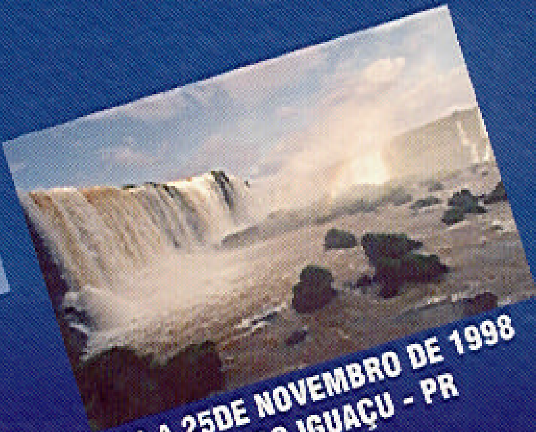
III SEMINÁRIO NACIONAL DE CONCRETO COMPACTADO COM ROLO



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Barragens de CCR – Discussões Relacionadas ao Projeto, Planejamento da Construção, Controle de Qualidade e suas Interrelações

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Barragens de CCR – Discussões Relacionadas ao Projeto, Planejamento da Construção, Controle de Qualidade e suas Interrelações

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Resumo

Há mais de uma década o método do CCR para construções de barragens ganhou popularidade em todos os Países. O CCR tem sido considerado para vários Projetos, sendo que a altura das barragens de CCR tem aumentado.
Isso é uma prova da popularidade da metodologia de CCR, entretanto há ainda alguma relutância em se projetar uma nova barragem de CCR, com altura maior que a de um Projeto precedente.
Nesta publicação pretende-se estabelecer uma discussão ao redor dessa argumentação, considerando o Projeto, as condições de Segurança, Velocidade de Construção, Planejamento e Controle de Qualidade, bem como as interrelações dessas atividades.

1- INTRODUÇÃO E ASPECTOS GERAIS

O CCR há mais de duas décadas vem ganhando popularidade na construção de barragens.

No Brasil o emprego do CCR, não se fez simplesmente pela possibilidade dessa técnica em reduzir consumo de aglomerante, visto que desde a década de 60 é comum o zoneamento das classes de concreto (CVC-concrteto convencional massa), o uso de resistências com controle de resistência à idade de um ano, ou pelo menos à 180 dias. Esses conceitos práticos já eram adotados, com intuito de melhor utilizar o potencial dos materiais. Por outro lado a dimensão territorial do Brasil fez necessário tomar providências em otimizar o uso de materiais existentes próximos aos locais das obras, bem como reduzir a possibilidade de se rejeitar materiais, quando do chegada ao local da obra. Disso decorreu uma série de procedimentos de controle, adotados nas maiores obras de concreto do País, como Ilha Solteira, Itaipu, Tucurui e outras.

Decorrente também dessa dimensão territorial, foram estabelecidos laboratórios em certas regiões estratégicas com intuito de conhecer os materiais, pré-qualificar materiais, técnicas e tecnologias, bem como treinar Mão de Obra, além de dar suporte ao controle de qualidade.Como exemplo dessas ações pode-se citar,os seguintes pontos importante:

Hidroelétrica-Volume de Concreto-CVC	*Época*	*Evento*
Ilha Solteira-3,680,000m3	1970-1972	Uso de CVC Massa com consumo de 84kg/m3 de aglomerante (61 cimento+23 Pozzolana). Concretos com controle à idade de 180 dias.
Itumbiara-2,080,000m3	1975-1980	Zoneamento de classes de concreto, com idade de controle de 90 e 180 dias.
Itaipu- 13,000,000m3	1977-1982	Zoneamento de classes de concreto, com idade de controle de 180 e 360 dias. Consumos de até 90 kg/m3 de aglomerante. Produções acima de 750m3/h
Tucurui- 6,000,000m3	1978-1984	Zoneamento de classes de concreto, com idade de controle de 180 dias. Consumos de até 95 kg/m3 de aglomerante. Produções acima de 500m3/h

A construção de Ilha Solteira e Itaipu podem ser consideradas como marcos no aspecto de adoção de planos ou sistemas de controle de qualidade de concretos CVC. As velocidades de concretagem atingidas em Itaipu, chegando a superar efetivamente a 750m3/h, foram possíveis de ser atingidas suportadas por um plano de controle adequado.

O plano de controle adotado nessas obras foi análogo ao mostrado na Figura 01, e descrito mais à frente.

Desta maneira ao se observar referências bibliográficas que citam como vantagens do RCC como a de reduzir o consumo de aglomerante, pela translação da idade de controle para datas mais velhas do tipo 180 ou 360 dias, ou ainda pela velocidade de construção, isso deverá estar muito mais associado à dimensão de uma determinada obra do que a uma metodologia ou rotina de controle.

Atualmente o Brasil se situa entre os 5 maiores construtores de Barragens de RCC, tendo estabelecido práticas próprias calcadas nas dificuldades, características e potencialidades de suas dimensões territoriais, bem como suas adversidades econômicas e seu estágio de desenvolvimento técnico e de capacitação profissional de seu trabalhadores.Observa-se, então, **que não há necessidade de estabelecer recordes**.

Por outro lado a construção de RCC se caracteriza por sua simplicidade, e não por uma oportunidade de deixar de executar determinados procedimentos. **É uma técnica de construção de se fazer com simplicidade e não a de se fazer mal feito!**

RCC may be considered **[XX-COE]** for application where no-slump concrete can be transported, placed, and compacted using earth and rock-fill construction equipment. RCC bas developed over the past 20 years in response to the need to provide more economical mass concrete structures. RCC is replacing conventional mass concrete as the primary construction material for gravity dams and has become a viable alternative material for structures other than dams. Ideal RCC projects will involve large placement areas, little or no reinforcement, little or no embedded metal work, or other discontinuities such as piles. Application of RCC should be considered when it is economically competitive with other construction methods. lt may be used in lieu of conventionally placed concrete in concrete gravity or arch-gravity dams. For many dam projects, the use of RCC may allow a more economical layout and project features such as an over-the-crest spillway as opposed to a side-channel spillway. RCC construction techniques have made RCC gravity dams an economicaily competitive alternative to conventional concrete and embankment dams.

