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INVESTIGATING THE POSSIBILITY OF CONSTRUCTING LOW COST ROLLER COMPACTED CONCRETE DAM

إنشاء سد ذات الخرسانة المضغوطة باستخدام المواد المحلية ذات التكلفة المنخفضة والرماد المتطاير

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الخلاصة:

يختلف تصميم، وخطوات بناء السد بواسطة الخرسانة المضغوطة، "RCCD" بشكل كبير عن إنشاؤه بالخرسانة التقليدية. تصف هذه الورقة تصميم الخلطات الخرسانية، وبناء النموذج، ونظام رصد وتحليل القياسات الحرارية ل RCCD التى تم تشييده باستخدام المواد المحلية المتوفرة منخفضة التكلفة. وأجريت عدة خلطات معملية لتحديد أفضل النسب لمكونات الخلطة المختلفة للسد في المرحلة الأولى من البحث. وقد تم اختبار عدد اثنى عشر (12) خلطة مع استخدام ثلاثة نسب مئوية مختلفة من الرماد المتطاير كاستبدال جزئى للأسمنت (0٪، 50٪، و 60٪) ومقسمة إلى مجموعتين، كل واحدة تضم ستة خلطات من الخرسانة التي تم تصميمها مع نسبة الماء/المواد الأسمنتية، w/c_m وهى 1.0 ، 0.9 لكل من المجموعة الأولى والثانية على التوالي، وكان محتوى الأسمنت المستخدم (150 كجم/م^3 و 120 كجم/م^3) وأجريت اختبارات لتحديد خواص الخرسانة الطازجة والمتصلدة. وفي المرحلة الثانية، وبناءً على نتائج الاختبارات، ثم تشييد النموذج الخاص لاختبار RCCD. ويقدم في هذا البحث وصف كل مراحل بناء السد، وأدوات القياس المختلفة المثبتة ضمن نظام الرصد الخاص بالسد وكذلك النتائج الخاصة بقياسات درجة الحرارة. وقد أوضحت نتائج الاختبار آثار الرماد المتطاير المستخدم على خصائص الخرسانة الطازجة والمتصلدة؛ وكيف يتأثر التحليل الحراري لــ RCCD ليتناسب مع الرماد المتطاير، والمناطق التي فى حاجة لأبحاث إضافية للرماد المتطاير، ومن خلال خصائصه البوزولانية والأسمنتية، أكدت النتائج أن الرماد المتطاير هو بديل جزئى مناسب للأسمنت البورتلاندي العادي وذلك لتقليل كمية الاسمنت المستخدمة دون التأثير سلبيا على خواص الخرسانة، وبالتالى يمكن أن يساهم في زيادة القوة وتحسين الأداء لكل من الخرسانة الطازجة والمتصلدة. وباستخدام المواد البوزولانية الطبيعية كالرماد المتطاير، في الخرسانة لبناء السدود الضخمة، فمن الممكن المساهمة الفعالة فى الحد من ارتفاع درجة الحرارة المتوقعة دون حدوث أية آثار غير مرغوبة، مثل النزيف، والميل إلى الانفصال الحبيبى، والميل إلى زيادة النفاذية. كما أنه يقلل من الضغوط الحرارية من خلال تقليل حرارة الإماهة أيضاً. وأوضحت النتائج التى تم الحصول عليها أن السد ذات الخرسانة المضغوطة "RCCD" يمكن إنشاؤه على نحو فعال باستخدام المواد المحلية المصرية المتاحة والرماد المتطاير.

ABSTRACT:

The design, and sequences for construction with Roller Compacted Concrete Dams, “RCCD” are considerably different from conventional mass concrete construction. This paper describes design mixes, model construction, monitoring system and thermal measurements analysis for RCCD constructed using the available low cost local materials. Trial laboratory concrete mixtures were conducted to define the best different RCCD proportions in the first stage. Twelve mixtures with fly ash of different cement replacement percentages (0%, 50%, and 60%) divided into two groups, each one includes six concrete mixtures that were designed with water/cementitious materials ratio, w/c_m of 1.0 and 0.9 for the first and second group respectively, two contents of cement of 150 kg/m^3 and 120 kg/m^3 were also examined. Tests were performed for determining fresh and hardened concrete properties. In the second stage, based on the laboratory results, RCCD model was then constructed. Descriptions of all construction stages, different instrumentations installed for dam monitoring system and temperature measurements results are also conducted and presented in this research. Test results clarify how fly ash interacts with Portland cement; its effects on the fresh and hardened concrete properties; and how RCCD thermal analysis is affected and proportioned with fly ash. Fly ash, due to its pozzolanic and cementitious properties, is a suitable replacement material for cement to reduce cement usage without invading concrete properties and can contribute to strength gain and may improve performance of fresh and hardened

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concrete. By using natural pozzolans, fly ash, in the massive concrete dam construction, it is possible to achieve a reduction of the temperature rise without any undesirable effects such as bleeding, tendency to segregate, and tendency to increase permeability. It also reduces the thermal stresses by reducing the heat of hydration. The obtained results indicated that RCC could be effectively produced using the available local Egyptian materials.

