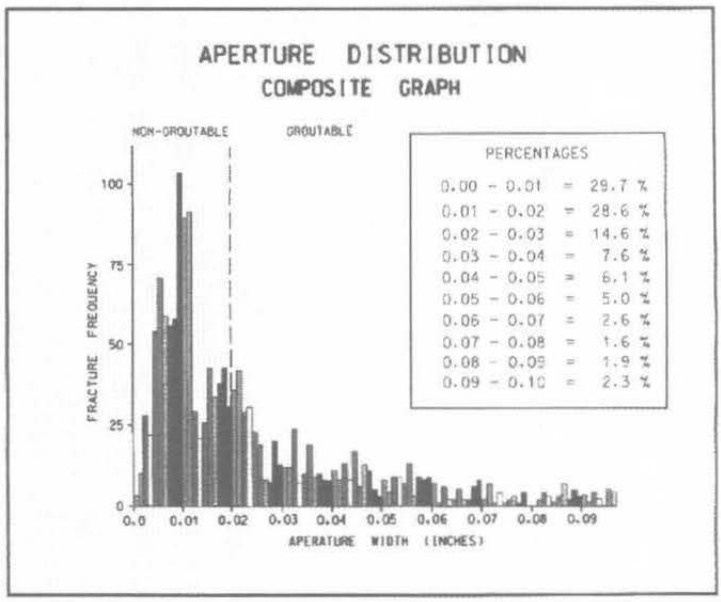

Fig. 2 Aperture Distribution

TEST GROUTING PROGRAM

The test grouting program for the Portugues Dam foundation was designed utilizing all of the previously obtained geologic and geotechnical information. The main purpose of the test grouting program was to obtain the necessary information to design a cost effective grout program that would reduce the grout curtain permeability to a minimum value of $1.0X10^{-5}$

cm/sec. Water pressure testing performed during the core boring drilling indicated permeability ranges from as high as 10^{-2} to as low as of 10^{-6} cm/sec. Figure 1, shows the location within the borings and along the dam alignment for the various permeability values. The majority of the high permeability areas are in the metaconglomerates and/or associated with the dikes and shear zones intersecting the foundation.

During the test grouting program a video camera was used to gather in-situ visual information of pre-grout and post-grout foundation conditions. The video camera data was collected prior to water pressure of each zone. A view of the previously grouted zone was obtained as the camera was lowered into the ungrouted foundation rock of the next zone.

The video camera again provided joint orientation and dip with it's direction, joint and fracture frequency, aperture condition and thickness. The aperture openings measured from the video were compared to the water pressure test data collected. Prior to the test grouting, a correlation was made between aperture opening size and frequency of joints with water pressure take and permeability results. Also a comparison between the extracted rock core joints and the in-situ characteristics of the same joints corroborated the video measurements. The data from the video logging collected during the test grouting provided similar results to the previous videos taken during the exploration phase. The main difference was that the 58% of 0.02 inch apertures observed in the exploration phase was higher than the percent of 0.02 apertures discovered in the test sections. The apertures were slightly tighter in the test sections.

The least expensive material for grouting the foundation would be to utilize Portland cement. The test grouting began by exclusively mixing and injecting Portland cement. Starting with Portland cement, grout mixes of 4:1 water to cement ratio by volume were injected into all zones, beginning at zone 1 (0-20 feet) until the deepest zone 5 (160-210 feet) was reached. Grout injection pressures began at 1 psi/ft increasing to a maximum of 2 psi/ft in an attempt to push the grout. The results were similar regardless of the depth of injection or the pressure applied.

Penetration of the fracture system at the Portugues dam foundation with Portland cement was extremely difficult. The instances where this grout penetrated generally ended with what appeared as early refusal or "slugging " of the hole. This was particularly true when the mix was thickened to more than a 3:1 water to cement ratio by volume. The opening size of the fractures proved to be too narrow for the penetration of Portland cement particles. Only about 5 % of the fracture openings are large enough to allow penetration with Portland cement according to the video camera results.

Microfine cements were considered as the next most cost effective grouting material for reducing the grout curtains' effective permeability's to the desired 10^{-5} cm/sec level. Microfine cement from three different manufacturers was utilized during the test grouting. All of the microfine cements had similar properties. The particle sizes were 97% smaller than 10 microns. The "Micro Cem" microfine is packed in 55 Lbs bags with pre-mixed fluidifier. "FosRoc" bags are 30 Lbs which also included a fluidifier. "GeoChem" microfine cement, came in 44 Lbs bags , which required mixing two grades of cement and adding a liquid fluidifier.