Isso evidencia que a aceitação inicial do RCC foi mais contundente em barramentos de reservatórios onde a perda d'água não era a consideração mais importante. O emprego do CCR para barragens em hidroelétricas entretanto foi mais contestado, não tendo ocorrido uma aceitação imediata.

Pode-se observar que do total de barragens executadas em todo o mundo cerca de 35-40% destina-se ao cenário das hidroelétricas, sendo observado um crescimento no uso do CCR para uso em projetos hidroelétricos.

Ano	***1985***	***1990***	***1995***	***1998***
Total (aproximado) de barragens em CCR	30	70	185	210
Percentual de hidroelétricas com barragens em CCR	25,8	30,0	38,5	39,5

Nas Hidroelétricas, deiferentemente de outros tipos de barramentos, pode haver a necessidade de se colocar vertedouros com comportas sobre a barragems (para controle de grandes vazões, como no caso de Salto Caxias, que possui um vertedouro com capaciadade para 49,000m3/s)

A colocação do Vertedouro, com comportas de controle sobre uma barragem, tem implicações de ordem cronológica, devido ao tempo requerido para a construção dos Pilares em CVC, bem como as respectivas montagens hidromecânicas, criando então um conflito programático.

Complementarmente a existência de pilares, comportas, etapas de construção implicam em:
- ✓ Cuidados na otimização dos acessos;
- ✓ Cuidados no dimesionamento de recursos (equipamentos e mão de obra);

- ✓ Cuidados na otimização de formas;
- ✓ Cuidados nas etapas construtivas;
- ✓ Cuidados na qualificação das equipes (devido à atividades distintas);
- ✓ Cuidados em planejar o uso de materiais para todas finalidades –CCV e CCR, e outras aplicaçãoes (ensecadeiras, aterros, etc..)

Todos essas dificuldades, sem dúvida alguma, introduzem custos adicionais e dificuldades cronológicas. Há a necessidade de se buscar uma " **melhor Engenharia- engineering**" nesse aspecto. O uso de RCC nessas situações requer uma maior reflexão.

A quality RCC product requires a coordinated effort between the structural designer, the planning engineer, the materials engineer, the materials laboratory, and those responsible for field quality control and quality assurance.
Na referência **[YY**]- "Concrete Manual"- em sua 8a. edição (cuja primeira edição é de 1936) cita (tradução):

"….A produção uniforme e econômica de um concreto depende em grande parte da inspeção na central de dosagem e mistura do concreto. Os ajustes são feitos com base nos resultados das granulometrias e dos ensaios de umidade dos agregados. Os teores e seqüencia de introdução dos materiais nos misturadores, em como o tempo de mistura são verificados frequentemente de maneira a minimizar as variações…
Por sua vez a referência **[ZZ]-** o "ACI Manual of Concrete Inspection"- em sua 6a. edição (cuja primeira edição é de 1941) cita (tradução):

"…O objetivo da inspeção é o de assegurar que a "boa prática" na construção das obras, é seguida em cumprimento ao Projeto e Especificações Técnicas", e não o de estabelecer essas práticas…"

As citações nesses documentos, já com mais de ½ Século, expressam o desejo e a acertiva de um Controle de Qualidade.

Dessa maneira, sendo o desejo comum e tão antigo, qual a razão para que esse conceito não seja intrinseco de todos os parceiros e colaboradores de um empreendimento ? Onde reside a dificuldade desse senso comum?

2- DESIGN AND CONSTRUCTION CONSIDERATIONS

O Projeto deve estabelecer condições de funcionalidade e operacionalidade do empreendimento. É o que faz transformar a ***<u>idéia</u>*** na ***<u>realidade.</u>***

Nessa transformação deve ter salvaguardas nos pontos estatísticamente vulneráveis, e/ou de importância relevante.

As Normas de Medição e Pagamento devem condicionar os acertos-premios e erros-multas.

O conhecimento de **<u>todas</u>** as propriedades dos materiais envolvidos e utilizáveis no Projeto-Construção deve ser dominado, em uma escala em que não ocorra risco.

2.1-RCC Mixes- Requirements:-To achieved the highest measure of cost effectiveness and a high-quality product comparable to what is expected of CVC structures, the RCC design should avoid, as much as possible, multiple RCC mixtures, and other construction or forming requirements that tend to interfere with RCC production; and the design should not require complex construction procedures.

2.2-Facing Techniques:-It may be necessary to provide a durable exposed surface. Cast-in-place CVC concrete or other system**[Pa-Chi]** will also provide increased watertightness for the upstream face as well as increased resistance to erosion and damage by freezing and thawing. The design for any water-retaining structure constructed using RCC, however, should not put primary reliance on an upstream facing system to protect against seepage. The design for providing watertightness of the structure should rely primarily on the RCC itself; on proper mixture proportions, lift surface treatments, and RCC placement, spreading, and compaction techniques. The CVC concrete used as face also provides a medium for installing contraction joints with waterstops and joint drains.

2.3-Seepage Control and Drainage:- One of the most important design considerations for RCC dams is the control of seepage. Excessive seepage is undesirable from the aspect of structural stability, possible long-term adverse effects on durability, adverse appearance of water seepage on the downstream face, and the economic value associated with lost water. Properly proportioned, mixed, placed, and compacted RCC should make as watertight a structure as CVC concrete. In addition to strength requirements, hydraulic structures must be designed to minimize seepage, to control uplift pressures, and to assure long-term durability. The joints between RCC lifts are the major pathways for potential seepage through an RCC dam. Seepage can be controlled by incorporating appropriate design and construction procedures (bedding mortar, contraction joints with waterstops, draining and collecting seepage water). Collection methods include vertical drains with waterstops at the upstream face and vertical drain holes drilled from within the gallery near the upstream ar downstream face.

