

# Roller Compacting Concrete “RCC” in Dams

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**Abstract**—Rehabilitation of dam components such as foundations, buttresses, spillways and overtopping protection require a wide range of construction and design methodologies. Geotechnical Engineering considerations play an important role in the design and construction of foundations of new dams. Much investigation is required to assess and evaluate the existing dams. The application of roller compacting concrete (RCC) has been accepted as a new method for constructing new dams or rehabilitating old ones. In the past 40 years there have been so many changes in the usage of RCC and now it is one of most satisfactory solutions of water and hydropower resource throughout the world. The considerations of rehabilitation and construction of dams might differ due to upstream reservoir and its influence on penetrating and dewatering of downstream, operations requirements and plant layout. One of the advantages of RCC is its rapid placement which allows the dam to be operated quickly. Unlike ordinary concrete it is a drier mix, and stiffs enough for compacting by vibratory rollers. This paper evaluates some different aspects of RCC and focuses on its preparation progress.

**Keywords**—Spillway, Vibrating Consistency, Fly Ash, Water Tightness, Foundation.

## I. INTRODUCTION

THE terminology of Roller Compacted Concrete (RCC) refers to its construction methodology. One of the most important parts of infrastructure is dams and is challenge to decrease the cost and increase its safety and workability. Three main properties of RCC dam make it unique throughout the other type of dams: high-speed construction, performance and economy [1].

The first performance of RCC has been used in 1974 and it was about a repair project of intake tunnel which was collapsed is the Tarbela Dam. Roller Compacted Concrete defines as a kind of concrete which compacted by roller and the mixture of this kind of concrete has to tolerant compaction (ACI 207. 5R-89) [1]. Roller compacting concrete has the ability such as either create new dams or repair old dams.

The most important parameters in design and sketching of dams are main body, seepage and excavation. Concrete dams are usually built on rock due to their massive weight. Rocks have high bearing capacity to resist gravity loads such as dams and very low coefficient of permeability and thus reduced seepage. A soil with a high coefficient of permeability permits water to stream underneath the dam. In the design of RCC dams with a strong foundation such as rock, there are no height limits. RCC dams have been manufactured at heights up to 156m. In selection of a suitable site, usually engineers try to find a rocks site with no shears and faults, as remediation to mitigate these problems can be very costly.

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Soils are considered to be the next important parameter at depths of 10 to 20m and the soil parameters have an extreme influence on the bearing capacity, settlement, (short-term and long-term). Therefore, shear strength efficient of parameters, deformation moduli, coefficient of permeability, poisons ratio and shear strength must be determined beforehand [2].

### A. RCC Construction

Slump properties of RCC are zero and the other properties are dependent on quality of vibratory roller compaction procedure. The properties of RCC have two main differences compared to the conventional concrete; consistency requirement and effective consolidation. The mixture should be dry enough to prevent sinking of the roller during the compaction and wet enough to distribute easily [1]. RCC dam is built layer by layer continuously from downstream like stair case. By placing a layer, initially hardening can directly support the equipment for the placement of the next layer and after depositing on the surface and spreading with small dozer. RCC tutorial for dams involve concrete placement in layers of 300 mm thickness for compaction. The RCC dam construction procedure is similar to gravity dam [3].

Normally, RCC is constructed without joints. It needs neither forms nor finishing, nor does it contain dowels or steel reinforcing. These characteristics make RCC simple, fast, and economical.

Transverse joints are inevitable every 15 m for preventing temperature cracks. And the high quality concrete is used at upstream and downstream parts of dam for creating a water-tightness connection and also resistance in cold weather against freezing and thawing action.

### B. General Considerations for RCC Dam

- Schedule
- Control of temperature
- Thickness of layers
- The capacity of aggregate sources
- Geography and geology, and
- Climate

One of the most important parts of dam construction is the age of arch. On this account, the volume of concrete can be reduced by using arch. In the 1950s one of the largest arch dam constructed in Japan was 110m high Kamishiba Dam. However, from 1950 to 1970 many arch dams had been constructed but the gravity dams are still constructed on good sites where arch dams cannot be used [4].

