Journal of Civil & Environmental Engineering

Zarrin et al., J Civil Environ Eng 2016, 6:2
http://dx.doi.org/10.4172/2165-784X.1000221

Review Article

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Roller-Compacted Concrete Dams Rehabilitation in Terms of Different Problem

Orod Zarrin[1]*, Mohesn Ramezan Shirazi[1], Hassan Moniri[1] and Mohammad Moniri[2]

[1]*Faculty of Civil Engineering, Eastern Mediterranean University, Famagusta, Cyprus*
[2]*Department of Civil Engineering, IAU, Shahrood, Iran*

Abstract

Roller-Compacted Concrete (RCC) started in the US and Canada near 30 years ago, at that time it was a new method to construct gravity dams or rehabilitated. After passing these years, it's become one of the popular methods in designing dams and called Roller Compacted Concrete. No slump is the specific property of the concrete of RCC dams. This type of dam needs place concrete in thin layers and compacted by roller to meet the require compaction. By one side, RCC dams can dissipate energy by stair step slope more than 70 percent of water energy and from the other side, all of the ordinary dams need to have an emergency spillway, but due to using all the length of the crest for spillway in the RCC dams, it is removed and the cost of constructing decreased. One of the most common problems which occur in the RCC dams at the beginning of its usage is hairline cracks throughout dam. This kind of cracks can start from upstream to the downstream. Rehabilitations have got several options depends on the kind of cracks and situation of cracks on dams such as drill holes, injecting grout, using different type of membrane and geomembrane, covered sealing system and covered geomembrane content. In this paper, try to investigate the different rehabilitation way of RCC in detailed and specified the best way for each kind of cracks.

Keywords: Crest; Drainage; Geotextile; Geomembrane; Grout; Membrane; RCC Dams; Rehabilitation; Spillway; Sealing

Introduction

One of the best solutions for remediation of existing dams is RCC (Roller Compacting Concrete) due to its economical and construction time. The application of RCC in rehabilitation of dams has different parts and some important parts of remediation in dams include erosion and scour protection of slopes, crests, stilling basins of embankment, repairing breaches and seepages, increased the hydraulic capacity for service and emergency spillways and construction of downstream gravity sections for seismic strengthening and increased sliding stability of concrete gravity, arch, and buttress dams. The following cases histories describe selected applications of RCC in a dam remediation project. The organization that has great investigation on RCC rehabilitation is U.S. Army Corps of Engineers, which prepares a list of advantages of RCC technique:

Costs: In comparison with conventional dams, RCC can decrease the costs in ranging from 25 to 50 percent.

Rapid Construction: In today's world time is an important factor. RCC's finishing time is typically 1 to 2 years less than regular concrete dams. Spillways: Constructing the spillway in main part of dams is cost-effective which by comparing to the embankment dams that require using spillways in an abutment [1].

Application in Construction of New Dams

Despite the fact that RCC is so economical, seepage is the fundamental problem faced with RCCs. In some cases, it may cause problems and might be acceptable by appearing of the seepage in the downstream of a dam. The RCC dams are not uniformed as expected to be, because of some natural characteristics of construction procedures such as permeability which may cause to segregation. The other considerable problems of RCC dams are high permeability due to dry concrete that contains low amount of cement and leads to low density zones, the permeability between lifts, and the high risk of joint's separation on upstream which will develop by thermal reaction. To solve the above mentioned problems, using concrete with high cementations content decrease permeability of lift joints. However, it can affect thermal cracking in plain concrete. The high cementations concrete in RCC will complicate construction due to controlling the temperature of mix, placing, and lift control to preventing cold joint. The seepage can be the main problem of RCC dams which can determinate the dams by leaching out of cement by the seeping water. Bursting the Camara RCC dam built in 2002 in Brazil revealed that seepage may have terrible effects. Consequently, to reach a sophisticate system in upstream, geomembrane and integral concrete of upstream and RCC can be the turning part of solution. The concrete of upstream facing is make by internally vibrated concrete placed at the same time by RCC, and will enrich upstream concrete facing.