2.4-Galleries:-For any major high-head (higher than 12-15m **[MIGUEL]**) dam a gallery is necessary to provide a location from which to drill drain or grout holes, to provide drainage for leakage, and to provide access for inspection. Several different gallery designs have been tried in RCC construction**[MIGUEL]** . Galleries in dams must be located to provide adequate space for RCC placing and compaction equipment in all areas adjacent to the gallery.

2.5-RCC Permeability and Durability:-Conventional cast-in-place or precast air-entrained concrete facing elements of adequate thickness can be used to protect the RCC from damage due to freezing and thawing.

The permeability ar watertightness of concrete may be of more concern than the strength, especially with respect to hydraulic structures. The factors affecting the permeability of RCC are essentially the same as those that affect the permeability of CVC concrete.

2.6-Thermal Control and Cracking:-Temperature-control measures for RCC typically will be quite similar to those used for CVC. These measures include limiting heat evolution, using insulation, requiring night-time placement, and limiting placement to cool weather. The large RCC surface areas cannot be efficiently protected from high ambient air temperatures, drying winds, and absorption of radiant solar energy and, thus, can experience greater early heat gain and more subsequent contraction and cracking. Precooling and/or postcooling techniques may not always be practical for RCC placements.

The extent of thermal cracking in an RCC structure will be affected by the type and degree of temperature control used. The selection of cement and fly ash proportions will significantly affect the heat of hydration and subsequent thermal cracking. To reduce temperature rise, low-heat-of-hydration cement, and the maximum pozzolan replacement of cement consistent with strength requirements, are generally used.

As in the case with most nonreinforced concrete structures, cracks do occur in RCC structures, and, if the structure involved is a dam or other water retention structure, leakage will also occur. Cracking may occur despite measures taken to prevent cracking. The possibility of unplanned cracking should be anticipated in design by providing for drainage conduits and sumps where necessary to remove water from the structure.

2.7-Contraction Joints:- Placing vertical transverse contraction joints in dams constructed with RCC and installing waterstops in these joints near the upstream face should be considered for crack control. The number and placement of these formed construction joints can be determined by a thermal study, construction considerations, and by examination of the foundation profile parallel to the dam axis. Joints should be considered where changes occur in the foundation profile (or where the RCC different construction steps can induces different modulus of elasticity, due to different ages) which may cause a concentration of stresses.

lf transverse contraction joints are used, standard or new developed waterstops should be installed in an internal zone of CVC at the joint near the upstream face. Designers must carefully consider the construction details for such features when RCC is specified, to minimize the impact of these features on the RCC placement process and to assure that these features will perform as intended.

2.8-Mechanical Properties:-RCC structures are generally unreinforced and must rely on the concrete strength in compression, shear and tension to resist applied loads as well as internal stresses caused by non-uniform temperatures (gradients). The compressive strength of concrete is high enough, and seldom a limiting factor in structural design. Unreinforced RCC, as is the case with unreinforced CVC concrete, has, limited capacity to resist shear and tensile stresses. Therefore, RCC structures are generally designed so that tensile stresses do not develop under normal operating conditions during the life of the structure.

The RCC construction process results in horizontal lift joints intervals. The strength at untreated lift joint surfaces is generally lower than that of the parent concrete. Therefore, mixture designs, placement procedures, and quality control measures to assure maximum bond and strength at the lift joint surfaces are important. Test data from constructed projects indicate that RCC joint strengths are sensitive to:

I. The time interval between the placement of successive lifts;
II. The water and cementitious material content (cement plus pozzolanic mterial);
III. The joint surface condition and treatment used.

ln general, the application of joint treatment (bedding mortar) and rapid placement of successive lifts will produce higher joint strengths. The design values for joint cohesion and tensile strength must be based on a laboratory test program.

2.9-Elastic Properties (Modulus and Creep):-Cracking in RCC structures normaly were considered due to the Thermal behavior, but sometimes they can be induced by creep deformation. Due to the construction speed, or some deflexion in the foundation plan or eventhought in RCC step, can induces differential deformations (setlement) that can causes shear effects, and consequently some cracks. This fenomena is sometime observed in CVC construction, but is normaly solved by using an adequated reinforcement. In RCC construction this fenomena need be well considered in the design. The adoption of a transverse contraction joint can be usefull.

2.10-Special Surface Treatments For Erosion Protection:-Concrete erosion is a major concern and must be considered when designing spillway aprons, stilling basin channels, and other concrete surfaces subject to high velocity flows, or when designing concrete surfaces exposed to the action of abrasive materiais, such as sand gravel, ar other waterborne debris. Erosion damage of concrete surfaces can be caused by cavitation or abrasion.

2.11-Anchorage Reinforcement:-It becomes necessary at times to embed reinforcing steel in the RCC for the purpose of anchoring various structural features and appendixies. These structural features could be intakes for outlet work, training walls for spiliways, parapets, etc. The anchorage of these features to the RCC structure can either be accomplished by installing the rebar during RCC placement, or by drilling and grouting the rebar in place foilowing RCC placement.

3- INVESTIGATION- SELECTION OF MATERIALS – RCC MIXES

3.1- Materials:-The required amount of material passing the 0,075mm (No. 200) sieve is greater for RCC than is acceptable for CVC **[Pa-Chi]**. The larger percentage of fines is used to increase the paste content in the mixture to fill voids and contribute to compactability. The additional fines are usually made up of naturally occurring nonplastic silt and fine sand, or manufactured fines. The use of extra pozzolanic material in lieu of natural fines passing the 0,075mm (No. 200) sieve was successfully used in various projects.

The cementitious materials should conform to the adopted standard quality requirements. The pozzolanic material can replaces the fines required, but need be evaluated in technical and economical basis. Water and admixtures (if used) should conform to the adopted standard quality requirements.

3.2-Workability and Density

The workability of RCC is the property which determines its capacity to be placed and compacted successfully without harmful segregation. It embodies the concepts of compactability and to some degree moldability and cohesiveness. It is affected by the same factors that affect the workability of conventional concrete, that is, the grading, particle shape, and proportion of the aggregate; the cement content; the presence of chemical and mineral admixtures; and the water content. However, the effect of each factor will not be the same for RCC as for conventional concrete.