## II. FOUNDATION PREPARATION AND DIFFERENT FOUNDATIONS

The general tutorials of the RCC dams are similar to the gravity dams. But RCC dam design has got some exception on

the rock with low quality.

#### A. Dental Method

By selecting the bedrock foundation for RCC, cleaning has got significant consideration due to its connection between dam and foundation. In the excavation, all waste materials (such as weathered and loose material) will be removed.

And before placing RCC concrete the gathered water which used for washing along unsuitable materials have been removed in cavities operation. If the fragment rocks appear, excavation should be done at the minimum depth and for improving rocks try to use dental concrete techniques for filling. The domain of dental usage in geotechnical engineering is in filling or shaping holes, cuts, grooves and river channels.

#### B. Rock Foundations

The significant part of rock foundation related to its surface which in the steep surface cutting and smoothing are enviable. It can prevent the undesirable settlement and distribute stresses. On the other hand, it causes another problem like invisible cracks.

Geologic hammer is one of the common tests on rock foundation that can determine the degree of weathering. During this test the number of blows for breaking and the sound of rock have been recorded. Those rock foundation that exposed to the bad weather susceptible to unsuitable layers and according to the type of the rock can be accepted by removing.

#### C. Gravel Foundations

By considering the mechanical strength, Gravel foundation is appropriate for rock fill and earth dams. In this case, by using the drainage and barriers systems leakage should be controlled. However gravel foundations usually used on the river and dams should be able to decrease the river flows and may be floods.

#### D. Sandysilt Foundations

The other kind of foundation that can be suitable for earth fill dams is sand and silt foundation [6].

#### E. Clay Foundations

The positive part of clay foundation is the impermeability that drainage usage becomes unnecessary. On the other hand, the most important issue that these types of foundations are facing is stability. Moreover, the failure dangers during the saturation impose designers to consider the effect of foundation saturation on dam [12].

### III. RCC PROGRESS

The ordinary tutorial of RCC dam:

- 1) Concrete transportation from plant to the site should be done by simple machinery.
- 2) The dam surface should be flat that concrete transfer by trucks from dam ground hopper to pouring areas.
- 3) For vibrating concrete should be compacted by rollers.
- 4) The stiffness and workability of concrete is very

important due to compaction by rollers.

- 5) The thickness of concrete layers should be enough to compact by rollers.
- 6) For preventing of segregation concrete should be spread uniformly by bulldozers.
- 7) The quality of concrete in the up and downstream should be high due to water tightness and freezing thawing resistance.
- 8) For preventing the temperature cracks every 15 m of concrete should be cut by blades.
- 9) Mortar spreading and green cutting is manner for treating the layers surface to get great bond for water-tightness and shear stress [5].

### IV. RCC MIXTURE

RCC success directly depends on its mix design, therefore  $\alpha$  and  $\beta$  coefficients have been used to design. The  $\alpha$  coefficient related to the ratio of cement slurry to voids between fine aggregate and should be consider greater than 1. The  $\beta$  coefficient related to the ratio of mortar to voids between coarse aggregate and should be considered greater than 1 as well [5].

Based on the above information the appropriate  $\alpha$  and  $\beta$  ratios for conventional dam is 1.5 to 1.8 and 1.2 to 1.5 and for structural concrete is 2.1 to 2.4 and 2.0 to 2.3 respectively. By comparing these values the suitable  $\alpha$  and  $\beta$  for RCC dam is  $\alpha = 1.1$  to 1.3 and  $\beta = 1.2$  to 1.5.

It is worth to mention that the cement slurry volume is very close to voids between fine aggregates and it revealed that the cement content is about 110 to 130 kg/m<sup>3</sup> and also water content range is between 80 and 105 kg/m<sup>3</sup> for RCC.

#### A. Mix Design of RCC:

- 1) Determine maximum size which is usually selected as 80 mm.
- 2) Determine cement content which is usually selected as 120 kg/m<sup>3</sup>.
- 3) Determine fine aggregate (sand) ratio, which is between 30% and 35%.
- 4) Determine water content, usually selected as 80 to 100 kg/m<sup>3</sup>.
- 5) Strength and surface appearance of RCD (without honeycomb voids) were evaluated with the large specimen compaction device [5].