High capacity colloidal grout mixers were used. Mixing and pumping microfine cements proved to be as easy as Portland cement. The microfine grout was extremely fluid, and even gave the impression that the mix was leaner or had more water than desired. Proportioning of the mixes required some separate mix design calculations due to the fact that all three of the microfine cements had different weights per cu. ft. and bag weights. A spreadsheet was prepared indicating the various water amounts to be added per bag to each of the microfine cements. Grout mixes were prepared on a volume basis. All of the microfine cements performed satisfactorily and much grater grout penetration was achieved over conventional Portland cement. Some areas of the test sections required extensive grout times with small grout injection rates in order to get grout into the fracture system. Even though microfine costs approximately 5 times more than Portland cement it is considered cost effective because filling the fine fractures will require a relatively small amount of grout.

There was a safety concern with handling these products. The extremely fine particles caused skin and respiratory system irritation. Adequate protection for the skin and respiratory system was required

Generally water pressure test were conducted by injecting water through a nipple installed on the ground surface at the top of the hole. Pressures were measured at the center of the zone tested by means of electronic sensors. Vibrating wire and strain gauge type piezometers connected to a computer were used to record the pressures. The standard COE water pressure test consists of a five minute test from the time the system stabilizes. Pressures used ranged from 1 psi/ft to as high as 2 psi/ft calculated at the center of the test section. The modified lugeon test (water pressure test) took no less that 50 minutes, since it required 5 intervals of ten minutes each. Pressures applied during each interval changed on a

step ladder fashion. It began with 0.4 of the maximum pressure, increasing to 0.7, then reaching maximum pressure, reducing to 0.7 of maximum again, and last to 0.4 of maximum pressure.

PERFORMANCE TEST RESULTS

In order to verify the grouting effectiveness at reducing the foundation rock permeability, a performance test utilizing water pressure tests (wpt) were conducted at intermediate locations between the upstream and downstream grout lines. Five grouting evaluation core borings were drilled and water pressure tested using packers to measure the reduction in permeability of the curtain. Water pressure test were also conducted on every grout test zone following the standard Corps of Engineers (COE) procedure to determine mass rock permeability as described by Zeigler, 1976. Modified water pressure test were conducted on selected sections which provided information regarding the effects of increased pressure on the rock mass flow patterns as described by Houlsby, 1990.

Data collected from all the water pressure tests was used for calculating the rock mass permeability's. For the performance test, the calculated permeability from each of the zones which were water pressure tested in the 5 core borings was compared to the average permeability of the corresponding grout test holes for the two grout lines on either side. Utilizing the arithmetic averages of all the core boring permeabilities we can observe a decrease of about two orders of magnitude from the calculated pre-grout permeability to the post-grout permeability. After grouting the permeability value was 1.66 E-05 cm/sec and the before grouting was 4.65E-03 cm/sec. See Table 1 for details. The after grouting effective permeability is close to that desired for the final foundation.

	AFTER GROUTING	BEFORE GROUTING
ARITHMETIC MEAN (cm/s)	1.66E-05	4.65E-03
GEOMETRIC MEAN (cm/s)	3.09E-06	5.29E-05
GEOMETRIC VARIANCE	3.3606	8.9506
K effective (cm/s)	5.42E-06	2.35E-04

Table 1 Grout Performance Test Results

During the test grouting program a "Duration Grouting " procedure was being developed as the results of the on going tests were being analyzed. This procedure was specifically designed for the conditions encountered at the Portugues Dam. It varies from standard COE procedures in several ways.

The grouting pressures used will range from 1 to 2 psi/ft depending on the conditions encountered in the hole and hole the grouting injection proceeds. A variation from the standard COE refusal criteria will be implemented by correlating between the water pressure test, ground conditions and the grout take.

The refusal criteria for Portland cement will continue to be the standard COE procedure. Except for an additional 15 minutes of grouting added after reaching the refusal criteria. The additional continuos pressure will ensure thixotropic stiffening of the grout to resist removal by groundwater of by water from nearby activities.

For microfine cements grouting refusal will not be reached when the rate of injection is reduced to 1 cu. ft. or less in ten minutes, measured in at least a 5 minute interval. The refusal criteria will be reached after increasing the injection pressure in successive intervals and holding the new higher pressure until the flow basically no longer continues. Because microfine cement has a viscoelastic property which causes its injection flow to have a time dependent component as well as an instantaneous component extended grouting time is required in very fine fractures and joints (Duration Grouting). Holding the microfine grout under pressure allows for additional penetration into the foundation. The expected result is to be able to inject even a small amount of grout into the very fine fracture openings. For example, in order to fill a 0.02 inch open fracture a radius of 2.5 ft a volume of only 0.0327 cu. ft. or 0.25 gallons is required.

CONCLUSION

The test grouting performed at the Portugues Dam was successful in providing conclusive data on the groutability of the foundation to the desired 10^{-5} cm/sec permeability. The majority of the grouting will be performed by injecting microfine cement. This is the only material which will penetrate the 0.02 and finer fracture openings in most of the foundation rock. Portland cement will be available for the few occasions it may be used. The implementation of the "Duration Grouting" procedure will be instrumental in achieving the necessary closure of the foundation grouting program.

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