3.3-RCC Mix Proportioning

A prática de dosagens e conceitos brasileiros, através do uso de adequado teor de finos, fez cair por terra as singularidades proclamadas por alguns autores, sobre os conceitos de dosagens com **"Alto teor de Pasta", "RCD", e "Pobre"**, evidenciando simillaridades entre praticamente todos os procedimentos e rotinas de dosagens.

O emprego de dosagens de **"Elevado (*ou Adequado*) Teor de Finos"**, mostrou **[CHI-PA]** através dos dados de controle do CCR em Salto Caxias **[Douglas]** uma evolução das características resistentes, praticamente inédita, e superior as evoluções de resistências de várias obras de CCR e de CCV massa, como evidenciam as Figuras 02 e 03.

Figura 3.1- Evolução da resistência do CCR de Salto Caxias comparada às de outras obras em CCR.

Figura 3.2- Evolução da resistência do CCR de Salto Caxias comparada às de outras obras em CCV.

É importante salientar que boa parte dessa evolução pode ser creditada aos efeitos de ação pozolânica *"moderada"* do Pó de Pedra.

O procedimento brasileiro de dosagem do CCR, para barragens, tem possibillitado que se use, apenas, cerca de 4% (em peso) de material externo ao local da obra. Isso implica em significativas vantagens de custo e de logistica de suprimentos.

A busca da otimização dos consumos de aglomerante e o emprego, preponderante e quase que sistemático do "Pó de Pedra" (cerca de 75% do volume de CCR nas obras brasileiras, até o momento, contem finos de Britagem), tem mostrado benefícios, mas que aínda podem ser melhorados.

O emprego de aditivos plastificantes- retardadores, mostrou-se benéfico que tanto do ponto de vista técnico como econômico **[Douglas]**.

O diâmetro máximo dos agregados tem a tendência de ficar entre 76 e 50mm, sendo que até o presente 85% das obras tem usado $\mathbf{D_{max}}$ inferior a 100mm

O conhecimento de propriedades, a obtenção de uniformidades como citado em alguns trabalhos, são argumentos que incentivam, ainda mais a otimização dos consumos de aglomerante, dentro de condições de segurança e qualidades orientadas por ensaios e controles.

4- CONSTRUCTION PLANNING - EQUIPMENT AND TECHNIQUES

4.1- Plant Requirements:-The batching and mixing plant requirements for a project to be constructed of RCC are essentially the same as for a project built with conventional concrete. The production, stockpiling, and retrieval of aggregate from the stockpiles are done in the same way and with the same equipment as for conventional concrete. Experience indicates that a forced mixers produces faster and more effective mixing and can be used for production of various concrete type.

4.2-RCC Placement Rates:-One of the cost-saving features of RCC is the rapid rate at which it can be placed and consolidated by earthmoving and embankment compaction equipment.

4.3-Transportation:-RCC that is properly proportioned can be hauled from the mixer or from the distribution point by a system that not introduces an unacceptable segregation

4.4-Placement:-The lift thickness should be determined by the designer and specified in the project specifications. The most important factor governing the placement and performance of RCC is the selection of mixture proportions. Next in importance are the dumping, spreading, and compacting of the RCC.

4.5-Spreading RCC:-The design of dams where lift thicknesses greater than 300mm have been used has been based on the realization that the constant spreading of the RCC with heavy dozers not only remixes and redistributes the concrete in such a way as to eliminate (ar overcome) segregation, but also provides most of the required compaction. This also results in the paste and mortar becoming thoroughly distributed in the mass.

4.6-Compaction:-Each lift is compacted using a vibrating steel-wheel roller. lt has been determined from various test sections and actual construction projects that RCC can be adequately compacted using a variety of vibratory compactors. The roller speed has a important effect in the compaction **[Luiz Fernando].** A uniformidade ao longo de toda a profundidade das camadas tem sido motivo de avaliações e adaptações de procedimentos de controle, como citado em**[Luiz Fernando]**.

4.7- Lift Surface Moisture Maintenance:-At the compression of rolling, lift surfaces should be moistened and kept damp at all times until the next lift is placed or until the required curing period has ended. This is very importantin hot wether condition.

4.8-Lift Surface Preparation:-The required lift surface preparation prior to the placement of the overlying lift of RCC depends to some extent on the construction procedures and sequence being used. In all cases the surface of the underiying RCC lift surface must be constantly maintained in a moist condition commencing immediately foilowing compaction; as necessary, the lift surface should be cleaned prior to placement of the next lift. The cleanup should include the removal of all loose material, debris, standing or running water, snow, ice, oil, and grease.

4.9-Lift Joint Bedding:-As previous mentioned the design of RCC structures where watertightness and bonding are required between lifts must require the application of a bedding mortar over the entire surface area between ali lift placements.

4.10-Bedding at Rock Contact:-lt involves the spreading of conventional con crete mixtures at the dam foundation abutments

5- CONTROLE DE QUALIDADE

No Brasil, tem-se procurado a busca pela uniformidade, e não somente a atenção pela "numerologia" de dados. É dada uma atenção maior quanto à**Inspeção**, muito importante nesse tipo de construção.

5.1- The Need for Quality Control:-Who does not want assurance that the concrete job with which he is concerned will be of the quality necessary to give good performance and the appearance of quality throughout its intended life? Probably no one!.

The designer wants it; his reputation and professional satisfaction depend on it. The contractor wants it for much the same reason, but sometimes there are adverse influences such as time and money problems. The owner wants it; his money is in the project and he has to live with what he gets. Any governmental agency having surveillance responsibilities wants it for the general good of the public, and of its reputation.

- ✓ Why then, if all responsible parties concerned want quality, don't have it automatically?
- ✓ Why do need to consider what it takes to get and assure quality?
- ✓ Perhaps the answer lies in the inadvertencies which are not uncommon in construction activities.
- ✓ Perhaps it lies in the deterioration many have noted in pride of craftmanship.
- ✓ Perhaps it is something inherent in human nature and culture.
- ✓ Perhaps it is because some are no different today that we need to do something special to insure quality in concrete construction.