The mix design should meet the required design such as specific strength and durability for performance and stability [3]. The RCC mixture at the beginning of use of this method was lean mix and after a while it was replaced by rich mixture [7]. Reducing the cement content causes segregation and fine aggregate can overcome this problem [5].

TABLE I  
MIX PROPORTION FOR RCC DAM

Mix Proportion	Binder	Rate of use	C(kg)	F(kg)	F/(C+F)
Rich mixture RCC	150 kg <	47.4%	91	103	0.53
Medium mixture RCC	100-150kg	18.6%	72	44	0.38
Lean mixture RCC	<100kg	18.6%	69	11	0.14
Others		1.4%			

The cement content of this kind of ordinary concrete is low, about 100 to 150 kg/m<sup>3</sup> and by washed aggregate has been used [1]. Normal mix is shown in Table I. One can see that for rich mix the ratio of use with 150 kg/m<sup>3</sup> of binder are 47.4%, and fly ash ratio to cement (F/C) is 0.53. In addition, for medium mix (between 100 to 150 kg/m<sup>3</sup>) and lean mix (less than 100 kg/m<sup>3</sup>) their ratios of usage are 18.6 and 16.1 percent respectively [5].

Totally, RCC mix contains cement, fly ash, fine and coarse aggregate and some additives with much less water in comparison with conventional concrete. This concrete is dry with no slump.

#### V. FLY ASH IN RCC

Fly ash has positive effect on the concrete structure by decreasing the water ingress and controlling seepage. The other aspect of using fly ash is about the thermal stresses which decrease heat of hydration and cause degradation in the thermal stresses and subsequently improve durability due to reduce the cracks which appears by low young's modulus in the earlier day and at the end reduce cost. Due to lower cement content with adding fly ash its hydration heat become decrease. The fly ash specific gravity is lower than cement specially Portland and by using mass replacement, more fly ash is required in comparison with cement volume. Flexural and split which are tensile strength have been measured. As you can see in the Fig. 1 by increasing the percentage of FA, both flexural and split strength reduce. The tensile test has direct relation to the C<sub>m</sub> cement content. Due to the pozzolanic activity of fly ash, it tries to combine with CH (calcium hydroxide) which liberated through cement hydration for producing C-S-H (Calcium silicate hydrates), and decrease the leaching calcium hydroxide risk. And because of fly ash long term reaction, decrease water ingress. According to the recent research, 60% of fly ash decreases concrete water absorption in comparison with the concrete without fly ash which can be seen in Table II [3].

The significant effect of FA on the concrete permeability appears from 2 to 20 months [3]. Fly ash has spherical particles and this characteristic can improve some concrete properties such as:

- Long term reaction and increase strength
- Decrease dry shrinkage
- Reaction of alkali aggregate control
- Decrease heat of hydration
- Water tightness [7].

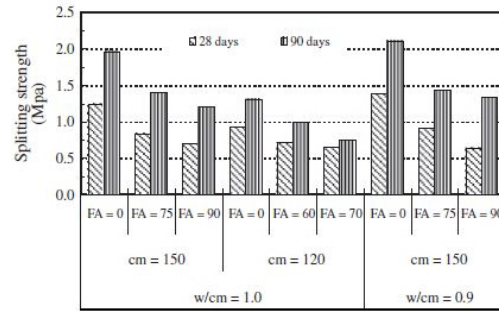


Fig 1 The ratio of spelling strength

TABLE II  
THE RATIO OF FLY ASH

Mix no	W/Cm	Cm (KN/m <sup>3</sup> )	FA (KN/m <sup>3</sup> )	Unit weight FA (KN/m <sup>3</sup> )	Absorpti on (%)	Fc-90/fc-28 (%)
1	1	1.5	0	23.7	7.42	105
2			0.75	23.6	7.20	140
3			0.90	24.0		
4		1.20	0	21.5	6.28	120
5			0.6	21.4	6.22	136
6			0.7	21.4	6.59	124
7			0	21.8	6.70	106
8	0.9	1.50	0.75	22.6	6.45	122
9			0.9	22.4	6.95	129

