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Grout enrichment of RCC for face of dams

Enriquecimento com calda do CCR para face de barragens

A. P. WENDLER [a]
apwendler@gmail.com

J. MARQUES FILHO [b]
jmarquesfilho@gmail.com

J. M. M. FRANCO FILHO [c]
joaquimmmff@jmalucelli.com.br

M. BIANCHINI [a]
mauriciobianchini.mk@gmail.com

Abstract

The construction of RCC dams emphasizes the minimization of interferences, such as execution of the upstream face, to ensure productivity. The study sought to evaluate the physical properties of the grout enriched RCC, replacing the conventional concrete usually employed in the face, using the same materials, concrete core, labor and equipment used in construction of the Maua Hydro Power Plant. Thus were made site experimental prisms (with different water / cement ratios and grout amounts) and subsequent core drilling, which were subjected to mechanical tests and permeability. The results showed that for grout water / cement ratio 0.74, the resulting material met the design specifications for cement consumption markedly lower (between 70 and 85% of the conventional concrete).

Keywords: dams, rolled compacted concrete (RCC), grout enrichment, permeability.

Resumo

A construção de barragens de CCR prioriza a minimização de interferências, como a execução da face de montante, para garantia da produtividade. O estudo procurou avaliar as propriedades físicas do CCR enriquecido com calda, em substituição ao concreto convencional usualmente empregado na face, utilizando os mesmos materiais, central de concreto, mão de obra e equipamentos, empregados na construção da Usina Hidrelétrica Mauá. Para tanto foram feitos prismas experimentais de campo (com diferentes relações água/cimento e quantidades de calda) e posterior extração de testemunhos, os quais foram submetidos a ensaios mecânicos e de permeabilidade. Os resultados mostraram que para relações água/cimento 0,74, o material resultante atendeu às especificações de projeto, para consumos de cimento notadamente menores (entre 70 e 85% do CCV).

Palavras-chave: barragens, concreto compactado com rolo (CCR), enriquecimento com calda, permeabilidade.

[a] *Universidade Federal do Paraná, Curitiba, Brasil;*
[b] *Companhia Paranaense de Energia Elétrica, Curitiba, Brasil;*
[c] *Construtora J. Malucelli, Barras, Brasil.*

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1. Introduction

During concrete dams technical evolution the concept of mass concrete has been developed in order to consider the volume change effects. These processes are generated by environment temperature, cement reactions, concrete design and construction procedures. After several years using mainly rock fill and earth dams, concrete solution competiveness returned throughout rolled compacted concrete (RCC) construction method. This method uses intensively earth dam equipment, minimizes human labor and its cement content is smaller than the conventional concrete solution ones.
Due the use of a very efficient mechanical process in terms of concrete pouring and compaction, any interference as concrete face slabs, drainage galleries, drainage courtains, joints and waterstops could create difficulties and slow down the process. These interferences must be treated to avoid unnecessary schedule critical paths [1].
After consolidation of RCC technique, Chinese engineers proposed the use of the sloped layer method, approximately fifteen years ago. This method permits to optimize batching plant, and the same engineers group to improve the work efficiency proposed the grout enrichment method to improve CCR permeability parameters in the concrete face slab. In the sloped method, the layer has a slight slope (1:8 to 1:12) limited by vertical joints or faces.
In the sloped layer method the pouring and compaction front is limited in a confined small area, using a limited maximum volume per layer. This constructive process permits a small time interval between successive layers, and it is possible to avoid the use of mortar bonding layer in the constructive joints interface [2]. Obviously, the layer length limit generates a horizontal limit for a sloped layers group, in general 2.0 to 3.0 m. This horizontal surface creates a cold joint and the use of mortar bonding layer is necessary to assure the necessary concrete strength parameters. The construction method generates clear and free vertical contraction joints and cold construction joints similar to the conventional concrete dams construction methods [3].
The grout enrichment method consists in the grout (cement, water and admixtures) addition to freshly poured RCC and its compaction using concrete vibrators. This process increases permeability, mechanical strength and surface finishing. Its use is particularly interesting to create adequate upstream slabs with controlled permeability [4].
Clearly to assure adequate mechanical parameters is necessary to study a limited grout amount in order to permit to obtain a homogeneous concrete, with adequate compaction. As RCC is very dry the process must permit conventional concrete vibrators work [5]. The enrichment occurs after pouring and spreading process, and the interference in the concrete process is lower than the initial RCC construction method [6].
The first Brazilian grout enrichment studies have been performed in experimental test fills in FURNAS Concrete Laboratory (state of Goias, Brazil), and in the drainage gallery downstream face of the Dona Francisca Hidropower Plant (in the state of Rio Grande do Sul, Brazil). However, there are none application in actual projects for two main reasons. The first one is connected to the lack of knowledge and the absence of a reliable data bank. Another important issue is the difference in the mix approach used in China in comparison to RCC Brazilian mix design. In China, the concrete mixes use the high paste approach, applying a significant amount of pozzolans, and cement content bigger than 150 kg/m³. Otherwise in Brazil the RCC mixes use a high pulverized aggregate content [4].
The present paper studies the grout enrichment in common Brazilian RCC mixes using cement content in the interval 70 to 80 kg/m³, in field conditions. In order to create an experimental matrix and process, the study considers two hypotheses. The first one considers that the RCC immediately before compaction has enough voids ratio and permeability for grout penetration. The second assumption considers that the final product could reach the usual technical specifications and requirements.