Quality control and resulting assurance is no different on concrete construction work. Basically this is inspection and the related testing of materials and concrete. It is however, more than making a few slump tests (CVC construction) or consistency (RCC construction) and cylinders for strength tests. In addition to the full scope of the duties and responsibilities of the inspection and testing staff, if they are to be effective it must also include all that may affect them in that effort.

5.2- The Need for Inspection :-The reason for having inspection is to assure the requirements and intent of the contract documents are faithfully accomplished. The term ***inspection*** as used in concrete construction includes not only visual observations and field measurements, but also laboratory testing and the assembly and evaluation of test data.

One important responsibility for the concrete inspector is the quality of the materials used in the concrete. However, the final materials entering the concrete mixture must be of specified quality. It is difficult and usually impossible to produce specified concrete from nonconforming materials.

On the other hand, a principal ingredient needed for specified concrete construction is good *quality workmanship* in all operations and processes.Manual skills, technical knowledge, motivation, and pride of workmanship -all contribute to good workmanship, which is the real key to quality concrete construction. Workers in concreting crews may have been exposed to some technical training but seldom adequately. Many workers have pride in their work and do make an attempt to attain satisfactory quality. However, the need to stay within cost limits often requires an emphasis on production rate.Credibility, statistical knowledgements, records routines are very effective and efficient where properly applied.

5.2- Quality Plan

An Overall Quality Plan or System for a construction can describes in general terms the overall Quality Control System used for the a Project with emphasis on:

- The quality objectives to be attained;
- The specific allocation of responsibilities and authority during the different phases of the project;
- The specific procedures, methods and work instructions to be applied;
- Suitable testing, inspection and examination at appropriate stages;
- A method for changes and modifications in a quality plan as project proceed;
- Other measures necessary to meet objectives.

The Quality Control System intents to increase the quality and productivity of the works and reduces costs. It must be designed to prevent and eliminate or reduces mistakes during the construction works, and provide repairs, if and when mistakes occur. The design of a structure should be accomplished with consideration of what measures will be required to insure that the required quality is attained. It is obvious that the design of projects where little quality control is anticipated should be more conservative than the design of a project where a very effective quality control program is anticipated.

While quality control is customarily considered to be an activity performed during RCC placement, it is also important that quality control issues be considered during design, planning, and the initial phases of construction of an RCC project, as previously mentioned.

Procedures need be established, maintained and documented in order to perform, verify and report that the service meets the specified requirements. The reliability, availability and maintainability of the operation need be monitored and reported.

A viable Quality Control System should consider the numerous construction operations basic not only to RCC but the CVC, also, and how they are performed. Preparation and advance planning are key to success and quality construction.

The Overall Quality Plan must be adjusted to the local conditions taking in count the workman labor performance, equipment and technical knowledge, as presented in **[MUSSI]**.The control can be based on the following main items:

- A qualified team;
- Adequate and modern technology;
- Adequate equipment and facilities;
- Elimination of mistakes and defects;
- Monitoring of the process;
- Standardizing

All data and information relative to the Quality Control System must be collected in a standardized routine and accurate manner.

RCC placing rates can be extremely high when compared to conventional concrete. With such rapid placement rates or short term construction periods, problems must be evaluated and solutions implemented in a short period of time. Any problems which delay RCC placing essentially delays all production. The most common placement delays are usually due to problems caused by:

1. Insufficient materials
2. Foundation preparation and cleanup
3. Joint cleanup
4. Equipment breakdown
5. Weather condition (hot or cold ; wet or dry; rain)

It must be assured that all personnel are correctly selected, trained, qualified and motivated so that the results anticipated by the company will be attained and even surpassed. Based on that was described above, it can be suggested that before start the works a "Quality Control Plan" and a "Manual for Quality Control" as used for Concrete Quality Control during Itaipu Project construction, can be adopted. This "Manual" can proposes measures which include the following basic points:

- Be aware of possible problems;
- Anticipate possible corrections;
- Guarantee quality;
- Seek modifications and improvements;
- Be objective, dynamic and compatible with the pace of construction;
- Controls must include materials and concretes (RCC and CVC);

For an overall view of the scheme that can be adopted Figure (5.01) shows a flow chart of actions with the following points:

Action 1 - Pre-qualification and knowledge-This corresponds to the stage of initial studies, knowledge and selection of materials and suppliers.
Action 2 – Informations for handling.
Action 3 - Control of arrival (delivered) of material- This action seeks to guarantee quality and uniformity of the material and products, based on pre-qualification data. These tests are proven by certificates, and will be performed by each supplier.
Action 4 - Control during production - This action is to evaluate the points or procedures that could be vulnerable during production.
Action 5 - Control of application- This point consists of disciplinary actions during production.
Action 6 - Inspection during execution- This action will have the function of evaluating the best procedures for executing the works.
Action 7 - Structure commissioning- This will have the function of formal commissioning of each stage of structures or services.

Figure 5.01- Quality Control Actions

In addition to inspection activities, a comprehensive RCC quality control program should monitor the aggregate properties, RCC mixture proportions, fresh concrete properties, hardened concrete properties, and in-place compaction. An example of possible tests and test frequencies are given in **[1-Espanha angola**[9.02]**]**, that was successfully adopted during Capanda RCC Dam construction in

Angola. The frequency and extent of testing should be adjusted according to the size of the project, the sensitivity of the design to variations in quality, and the rate of RCC production.

Quality control of the material and concrete that was adopted for the Capanda Project, was the Constructor's responsibility. To perform these activities, a "Quality Control Plan" was devised, in order to comply with Design and Specifications requirements. Logistic conditions for construction of the Development were also considered such as, procurement of basic materials, distance from site to production centers, quantity and quality of labor available, schedules, and assurance of quality parameters compatible with the magnitude of the works.

The "goal" of quality control is to identify problems before they occur or sufficiently early in the process so they can be corrected. Monitoring and reacting to the trend in performance is preferable to reacting to specific test results. By continuously tracking trends it is possible to identify detrimental changes in material performance and initiate corrective actions. Further, it is possible to modify the frequency of testing based on trend performance.

