Alexandria Engineering Journal (2014) 53, 131–142

Alexandria University

Alexandria Engineering Journal

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www.sciencedirect.com

ORIGINAL ARTICLE

Investigating the possibility of constructing low cost roller compacted concrete dam

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Received 16 June 2013; revised 24 November 2013; accepted 27 November 2013
Available online 22 December 2013

KEYWORDS

Roller Compacted Concrete Dams "RCCDs";
Local material;
Fly ash;
Construction stages;
Monitoring system;
Thermal measurements

Abstract This research was set with the objective of investigating the possibility of constructing Roller Compacted-Concrete Dam, RCCD, using local material to reduce its cost. Trial laboratory concrete mixtures were conducted to define RCCD proportions in stage-I. Twelve mixtures with fly ash, FA, of cement replacement percentages (0%, 50%, and 60%) designed with water/cementitious-materials ratio, w/c_m of 1.0 and 0.9. C_m-content of 1.50 kN/m^3 and 1.20 kN/m^3 was also examined. In stage-II, RCCD scale model was constructed based on the laboratory results. Descriptions of RCCD construction stages, dam monitoring system instrumentations and temperature measurements analysis were conducted.

Results clarified how FA interacts with Portland cement and showed its effect on concrete properties especially strength development ratio. FA long-term reaction refines the pore concrete structure to reduce water ingress and control its seepage. FA reduces the thermal stresses by reducing the concrete hydration heat and reduces temperature-related cracking due to low early young's modulus and finally leads to durability improvement that minimizes the dam construction cost. Results indicated that RCCD could be effectively implemented with site local Egyptian materials. However, more further field measurements and a RCCD prototype are required to be examined analytically and verified with in situ data to evaluate that technique.

1. Introduction

Roller compacted concrete, RCC, or rolled concrete is a special blend of concrete that has essentially the same ingredients as conventional concrete but in different ratios and increasingly with partial substitution of fly ash for Portland cement [1]. RCC is a mix of cement/fly ash, water, sand, coarse aggregate and common additives, but contains much less water. The produced mix is drier and has no-slump. RCC is placed in a manner similar to paving. The material is delivered by dump trucks or conveyors, spread by small bulldozers or specially

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

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http://dx.doi.org/10.1016/j.aej.2013.11.009

modified asphalt pavers and then compacted by vibratory rollers.

In dam construction, roller compacted concrete began its initial development with the construction of the Alpa Gera Dam near Sondrio in North Italy between 1961 and 1964. Concrete was laid in a similar form and method but not rolled [2–4]. RCC had been touted in engineering journals during the 1970s as a revolutionary material suitable for, among other things, dam construction [5]. Initially and generally, RCC was used for backfill, sub-base and concrete pavement construction, but increasingly it has been used to build concrete gravity dams. The low cement content and use of fly ash cause less heat of hydration while curing corresponding to that of conventional mass concrete. RCC has cost benefits over conventional mass concrete in dams. This includes higher rates of concrete placement, lower material costs and lower costs attributed to less post-cooling and formwork. For dam applications, RCC sections are built lift-by-lift in successive horizontal layers resulting in a downstream slope that resembles a concrete staircase. Once a layer is placed and is initially hardened, it can immediately support the earth-moving equipment to place the next layer. After RCC is deposited on the lift surface, small dozers typically spread it in one-foot-thick (300 mm) layers [6]. The first RCC dam built in the USA was Willow Creek Dam in Oregon on a tributary of Columbia River. US Army Corps of Engineers initiated such construction between November 1981 and February 1983 [5,7]. Construction progressed well under budget (estimated $50 million, actual $35 million).

On initial filling, leakage occurred between the compacted layers within the dam body was unusually high. This condition was treated by traditional remedial grouting at a further cost of $2 million which initially reduced the leakage by nearly 75%. Over the years, seepage has decreased to less than 10% of its initial flow. Concerning the dam's long-term safety, it is indirectly related to its RCC construction. Within few years of construction, problems were noted with stratification of the reservoir water caused by upstream pollution and anoxic decomposition which produced hydrogen sulfide gas which could in turn give rise to sulfuric acid, and thus accelerate damage to the concrete. The controversy itself, as well as its handling continued for some years. In 2004 an aeration plant was installed to address the root cause in the reservoir, as had been suggested 18 years earlier [5]. In the quarter century since Willow Creek Dam, considerable studies have yielded numerous improvements in the concrete mix designs, dam designs and construction methods for RCC dams. By 2008, about 350 RCC dams existed world-wide [8]. Currently the highest dam of this type is Longtan Dam, at 216 m, with Diamer-Bhasha Dam planned at 272 m. RCC techniques reduced the cost of conventional concrete dam construction and were used in massive concrete structures with the advantage of limited construction period and cement content [9,10]. Since the RCC placement rate is much faster and the cost of placement is lower than the cost of conventional concrete, the cost may be reduced by one-half to possibly one-third the cost of conventional concrete [11]. From the overall design criteria, the soils approach to RCC mixture proportioning considers RCC as cement-enriched aggregate and the mix design is based on moisture-density relationships. There is sufficient paste in the RCC mix to fill all the voids in the well graded aggregate for the concrete approach, making no-slump and a fully compacted concrete mixture. This approach has a moist consistency than that of the soil approach when the same aggregate type is used [12]. Since there is no "one procedure" which is best and fits all cases, therefore, design needs, materials availability and planned placement procedures are the governing factors for proportioning RCC mixes [13].

Nowadays, several completed RCC dams all over the world, are being constructed in all types of climate. The size of RCC dams has significantly increased where some of the largest dams in the world are now being constructed implementing RCC technology [14]. Considering the RCC development, its application in developed countries, especially the Arab countries, is still limited [10]. Since one of the purposes of constructing RCCD is to control floods and redirect them to certain specific passage-way to be optimally used for agriculture and domestic uses, therefore its construction is importantly needed. This importance increases especially when using available local materials in RCCD construction in Egypt, especially Sinai.

This research was initiated with the objective of investigating the possibility of constructing roller compacted concrete dams using local material in order to reduce the dam construction cost. The investigation phases after reviewing the literature reported above are presented in this paper under the following headlines:

- Executing experimental work.
- Experimental results and analysis.
- Scale model of the RCCD.
- Analyzing and presenting RCCD thermal results.

It is necessary to mention that the experimental work and the RCCD model construction and different measurements were executed at Construction Research Institute–National Water Research Center–Ministry of Water Resources and Irrigation, CRI–NWRC–MWRI.

2. Executing experimental work

Twelve concrete mixes with different fly ash replacement percentages divided into two groups of six (6) mixes were designed (i.e., with w/c_m of 1.0 and 0.9) [15].

2.1. Used materials

Commercially available Egyptian Ordinary Portland Cement (OPC), complying with the Egyptian Standard Specifications (ESS), was used. Most RCC projects have used Class-F pozzolanic fly ash (FA), due primarily to the effect of its spherical particles on workability. Use of FA Class-F in RCC serves three purposes:

- partially replaces cement to reduce heat of hydration generation,
- reduces cement quantities, and
- acts as a mineral addition to the mixture to provide fines to improve workability.

The used aggregates were chosen from a quarry located on Cairo-Suez road. Overall aggregate is composed of four components, namely, fine and three fractions of coarse aggregate