2. Experimental program

2.1 Design of the experiment

The first step to design the experiment is to determine the main factors that affect the experiment, the variability sources and the physical characteristics of the materials used in the proposed tests. The grout enrichment RCC process presents the following random errors:
a) RCC mass variabilities
- Mix variations;
- Changes of water content generated during construction;
- Time interval between RCC placement and grout application;

b) Concrete compaction variabilities
- Type of vibrator;
- Distance between successive immersion points;
- Vibration immersed time

c) Enrichment process variabilities
- Grout mix and workability;
- Grout amount per length;
- Grout uniformity and application method

Mechanical strength and permeability are chosen as output response variables, since they are usually the adopted parameters in das design. These factors are correlated to upstream concrete face durability and watertightness. The chosen controllable variables are the grount amount per length and the grout mix (water cement ratio).
Table 1 presents the experimental matrix used in this research, showing the main variables, levels and range. The statistic model is a two-factor factorial design, permitting to analyze the two controlled factors individually and its interaction [7]. The following equation presents the chosen statistical model, calling A and B the controlled factors.

Table 1 – Experimental matrix

Factors	Units	Value
Grout amount	l/m	15 / 17 / 19
Grout mix (w/c)	–	0,74 / 0,8 / 0,9
Vibrator diameter	mm	140
Vibration time per immersion point	s	15
Time interval between RCC placement and grout application	h	1

Figure 1 – Grout mix detail

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk} \quad (1)$$

Where:
μ = General average;
τ_i = Effect of ith level of factor A;
β_j = Effect of jth level of factor B;
$(\tau\beta)_{ij}$ = Effect of interaction AB;
ε_{ijk} = Random error component.

2.2 Procedures

In order to perform de experiment design, ten prismatic samples have been molded, each with (0,30 x 0,60 x 0,70) m. The several combinations showed in the experimental matrix has been performed in nine of them, and the last one have been molded only using a common upstream face conventional concrete. Four core samples have been drilled from each prismatic sample, in order to perform mechanical strength and permeability tests.

The basic grout enrichment process consists in initially RCC pouring inside the molds, after this grout application, and finally compaction using concrete immersion compactors. The molds have to be wet before pouring aiming to avoid concrete humidity losses. The grout mixes have been prepared in a manual device, and manually applied over non compacted RCC using a graduated bucket. Immediately after grout application the concrete has been compacted using a pneumatic vibrator in two points.

Figures 1 to 4 show the enrichment process and the final appearance of the concrete surface. Non homogeneous surface areas are more observable when grout w/c ratio decreases.