Tests must be performed rapidly. The rapid placing rates and typical 20 or 24 hour per day construction timetables require careful attention and interaction between Quality Control testing, inspection personnel, and production personnel. Fresh RCC properties may vary with daily, weekly, or monthly fluctuations in ambient weather conditions. This, in turn, affects water requirements, compaction characteristics during construction, and the quality of the concrete. Normally, construction activities continue throughout a variety of warm, cold, wet, or dry ambient conditions. Quality Control System personnel should assure that continuous adjustments in moisture and, if appropriate, other mixture proportions are made continuously to adapt to these conditions.

Because of the rapid construction rates of RCC, a major disadvantage in the use of concrete test cylinder compressive strengths as a method of control is the time required to obtain results. Even more so than in CVC concrete, the use of concrete test cylinder compressive strengths as a method of control in RCC construction has a major disadvantage in the time required to obtain results. Because of the rapid rate of placement in RCC construction, and the fact that layers of material can be covered with new lifts within hours, test cylinders serve as record data for quality assurance and are not an effective method of day-to-day quality control.

Emphasis on thorough control of materials (gradation, cementitious content, and moisture content) and conditions during placement is essential to proper RCC. An advantage of RCC and the above approach is that unacceptable material is identified early and can be removed at relatively low cost.

It is important that qualified personnel be in close contact with the mixing plant at all times to maintain water contents at the optimum level for compaction. The control measures that should be instituted in RCC construction are essentially material dependent.

5.3 – Materials:- What inspection and testing then is necessary to provide the quality desired?

This may be divided into material-acceptance testing, concrete production inspection and testing, and inspection of concrete placement and other aspects of construction. Together with these go sufficient record-keeping to show what was done and what was obtained. The extent to which each is carried out may vary somewhat in accordance with the size and importance of the job, but this should only be in degree as each is an element in getting quality, regardless of size of job.

Concrete materials other than aggregates can be accepted on certification of the producer but it should be required that these certifications be accompanied by a copy of his test results showing that the cement, pozzolanic materials, or admixture does in fact meet specification requirements. Random samples of delivered materials can be taken, possibly at one month intervals more or less as experience may indicate advisable, and tested for conformance with certification tests.

Cement can be accepted on manufactures certification, or the suppliers may be required to be "pre-qualified" (see **Action 1** - Figure (**5.01**)).Admixtures can be accepted on manufactures certification, or the suppliers may be required to be "pre-qualified", also (see **Action 1** - Figure (**9-01**)).

The quality and grading of aggregates significantly affects the fresh and hardened properties of RCC. The grading of both fine and coarse aggregate affects workability, and the ability to effectively compact or consolidate RCC. In addition to standard gradation analyses, high fine mixtures also require testing for limits of liquid and plastic index. The aggregate source, whether a new on-site source or a commercial off-site source, should be inspected and approved in advance (see **Action 1 -** Figure (**9-01**. An increase or decrease in moisture of only a few tenths of one per cent can change the compacting characteristics of RCC. This is mostly affected if large amount of fines is used **[Douglas]**. Overly wet stockpiles limit the available water which may be batched as ice if (normally is not) cooling is required.

P.V.C. Membrane if used as element for impermeabilization of upstream facing, can be controled through factory samples taken before this was sent to site. The same as for PVC membrane, the Quality Control Plan for waterstop can determined that Delivery factory samples be taken of the water stops before these were sent to site.

5.4- Proportioning and Mixing

As with conventional concrete, equipment used for volumetrically proportioning or weight batching of RCC must be carefully calibrated to meet project requirements. This calibration must be maintained throughout the construction period. Experience has shown that the appearance of freshly mixed RCC alone does not provide an adequate indication of the thoroughness with which the material has been mixed. A mixture with homogeneous appearance may not have cement well distributed. A mixture with virtually no cement may handle and appear the same as a lean mixture with cement. Mixer efficiency tests are needed to establish initial minimum mixing times (or retention times for continuous mixers) and maximum mixer loading. Periodic verification of the mixing time should be made during construction by additional tests.

Evaluating RCC mixture proportions has two main aspects:

- ✓ First is establishing that materials enter the mixer with the desired proportions.
- ✓ Second is evaluating the workability of the RCC and the uniformity (or variability) of the mixture proportions after it leaves the mixer or after it has been placed.

5.5- Calibration

5.5.1-Batch-type Plant:- Modern batch-type mixers are relatively straight forward to calibrate and operate. The primary concerns with RCC are matching aggregate feed rates and storage capacities to high production rates, finding the best batching sequence for each mixture, and getting all materials uniformly blended with a reasonable mix time. The combined charging, mixing, discharge, and return time determines the maximum production rate. Mixture proportions are input from manual or computer controls and typically are recorded by load cells.

5.5.2-Continuous mixing Plant:- Continuous mix plants ate relatively easy to calibrate and operate. Mixture proportions are converted to a continuous feed rate in tons/hr (kg/hr). Materials used for calibration tests are accumulated over a fixed period of time rather than being measured individually for a separate batch. As with batch type plants, materials may be individually fed into mixer from separate bins or they may be accumulated on a common final feed belt. This is determined by whether the mixer has, for example, one belt for all aggregate bins or multiple belts with one for each bin. Calibration with just one belt operating may not be the same as when the plant is in full operation with all feed belts operating. Load cells or weigh bridges to provide weight controls rather than volumetric control, and computer print-outs have been used on some RCC projects but have not been necessary on other projects. Also, as with batch type plants, the mixer should be calibrated at the minimum, average, and maximum production rates expected.

Tabela de CV- Misturadores contínuos e por lotes

As with batch type plants, a diversion conveyor belt, or another equivalent system, is recommended to sample RCC at the plant without stopping the production on large projects.

Foto de amostrador

FIGURE 9.14- Sampler used at RCC Continuous Plant at Capanda dam-Angola

Variability tests can be used to establish minimum mixture retention times and the effectiveness of the mixer feed procedure for both batch and continuous type mixers. They also are used to determine the more important issue of how well and uniformly the RCC is mixed at the placement after it has been delivered and spread.