Moreover, the placement of concrete requires higher care and different mix design from the body of RCC dam, and also needs vertical joints for water penetration. Using artificial materials is the other part for protecting upstream permeability which can be named by watertight sealing element and embedded water-stops. These instruments have negative influence on time and cost during the construction procedure through entire dams. In order to overcoming this problem, selecting geomembrane system has significant benefits in terms of cost and schedule which can provide upstream impermeability. Some of the other advantages of geomembrane will be presented below:

1. Reducing cement content,
2. Reducing or omitting pozzolan,
3. Reducing fly ash,
4. Omitting the temporary system for cooling,
5. Reducing bedding mix for lift surface,

***Corresponding author:** Orod Zarrin, Faculty of Civil Engineering, Eastern Mediterranean University, Famagusta, Cyprus, Tel: +989113393991; E-mail: orod.zarrin@gmail.com

Received February 13, 2016; **Accepted** March 07, 2016; **Published** March 09, 2016

Citation: Zarrin O, Shirazi MR, Moniri H, Moniri M (2016) Roller-Compacted Concrete Dams Rehabilitation in Terms of Different Problem. J Civil Environ Eng 6: 221. doi:10.4172/2165-784X.1000221

6. Omitting or reducing of contraction joint in upstream,
7. Reducing the coast of horizontal joints treatment [2].

Design Principles

The first designing method for RCC dams is according to the concrete with low cement content. This has benefits such as lower temperature in contrast to conventional concrete, subsequently decreasing the tensile stresses (less than 120 kg/m3), as well as the water cement ration in less than ordinary concrete due to compacting by roller.

Designing and analysis a RCC dam by using uplift force is directly involved with lift joint, permeability, placements methods to prevent segregation, and techniques used at upstream facing for water tightness. The uplift reduction is therefore a function of the water tightness of the upstream facing and of the efficiency of the drains. The uplift can be reduced in dam foundation using a tight connection for foundation sealing system such as cut-off wall or grout curtain. The presence of a perimeter plinth at the heel of the upstream face with a short grouting curtain which will bond the plinth to the rock and will intersect the grouting curtain from the gallery will reduce the remaining possible infiltration paths of water from the reservoir, which basically is:

1. Through permeable foundation
2. Through the bottom part of defective vertical joints
3. Through horizontal lift joints not perfectly treated [3].

It is worth to mention that using upstream geomembrane sealing can enhance the RCC mix design by decreasing the amount of cement and pozzolan. The below table present the data of cement and pozzolan content using a geomembrane (Table 1).

The geomembrane technique for RCC is divided in two parts:

1. Exposed sealing system
2. Covered sealing system.

The exposed sealing system

Exposed system: at this method, geomembrane is installed on the upstream which is exposed to reservoir's water and environment (Figure 1).

The covered sealing system

Covered system: In this method, geomembrane uses as formwork by casting on precast panels. The geomembrane in covered sealing system permanently embedded, however just on the open joints, geomembrane remain exposed to water of reservoir (Figure 2) [4].

RCC Stepped Spillway

Using stepped spillways in RCC dam has a great advantage, which can dissipate the energy of water through the spillways slop [5] (Figures 3 and 4).

Comparison of the Two Systems

In the both solutions, geomembrane prevents the water penetration over entire surface and makes RCC waterproof through all lift joints. The geomembrane is the best water-stop for covering the face, otherwise in conventional techniques for water-tightening the RCC dams try to use PVC water-stops at construction joint. The advantages of the geomembrane usage is avoiding water infiltration in lift joints, reducing design constraints, such as conventional concrete layers on the upstream face, special paste treatment of joints or bedding mixes. Therefore, it leads to place the RCC mix through the dam's cross-section without placing bedding mix on the joints and concrete at the upstream face. However, in some cases the bedding mix may need to be used to increase the shear strength and stability of dam.

Moreover, on the upstream face, the bedding mix may be required just for preparing a slight thickness for touching formwork. Its use was mainly dictated by the need to achieve good compaction of the RCC mix at the upstream concrete. The projects of RCC dams, which used geomembrane instead of bedding mix, are the dams of Riou (France), Balambano (Indonesia), Concepcion and Nacaome (Honduras). The exposed solution provides some additional technical and economic advantages as compared to the covered solution [5]. One of the fundamental principles usage of face drainage system appears at the design stage and throughout of the geomembrane service life in dams. Face drain system, are accepted by many experts, due to reduction abilities at the design uplift in the part of designing. The advantages of face drainage system during service life of dams are revealed in the following paragraphs:

Monitoring: In order to control the quantity of drainage water, the face drainage system lets the performance of waterproofing system be monitored by measuring fluctuations with respect to an

Dam	Country	Cement (Kg/m³)	Pozzolan (Kg/m³)
Winchester	USA	104	0
Urugua 1	Argentina	60	0
Concepcion	Honduras	95	0
Riou	France	0	120
Siegrist	USA 5	9	34
Nacaome	Honduras	64	21
Big Haynes	USA	42	42
Burton Gorge	Australia	85	0
Spring Hollow	USA	53	53
Balambano	Indonesia	78	42

Table 1: Cement/pozzolan cement in rcc dams with geomembrane sealing.