The core drilling process has been performed at the age of

Figure 3 – RCC grout enrichment - compaction

Figura 2 – RCC grout enrichment– grout application

Figure 4 – Surface appearance (w/c 0,74)

Table 2 – Concrete mixes

Mixes/Materials		Concrete CCR	Concrete CVC face
Cement	(kg/m³)	75	195
Water	(kg/m³)	125	190
Artificial sand	(kg/m³)	1272	1144
Coarse aggregate 25 mm	(kg/m³)	619	1018
Coarse aggregate 50 mm	(kg/m³)	619	–
w/c ratio		1,67	0,97
Admixture	(l/m³)	0,9	1,32
Slump	(mm)	–	70 ± 10
Cannon time	(s)	15 ± 5	–
Entrained air	(%)	–	1,0 ± 0,5
Theoretical density	(kg/m³)	2710	2547
Characteristic compressive strength	(MPa)	7	12
Design parameters determination age	(days)	180	180
Confidence interval	(%)	80	80
Maximum aggregate size	(mm)	50	25

53 days. The tests have been executed in Laboratorio de Materiais e Estrutura, LAME, in Curitiba (state of Parana, Brazil). After the mold removal, visual observation shows non homogenous concrete nearby the downstream face, in the sample bottom and far from vibrator immersion points, as exhibited in Gigura 5.
The (10 x 20) cm drilled samples have been tested using the recommendations of the Brazilian standard NBR 5739 [8] to determine its compressive strength, and NBR 7222 [9] to determine the splitting tensile strength. Permeability testes using the Brazilian standard NBR 10786 [10] were performed over the (15 x 15) cm samples, similarly to the equipment developed in the United States Bureau of Reclamation.

2.3 Materials and mixes

The study used the same materials and mixes applied in the construction of Maua Hidropowerplant, in the state of Parana, Brazil. This choice is based on the use of actual construction materials, mixes and processes. The approach permits to compare the experiment results with the real site conditions, and using the site facilities it is easier to obtain materials and equipments.
The grout mixes used cement type CPIV RS, according with Brazilian Standards, from Votorantim and set retard admixture PLASTIMENT VZ, supplied by Sika Brasil. The RCC mixes are shown in Table 2, and the RCC and the upstream face conventional vibrated concrete(CVC) used artificial sand.

3. Results and analysis

3.1 Grout flow tests

During the prismatic samples casting process, fresh concrete and grout have been tested. Cone flow tests have been performed in the grout mixes, according with Brazilian standard NBR 7682 [11], using March Cone. This test purpose is to obtain a correlation between the flow test result and the grout penetration inside RCC mass.
Table 3 shows the cone flow tests results, where all grout mixes have efflux time less than seven seconds, using admixture content less than 1% of cement content. During the tests, the first grout w/c ratio level has been adjusted from 0.7 to 0.74 in order to

Table 3 – Site test results

Parameters	Prismatic samples 10 (CVC)	Prismatic samples 1 / 2 / 3	Prismatic samples 4 / 5 / 6	Prismatic samples 7 / 8 / 9
Room temperature (°C)	29,8	31	24,3	24,3
Slump (cm) / Cannon time (s)	5,5	10	10	12
Concrete temperature (°C)	31	32,5	29,5	29,5
w/c ratio	–	0,74	0,8	0,9
Admixture (%)	–	1	1	1
Efflux time (s)	–	6,7	6,1	5,7

Figure 5 – Prismatic samples appearance after demolding

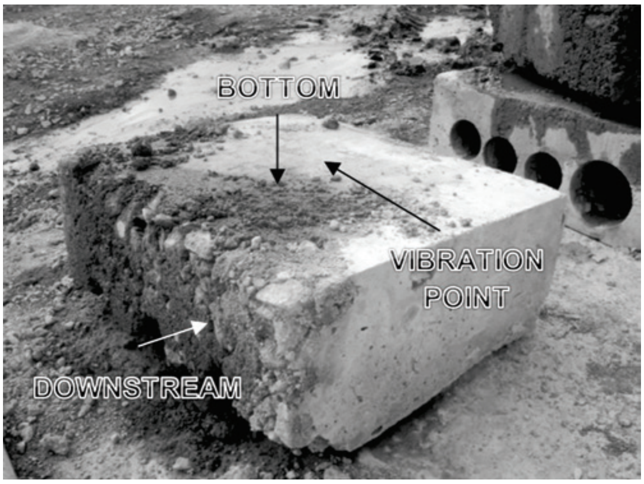
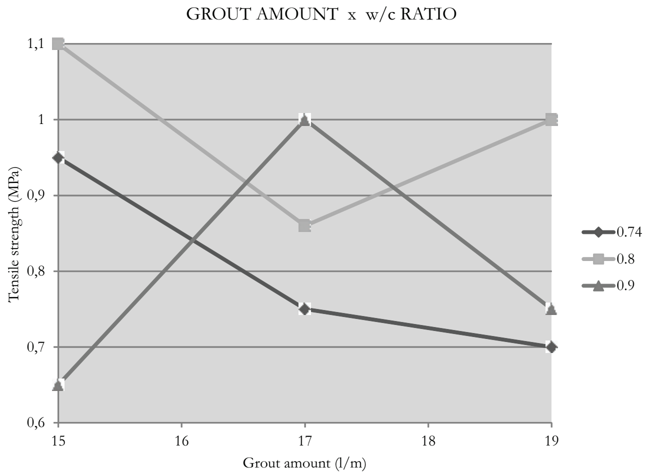