#### VI. ADVANTAGES

Cost: RCC cost depends on the type of structure complexity and differs from 25% to 59% lower than conventional concrete. Spillway: one the most important parts of a dam is spillway and in the conventional dams such as embankment dam, which needs a spillway built in the abutment, roller compacted concrete offer a cost effective and attractive option for construction of spillways in the main part of dam structure. Lower formwork cost is required due to layer placement process. Using the pipe cooling for decreasing the temperature is unnecessary because of low temperatures. Lower formwork cost is required due to layer placement process. Using the pipe cooling for decreasing the temperature is unnecessary because of low temperatures [4]. The other advantage of RCC dam is the replacement in contrast to other dams such as CFRD (concrete face rock-fill dam) and proves to be one of economical dams [9].

#### VII. RCC DAM PURPOSE AND DESIGN: CONSIDERING STRESS AND STABILITY

The major concerns in design and analysis of gravity or RCC dams are related to cracking. The other concerns include stability of the structure, durability and leakage. By investigating these factors, such as structural stability and uncontrolled leakage on transverse cracks, engineers can determine the RCC major problems and critical factors. In RCC dams, experiencing high thermal stresses present invisible cracks equivalent to the pivot of the dam, the hidden cracks happen in both RCC and traditional dams. Dams with invisible cracks are safe and stable under medium load situation but this condition related to closing cracks and

Impermeability of the cracks however factor of safety is, reducing with these cracks. Thus, experience has presented about invisible crack, if the crack unseals and opens, filling with water occur. For predict the degree of cracking a dam, at first should be evaluated the number of factors in a structure [7].

#### VIII. SPILLWAY DESIGN

One of the important parts of RCC design is about spillways and determining flow situation. For designing an embankment, assessing the embankment condition along with downstream area and foundation is one of the first operations.

Most important steps in the design that designers have to consider are:

- Dam condition
- Downstream region
- Spillway operation and required capacity
- Flow characteristics for selecting proper place for spillway.

For preventing the erosion and increase the durability of facing concrete in RCC, try to use mass concrete for spillways. Stair step is a favorite pattern for spillways used in RCC. It does not mean that RCC facing cannot be compacted. In addition, for improving durability, better surface for flow and decreasing the waste concrete edge compaction is necessary. Another important part of design process of RCC is to investigate the aggregate source. The investigation is to identify aggregate properties for the specific project.

For decreasing the costs, selecting a source of aggregate near the project site is considerable in terms of transportation fuel cost. In the situation of distance of RCC to the aggregate sources, all of the possible nearby mines should be considered. By identifying the suitable source, aggregates need to be tested for determining the best materials in terms of cost effective and suitability for using in project [10].

#### IX. SHEAR FRICTION FACTOR

In the RCC dams resistance against sliding is related to cohesion, stress and friction coefficient of sliding.

The below equation shows Shear Friction Factor (SFF) which can measure the stability of dams against sliding.

$$SFF = (cA + (N - U) \tan w)/T \quad (1)$$

- c cohesion of unit
- A cross section area
- N confining force to sliding surface
- U cross section uplift force
- w sliding friction angle
- T is the driving force parallel to the sliding surface [8].

#### X. HEAT OF HYDRATION

For decreasing the thermal stresses caused by heat of hydration, using the concrete with lower elastic modulus is vital and lean mixture can help to satisfy this limitation. Water-reducing and air-entraining are used in roller

compacted concrete [1]. By building a dam uniformly like RCC dam, the temperature of dam is governed by heat of hydration and seasonal temperature [5].

#### XI. COMPACTION OF RCC DAM

Aggregate should be less than 76 mm, greater than this size can cause problem in compacting and spreading as well. By increasing the size of coarse aggregate, the compaction for small layer becomes difficult and the influence of coarse aggregates in thick layer is not significant. On the other hand, the aggregate less than 75 mm increase the cohesiveness of mixture by decreasing the voids [1].