5.6- Quality Control of RCC During the Production

Mix design and statistical data on RCC mixes mainly used in the dam construction and their respective control parameters are shown in Figure (5.01).

Figura 12 do Texto capanda

Figure 9-17- Statistical Data for Control of RCC produced at Conventional Gravimetric Plants (Batch) and at Continuous Mixing Plants with Gravimetric Batchers (Pug-Mill) [9.10].

To check homogeneity of cement proportioning or mixers efficiency, daily tests were made with reconstitution of cement contents in the RCC fresh mix. This correlation was called test calibration standard. Data obtained during control made through this determination are shown in Figures (9.18), that also shows the results obtained in other RCC applications[9.13 to 9.16].

Figura 13 do Texto capanda+ JORDÃO e SALTO CAXIAS

Figure 9-18-Reconstitution data of Capanda RCC Cement Content compared with contents of other applications. Note the proximity of the values measured, compared with the theoretical values when using Gravimetric Batch [9.10]

Once concrete proportions and cement content have been selected for the strength required and are being batched uniformly from the same aggregate, the consistency of the RCC is the primary item for inspection and control. A variable consistency is likely to add to variation in concrete strength. Excessive consistency usually decreases strength through increase water-cement ratio or stratification. RCC of insufficient consistency, is likely to lead to poor compaction.

The VeBe apparatus used to measure the consistency of no-slump CVC concrete is used to measure the consistency of wetter RCC mixtures. It provides an indication of the workability or ease of consolidating the concrete in place. When it is used for the wetter types of RCC mixtures, typical VeBe times are 10 to 30 seconds.

It was tried to check the influence that non applying the overload would have to this test results by making tests with the same sample of RCC this indicating a smaller dispersion in tests made with overload. Technique achieved with the Capanda RCC did "**NOT"** produce evidence of absolute applicability of this method, probably due to low plasticity of the RCC, due to the cement content adopted and different cohesiveness of fine aggregate type and content also. It was found that extreme remolding- consistency time values do not always correspond to RCC with deficient compactability.

The moisture or water content is important for several reasons:

- ✓ to determine the W/C or W/(C+PM) ratio on projects that may use it in design or design specification requirement;
- ✓ to assure the optimum or desired moisture content for workability and compaction, and
- ✓ as one of the indicators of mixture variability.

Some moisture test methods are:

(a) Chemical tests (ASTM C-1079)
(b) Drying tests (hot-plate, oven, microwave)
(c) DMA- Brazilian Method of Test
(d) Nuclear tests- mostly useful for compaction control during the RCC placement

Pacelli and al [9.17] developed a very simple and rapid method of test to determine the water content and unit weight of RCC. Aiming to establish an alternative to usual methods, a procedure for controlling the unit water of RCC and the unit weight of fresh concrete has been developed. Such method, known as " Water Measurer Device - WMD (DMA in Portuguese), allows the prompt control of unit water during the RCC fabrication.

This method has been conceived having as physical principle, the density of materials compounding concrete. That is, as water is a material with lower density, the more water in a RCC mix, the lower the density.

5.7 – Grain Size Curve Reconstitution of RCC Mix

The RCC mixes used in Brazilian RCC Dams, were proportioned with aggregates having specific gravity of about 2,65-2,95 t/m3, combined so as to obtain the smaller void index. To achieve this, a reference grain size curve was initially adopted for aggregates as follows:

$\mathbf{P = (d/D_{max})^{1/3} \times 100\%}$ where

P = Percent Passing;
d = size of the sieve (mm)
D_{max} = MSA (mm)

Figure (5-XX) shows grain size range specified for the RCC, together with the ranges effectively obtained and their dispersions, in batch and continuous mixing plants. The grain size range specified was determined by the equation mentioned before, with small adjustments for fractions less than 0.3 mm.

Figura 14 do Texto capanda+ JORDÃO e SALTO CAXIAS

Figure 5-xx- Granulometric curves for RCC Mixes from reconstitution tests. Note the proximity of average values compared with theoretical value used

The use of per batching proportioning instead continuous type permits to eliminates this type of control.

5.8- Molding of RCC Cylindrical Test Specimens and Compressive Strength

RCC test cylinders (150mm by 300mm) should be made using procedures suited to the consistency of the mixture, the maximum size aggregate (MSA), and the number of samples to be made before the mixture begins to dry out. Test specimens should be compacted in rigid molds or in removable liners supported during compaction by rigid molds. Wetter consistency mixtures with a VeBe time less than about 30 seconds are well suited to consolidation. The RCC is consolidated in three layers. Other surcharges and modifications have also been used.

The great importance of this care and correctness in all the operations of making concrete strength tests cannot be overemphasized. In most acceptance confrontations the indicated strength of the concrete is the deciding factor. Usually other questions can be worked out if strength tests are good. If they are not, there is a real problem. So it is important that they not be low due to carelessness and ineptness in sampling, molding, curing, and testing. Aside from dishonesty, there is little that can be done to make a test cylinder stronger than the potential of the original concrete. But there are many things that can reduce its strength. Well practiced and supervised persons should do this work with care to see primarily that the sample is truly representative and that the cylinder specimens are evenly filled and fully consolidated without voids or rock clusters in any portion; that they are kept wet with visible moisture on the surface at all times and in moderate room temperatures until testing; that capping for testing should be strong, thin, precisely flat, and especially not convex. This need for perfect planes applies also to the two loading surfaces of the testing machine. Convexity or other irregularity of end surfaces has seriously reduced test values and caused needless trouble and concern on too many occasions. **Don't let it happen to you! Eternal vigilance is the price of success in concrete construction just as it has been the price of liberty in the history of mankind!**

5.9- RCC Quality Control During Placement

RCC methodology has established the convenience of adopting additional controls on site during placement and compacting phases.

Appearance tells much of how well the work was done but by no means all. And if it is not what it should have been, it is too late to do much about it. Unlike the neatly tabulated results of strength tests in proof of the quality attained, the often hidden good results of construction inspection are not readily documented even though daily shift reports are required. Accordingly, construction inspection will encourage quality by seeing and approving or disapproving, step by step, while action can still be taken if necessary for corrections.