Figure 7 – Splitting tensile strength results



improve the grout penetration in RCC mass. The 0.70 grout mix has been tested using admixture contents equal 1.0%, 1.2% and 1,6% without any significant change in the efflux time that exceeded 7 seconds.

The 0.7 grout mix has been tested in field conditions and the first tests occurred under temperature condition greater than 30ºC. For the prismatic samples 4 to 9 these tests have been repeated, under better weather conditions. The tests obtained ellux time of 7.1 seconds for grout without admixtures and 6.5 seconds for mixes using 1.0% admixture content. These results indicated the chosen the efflux time limit of 7 seconds for all grout mixes.

3.2 Grout enriched RCC

Figures 6 to 8 show the laboratory tests results, considering the obtained values as functions of grout amount per length and grout mix. The permeability and compressive strength tests have been perfomed at ages of 60 and 79 days.

The results presented in these figures shows have very important dispersion for all tests, compressive strength, tensile strength and permeability, and the data analysis doesn't show a recognized pattern. In spite of these interpretation difficulties, it was not possible to identify compaction defects, as voids presence in the grout enriched concrete. This significant variance coud be generated by variations in final concrete due to the admixture efficiency.

In spite of the variability, the consistency of the enrichment could be demonstrated verifying that the enriched RCC compressive strength is higher for grout w/c ratio 0.74 than the 0.9 one. This result is correlated to Abrams' law, since greater w/c ration furnished smaller compressive strength [12]. The greatest compressive strength is 11.63 MPa, for the combinated factors w/c ratio 0.74 and grout amount equal to 19 l/m.