#### XII. RCC LAYERS AND COMPACTION

RCC layers thicknesses can be up to 600 mm. For preventing the cold joint, placement of concrete operation should be continuous and for this reason the selection of plant is very important due to its capacity and distance to project [1]. The thinner or thicker layers have to optimize to get the best result. The thinner layer enables joints to be covered faster by better bonding. The thicker layer subjected to more seepage paths owing to weak joint bond. Thinner layer is usually use for small job and thicker layer for larger job. The minimum number for suitable compaction by roller machine to get the best compaction has been specific by mix design, the layer thickness and the type of compactor. The most important item which controls the compaction requirements is layer thickness. The layer thicknesses normally selected between 150 and 900 mm. By increasing the number of passing, the density of RCC decrease and for this reason in the US 300 mm has been selected for thicknesses of layers. For transition the concrete conveyors can be used and constructor can continue in the moist weather. For using this method degradation of water in the mixture is necessary due to high humidity and nonexistence of surface drying [3]. Compaction energy is also an important factor in determining the strength of RCD. So the consistency of RCD mixture was measured with the VC meter shown in Fig. 2 [5].



Fig 2 VC Meter

## XIII. RCC DAM CONSTRUCTION CYCLE

- Lean and dry concrete transfer by trucks from plant to site.
- Bulldozers spread concrete in thin layers.
- After spreading transverse joints are necessary by vibratory joint cutter.
- Compaction by rollers.
- Curing between 24 to 48 hours.
- Surface treats by green cut.
- By spreading mortar the next layer of concrete will be placed [11].

## XIV. VC TEST

One of the common tests for RCC is VC which is instant of slump because as mention earlier RCC doesn't have slump. For determining the compaction energy which is a significant factor in RCC try to use VC test to measure the consistency of RCC concrete. This test has been done by using two different kind of container in terms of size; standard-size with 24cm for diameter and large-size with 48cm for diameter. In the standard size the mix size should be less than 40 mm but in the large size use of full size is free [11].

## XV. CONCLUSION

This article has revealed that, the use of RCC dams are so economical and can improve old dams easily. In addition, this kind of dam can decrease the construction period which is very important in the sites with unfavorable conditions, such as weather or aggregate source. One of the most important aspects of RCC is using fly ash due to decreasing heat of hydration with any specific effect on the concrete strength or other harmful effect such as segregation, bleeding or permeability.

From an owner stand point as well as a designer and constructor, the application of RCC dams is developing as a more economical, safe and practical solution for water storage projects. The applications of roller compacted concrete and development has gone from the early days at Willow Creek where the first RCC dam was designed and constructed as an RCC dam. Since then many other applications of RCC have been used as ballast for larger dams, spillways in existing earthen structures as well as pavements [9].

## REFERENCES

- [1] Muayad Umar Rashed, "Roller compacted concrete (RCC) innovations in civil constructions world".
- [2] Jean-Pierre Becue, Gérard Degoutte and Danièle Lautrin, "Choice of site and type of dam".
- [3] Mohamed I, Abu-Khashaba, I. Adam, A. El-Ashaal, "Investigating the possibility of constructing low cost roller compacted concrete dam, Alexandria Engineering Journal". (2014) 53, 131–142.
- [4] P.K. Mehta and P.J.M. Monteiro, "Roller compacted concrete".
- [5] Isao Nagayama and Shigeharu Jikan, "30 Years' History of Roller-compacted Concrete Dams in Japan".
- [6] Paul C. Rizzo and John Charlton, "Foundation preparation for RCC dams founded on difficult foundation conditions," Hydro2008 in Lubljana, Slovenia, 2008.
- [7] Kimitaka UJI, "Roller compacted concrete dam and utilization of fly ash in japan."
- [8] [http://www.cement.org/think-harder-concrete-/paving/roller-compacted-concrete-\(rcc\)/faqs](http://www.cement.org/think-harder-concrete-/paving/roller-compacted-concrete-(rcc)/faqs)
- [9] Ted Warren, "Roller compacted concrete for dam construction."
- [10] Timothy P. Dolen and Fares Y. Abdo, "Roller compacted concrete for dam safety modifications," IBIRCON, 2008.
- [11] Shigeyoshi Nagataki, Tadahiko Fujisawa, Hideaki Kawasaki, "State of art of RCD dams in Japan. IBRACON, 2008.
- [12] M. EminEmiroglu, "Influences on selection of the type of dam," International Journal of Science & Technology Volume 3, No 2, 173-189, 2008.