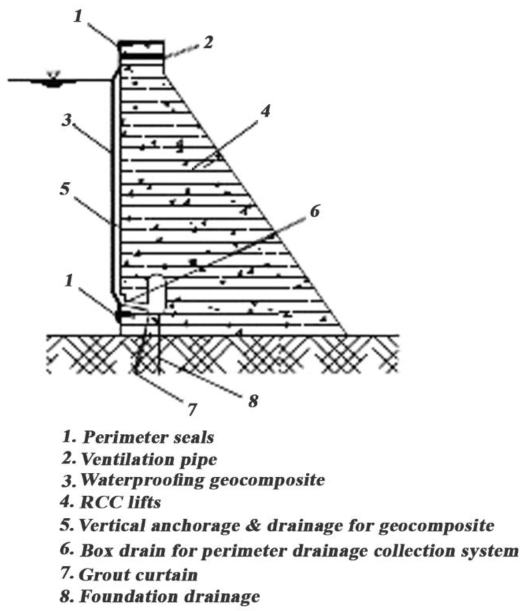

Figure 1: Cross section of exposed system.

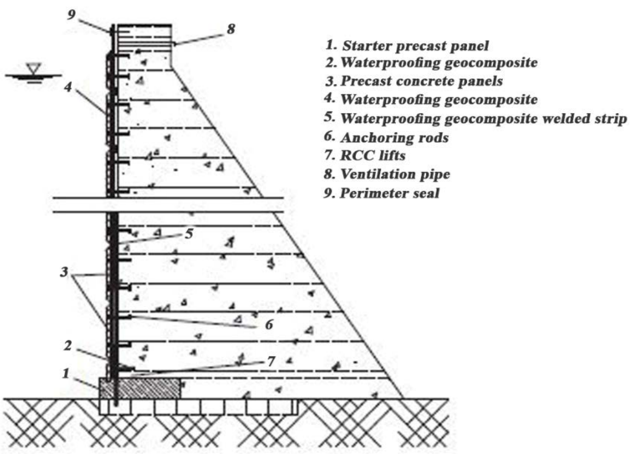

Figure 2: Cross section of covered system.

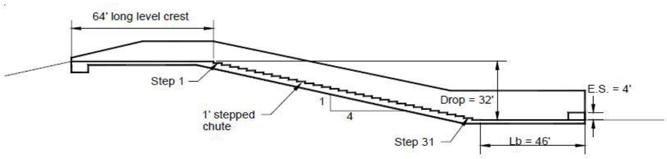

Figure 3: Renwick Dam stepped spillway having a 32 ft (9.1 m) spillway drop.

Figure 4: Physical model of Renwick Dam stepped spillway.

assessed average or "normal" quantity corresponding to satisfactory behavior of the dam and its impervious liner. Therefore, this system (drained upstream facing) allows seepage control and monitoring more accurately. By designing appropriately and monitoring the dams accurately, it is easily and quickly possible to access and repair the damage parts.

Dams safety: The capacity of drained upstream facing is considerable for impervious geomembrane to avoid the damage of waterproofing liner due to the behind water. The penetration of water to dam's body through the joints will be removed by upstream facing system and will lead to decreased pore pressures. This issue helps to increase the safety at the lift and uplift pressures and totally increases the safety factors of dams. Sealing layer's safety during rapid draw-down of the reservoir: removes the water gathering behind the liner and will balanced the backpressure during dewatering of liner

The reservoir safety: It drains the water of behind liner and makes an impervious liner [6].

Geomembrane

The installing of geomembrane on rehabilitation is similar to that use in the RCC dams, including a PVC geomembrane, thickness 2.5 to 3.0 mm, heat-coupled at manufacturing to a 200 to 700 g/m2 geotextile. For covering systems, the thicknesses of PVC geomembrane decrease to 1.5 to 2.0 mm and heat-coupled will remain constant like previous one. In order to resist the fresh concrete offensive, all of geotextile should be polypropylene fibers. And also using polyester is acceptable when placed far from concrete by using drainage geonet.

For those dams that have geomembrane with very low penetrability (1012 m/s), the necessities of bedding mix or impervious upstream layers decrease, therefore the support surface can be formed directly on the RCC lifts. In the RCC dams, the concrete surface is rougher than ordinary concrete; consequently the construction surface is controlled just for absence of honeycombs and stability. Normally, metal formwork has a positive influence on the surface to make it smooth (if it can tolerate the RCC compaction). Actually, the bedding mix and upstream concrete are used to increase the strength of bonds between lifts and create further supporting line. The solution of rough surface can be handled by installing an anti-puncturing geotextile but there is no report of necessity. The location of vertical joints needs additional support to prevent penetration of geomembrane into the joints [1].