The inspector on the placement operations should watch all details that are related to the overall success of RCC placement operations. The following list indicates some of the items to be checked:

a. Lift surfaces have been adequately cleaned prior to placement of bedding mortars or RCC;
b. Bedding mortar is placed at the required thickness and correct consistency and is adequately spread;
c. RCC is deposited, spread, and compacted only on fresh bedding mortar that has not begun to dry or set;
d. RCC is deposited on lift surfaces in the proper location and spread in the required layer thickness, and the action of the dozers is controlled in a manner to eliminate voids and ensure proper compaction;
e. RCC as it is deposited and spread is of the required workability as determined by the VeBe tests and by observing spreading and compaction operations;
f. Compaction of the RCC occurs while RCC is still fresh and has not begun to lose workability;
g. Lift surfaces are maintained in a moist state at all times;
h. Internal vibration at interfaces between RCC and CVC concrete is in the right location and done correctly with immersion vibrators in the right number and adequate size and for sufficient duration;
i. CVC concrete is deposited and consolidated in those areas where it is required such as around waterstops and drains, against abutments, and other locations as shown on the plans;
j. Installation of contraction joints if required, is completed prior to compaction by rollers and before RCC has begun to lose workability;
k. The passes in a specified translation speed for the vibratory roller on each lift of RCC are obtained.
l. All testing, including VeBe tests, nuclear density tests, aggregate moisture, and grading tests are taken, monitored, and evaluated.

5.10- Compacting Control - Density and Compaction Ratio

Most vibrating rollers have multiple frequency, amplitude settings and travelling speed. Frequency and amplitude may be displayed on the roller or indicated by “compaction meters” installed in the equipment. Normally, the vibration is interlocked with the motor drive and cannot be checked without the roller moving. Portable tachometers can be placed on the lift surface to test the equipment as it passes by. Amplitude is not easily tested in the field. This is usually a factory calibration test. If there is reason to believe the equipment is not working properly, the equipment manufacturer should be consulted.

Compaction is affected by the roller travelling speed. This condition must be considered during the RCC layer compaction and the speed need be recorded.

Low densities are the result of various deficiencies including high or low moisture, incomplete rolling, incorrect vibratory amplitude or frequency or speed time delay before rolling, poor gradation or segregation, and non-representative testing.

The in-place density of RCC layers can be determined using various procedures. It is however advisable that the procedure used enables not only determination of the compaction value but possibly a supplementary or corrective action of the compacting operation based on the results obtained. Therefore, process swiftness and safety are fundamentally important.

For the RCC used in Salto Caxias Dam, minimum required compressive strength was (f'ck) of 8 MPa, at age of 180 days, with a deficient quantil of 20% (reduced normal variable "t"= 0,84).

Caxias, Jordão etc..

Figure **(5.YY)** shows coefficients of variation obtained in the control of RCC for **Capanda, Salto Caxias, Jordão and Val de Serra**, compared with the same parameters for other projects, as well as with same control parameters for CVC mass concrete with cementitious content (cement+pozzolanic material) between 84kg/m3 and 134kg/m3, used in projects for Ilha Solteira Dam, Tucurui Dam and Itaipu Dam **[Livro].** Parameters of these conventional concretes refer to an universe of approximately 25,000 samples representing about 8,800,000 m3. Figure **(XYY**) also shows comparison values for coefficients of variation, for compressive strength for CVC concrete mainly used in those Projects.

Figura Livro + JORDÃO e SALTO CAXIAS

Figure 5-YY-

Quality performance of Concrete Plants, concrete and operators control may be evaluated from dispersion in the results for compressive strength obtained for the concrete produced by them. In the same way, quality of the strength tests may be evaluated from its own internal dispersion from control. Internal dispersion of the test is evaluated from the difference between the individual values obtained for strength tests in specimens of the same series, broken at the same age.

6- Summary and Recommendements

The following recommendations can be summarized:

I. Inspection is not an end in itself, but rather it is a part or subsystem of an overall Quality Assurance system;
II. The overall Quality Assurance system starts with essential and overriding social parameters that have to be considered and met;
III. The engineer should involve himself in these so as to be able to provide his input to influence the overall decisions;
IV. Where the engineer is given the responsibility for design, he provides his thinking as to what is needed in the drawings and specifications in order to provide the owner with the structure or plant that will perform the service needed at minimum cost consistent with the quality required;
V. Quality is more than quality of materials. It should be thought of as the quality of the finished project judged by how well it serves society: physically, functionally, emotionally, environmentally, and economically;
VI. Specifications should be in tune with nature and designed to provide clear requirements that can be met by reasonable men trying to do the work;
VII. Inspection comes into its own during the construction phase or subsystem. There are three basic approaches to conducting the construction operations:
    (a) Conventional construction where the owner is represented by the engineer and a contractor does the work - still the best approach in most situations;
    (b) Turnkey type of construction, most useful in very complicated and highly technical and specialized facilities;

(c) Construction-manager approach in which the owner delegates the managing of the construction phase to a construction manager, who may be different than the design organization, with a contractor doing the actual work - lack of continuity;

VIII. Quality Control by the various producers or contractor requires inspection as well as inspection for acceptance by whoever represents the owner;

IX. Inspection is, therefore, a key element in the construction phase;

X. Inspection is seeing that good construction in accordance with the plans and specifications is acco mplished;

XI. The inspector has to be technically knowledgeable in the field of inspection he is charged with;

XII. It can be expected all these qualities but have not insisted on proper training and attitudes, and have not been willing to pay adequately for this most important activity. It is time that proper training be required and commensurate pay be allowed for this work. Maybe a practical school with a degree in inspection can find a place in our educational systems;

XIII. Communication is the most essential element in inspection. Preconstruction conferences, and regular meetings during construction between all parties are essential to get the work done properly and expeditiously, to eliminate adversary relationships, and to maintain a team effort;

XIV. The inspector should be proud of his work and be a fullfledged member of the engineering team.

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