In an analysis of variance, ANOVA, the isolated effect of each vari-

Figure 6 – Compressive strength results

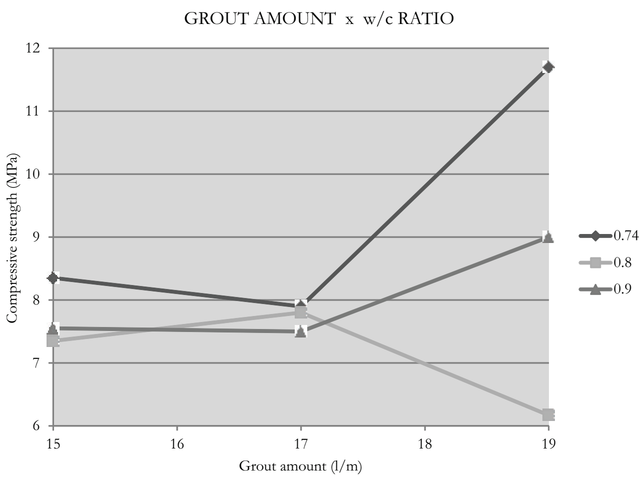


Figure 8 – Permeability results

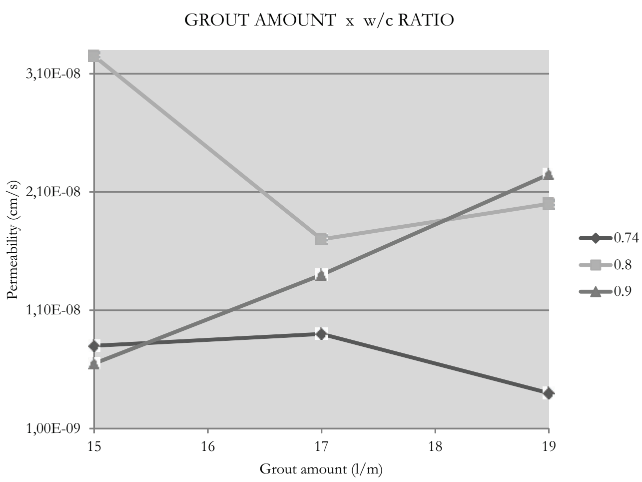


Figure 9 – Comparison enriched RCC x CVC – compressive strength

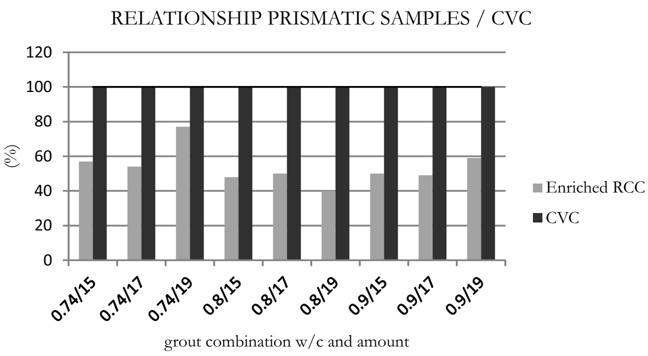
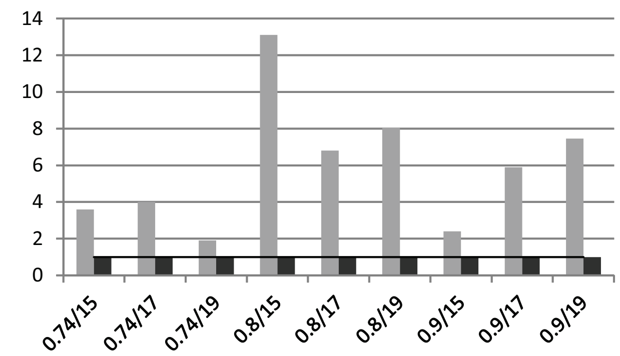


Figure 10 – Comparison enriched RCC x CVC - permeability



able is not significance, as well their interaction, for 95% confidence interval. The splitting tensile strength tests presented greater variability than the compressive strength. This result could be considered normal, since the tensile tests have been performed in core drilled samples [3].

The tests results for grout enriched RCC and upstream face conventional concrete are shown in Figures 9 and 10. Comparing the two approaches, a simple analysis shows that the CVC parameters are greater the grout enriched RCC. The enriched RCC compressive strength corresponds to 40 to 76% of the CVC ones. For grout w/c 0.74, the permeability tests showed that the enriched RCC results are approximately two to four times greater than the CVC ones. The final cement content of the grout enriched RCC is 70 to 85% of the CVC cement content, and, this situation could explain the differences between the two approaches results. The enrichments was studied in order to verify the possibility to penetrate in the RCC mass using economical mixes, and these results differences have been expected.

4. Conclusions

a) Used as plasticizer and set retarder, the admixture led to difficulties to grout penetration under high temperatures. Its effect was not observed for temperatures greater than 30ºC. The variabilities observed in the mechanical strength and permeability tests could be generated by the admixture behavior that not permitted a homogeneous concrete compaction. Thus, it is necessary to propose new studies considering another admixtures, cement content, grout amount per length and temperatures, in order to improve the grout enrichment results. This paper main purpose was to apply the technique under site conditions, with materials and construction conditions really used in Maua Dam, as an initial feasibility analysis.
b) The grout efflux time must be limited to a maximum of 7 seconds, in the cone flow test, for RCC cannon time between 10 to 12 seconds, in order to permit adequate penetration.
c) The experimental program has been performed in the Maua site, using same materials, equipment and labor crew. This approach permitted to analyze the process under real work conditions, but it was not possible to verify grout enrichment productivity. This analysis could be performed using test fills.
d) The compaction chosen process used 140 mm diameter vibrators and 15 seconds or immersion. The process showed appropriate final result in terms of visual uniformity. I was not observed voids or segregation points in the compacted mass surfaces.
e) The grout enrichment RCC results are lower than the reference CVC, due the enriched RCC cement content is notably lower. Even with situation, the combination grout w/c ratio equal to 0.74 and grout content of 19 l/m obtained compressive strength 76% of the CVC one, and almost achieve the real design required strength of 12 MPa. This combination permeability is 2 to for times greater than the CVC one, but attend the design requirement of 10-9 cm/s. Therefore, for w/c ratios of 0.74 the grout enriched RCC has similar permeability behavior of the site upstream face CVC, and attend the design requirement for permeability and compressive strength.

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