Type of geomembrane

The most important requirements that the geomembrane should be satisfy are:

1. Durability
2. Elasticity (to accommodate movements and openings)
3. Burst resistance (to bridge opening, but a robust bridging material below the geomembrane can reduce the requirement)
4. Flexibility (to accommodate the subgrade at the position of the watertight perimeter seal) [1].

Covered Geomembraine System

The covered system of geomembrane is just used during the construction of RCC dams and is not used in rehabilitation methods. This system should be embedded in the concrete to create a permanent formwork. Embedding in the panel can secure the geomembrane during pre-casting. The precast concrete covers the liner against the reservoir water. The shape of panels is so important because they have to be able to interlock without destructing the liner. The permanent geomembrane is typically PVC, both in ribbed (mostly a 15 mm long rib per 150 mm), and geocomposite configuration that is used for rehabilitation of dams [7].

In the case of a geocomposite, first fresh concrete is placed into the casting bed, followed by rolling and vibrating the liner material onto the exposed concrete surface of the panel, with the geotextile side of the material placed on the fresh concrete. The liner stays constant by attaching to the panel over the bond made by absorption of concrete paste into the geotextile material. Initially, using PVC liner by attaching to the precast panels was tested in Penn Forest Dam project by detaching several panels partially and welded to the liner by PVC joint strips on each adjacent panel.

According to the destructive test, the stresses in the PVC liner did not concentrate at the joint of panels and has been distributed throughout the panel. During the test, it was clear that those panels which pulled apart and placed the PVC material, facing failure due to the stress concentration, and the behavior of the liner is elastic with about 50 cm stretch before failing. This kind of attachment method has more advantages in comparison to the old method for liner attachment (T ribbed surface anchor) such as improved liner elongation, greater flexibility and enhanced resistance to stress concentrations [8].

Drainage and Ventilation Layer

One of the most important characteristic of RCC dams is drainage, which can reduce the design uplift, and avoiding the long contact of water with the lift joints. And also the geotextile along with geomembrane makes drainage medium. The special characteristic of geotextile in transfer water can move it vertically which don't affect the lift joints. Therefore the penetration of water in the reservoir becomes very low. The reduction of geotextile thickness under hydrostatic load cause to reduction of transmissivity characteristics. Ventilation is necessary for drainage layer and it can be achieved by creating an opening above the maximum water level in the geomembrane or by continuing the anchoring profiles up to the crest, or by the pipes which embedded in the surface of the RCC lifts and exiting at the downstream face. Usually, every 15 to 20 m needs horizontal ventilation [9].

Conclusion

Due to natural characteristics of RCC dams such as permeability, are not uniformed as expected to be. The considerable problem of RCC dams are high permeability due to dry concrete that contains low amount of cement and leads to low density zones, the permeability between lifts, and the high risk of joint's separation on upstream which will develop by thermal reaction. This problem can be solved by using concrete with high cementations content; however, it can affect thermal cracking in plain concrete. The high cementations concrete in RCC will complicate construction due to controlling the temperature of mix, placing, and lift control to preventing cold joint.

The other problem of this kind of dams is seepage that can be deadly by leaching out of cement by the seeping water. Designing an upstream system carefully can be the solution, for this purpose, geomembrane and integral concrete of upstream and RCC can be the turning part of solution.

The concrete of upstream facing is make by internally vibrated concrete placed at the same time by RCC, and will enrich upstream concrete facing. In addition, the placement of concrete requires being different from mix design of the RCC body, and also needs vertical joints for water penetration. Using artificial materials is the other part for protecting upstream permeability which can be named by watertight sealing element and embedded water-stops. These instruments have negative influence on time and cost during the construction procedure through entire dams. In order to overcoming this problem, selecting geomembrane system has significant benefits in terms of cost and schedule which can provide upstream impermeability. The uplift reduction is therefore a function of the water tightness of the upstream facing. The uplift can be reduced in dam foundation using a tight connection for foundation sealing system such as cut-off wall or grout curtain.

The other way to reduce the uplift is face drainage system. Face drain system, are accepted by many experts, due to reduction abilities at the design uplift in the part of designing. The advantages of face drainage system during service life of dams are: the monitoring which can control the performance of waterproofing system by measuring fluctuations, the dams safety which can control the capacity of drained upstream facing for impervious geomembrane to avoid the damage of waterproofing liner due to the behind water, the reservoir safety can drain the water of behind liner and makes the liner impervious. In general, the cover system is not vital unless the cracks appear to the surface and then it became serious concern which can cause failure. As an additional precaution against such events, cover can be provided in the vulnerable horizontal zones, or in the zone of reservoir fluctuation, and can consist of a steel plate or a layer of concrete or shotcrete.

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