***Keywords**: Roller Compacted Concrete Dams, “RCCD”, Design Mixes, Model Construction Stages, Monitoring System, Thermal Measurements, Low Cost Local Materials, and Fly Ash*

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, aggregate and common additives, but contains much less water. The produced mix is drier and essentially 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 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 because the low cement content and use of fly ash cause less heat to be generated while curing than do conventional mass concrete placements. Roller-compacted concrete has many time and cost benefits over conventional mass concrete dams; these include higher rates of concrete placement, lower material costs and lower costs associated with 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, 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 (300mm) layers [6]. The first RCC dam built in the USA was the Willow Creek Dam on Willow Creek, a tributary in Oregon of the Columbia River. It was constructed by the Army Corps of Engineers between November 1981 [7] and February 1983 [5]. Construction proceeded well, within a fast schedule and under budget (estimated $50 million, actual $35 million). On initial filling though, it was found that the leakage 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 since decreased to less than 10% of its initial flow. Concern over the dam's long-term safety has continued however, although only indirectly related to its RCC construction. Within a 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, considerable research and experimentation have yielded innumerable improvements in concrete mix designs, dam designs and construction methods for roller-compacted concrete dams; by 2008, about 350 RCC dams existed world-wide [8]. Currently the highest dam of this type is Long tan Dam, at 216 m, with Diamer-Bhasha Dam planned at 272 m. RCC techniques reduced the cost of conventional concrete dam construction and has been 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 much less than the cost of conventional concrete, the cost may be one-half and possibly one-third the cost of conventional concrete [11]. From 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 more than 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 wetter consistency than the soils approach when the same aggregate type was used [12]. Since there is no one procedure is best and fits for all situations, therefore, design needs, materials availability, and planned placement procedures are the governing factors for selecting the materials and proportioning RCC mixtures [13].

Nowadays, several completed RCC dams all over the world are being constructed in all types of climate and in different countries. The size of RCC dams has significantly increased where some of the largest dams in the world are now being constructed using RCC technology [14]. However considering all the RCC development taken place all over the world, still its application in developed countries and especially the Arab countries is still very limited [10]. Since the purpose of constructing RCCD is to obstacle the floods as well as to redirect it to a certain specific pass-way to be optimally used for agriculture and domestic uses, therefore its construction is importantly needed. This importance increases especially when using the available local materials to be applied in constructing RCCD in Egypt especially in Sinai. The experimental work as well as RCCD model construction and different measurements has been undertaken at Construction Research Institute, CRI, National Water Research Center, NWRC, Ministry of water Resources and Irrigation, MWRI, to intensively investigate the feasibility of producing RCCD construction using the Egyptian locally available materials. In the current paper, material selection, mix proportioning, trial lab mixes results, RCC dam model construction, its different instrumentation monitoring system and thermal measurements analysis are introduced.

2. TRIAL LAB. MIXES

For RCC development technology with respect to RCC design mix techniques, the concrete philosophy was followed where the RCC mix is considered to be a true concrete whose strength and other properties follow the water/cement relationship. Twelve (12) mixtures with different fly ash replacement percentages divided into six (6) mixtures for the two groups of concrete mixtures that were designed with w/cm of 1.0 and 0.9 [15].

2.1 Materials

Commercially available Egyptian ordinary Portland (OPC) cement, comply with the Egyptian Standard Specifications (ESS), was used. Nearly all RCC projects using pozzolans have used Class F fly ash, due primarily to the effect of its spherical particles on workability. Use of Class F fly ash in RCC serves three purposes: (1) as a partial replacement for cement to reduce heat generation, (2) to reduce cost, and (3) as a mineral addition to the mixture to provide fines to improve workability [13]. 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 (size 1, size 2, and size 6). The physical properties of both fine and coarse aggregate fractions are listed in Table 1, while the overall grading curve of the aggregate is shown in Fig. 1 compared to the typical mass RCC grading mentioned in ACI 207.5R [13]. Tap drinking water was used to mix all concrete mixtures and no chemical admixture was used throughout this study.

Table 1: Aggregates physical properties

Aggregate type		%	Unit weight t/m^3	Specific gravity
Fine		43	1.82	2.71
Coarse	Size 1	10	1.44	2.65
	Size 2	22	1.44	2.59
	Size 6	25	1.41	2.53

2.2 Fly Ash Specifications and Properties

As mentioned above, Fly Ash (FA) complies with both of BS 3892 and ASTMC618 Class F was selected to be the only pozzolanic material added to RCC mixtures. The physical properties and chemical composition of fly ash, as provided by the manufacturer, is presented in Table 2.

Table 2: Physical properties and chemical composition of fly ash

Physical Property	Value	BS 3892 Limits	ASTM C618 Limits
Retained on sieve 45 µm, %	10.10	12 max	34 max
Soundness, mm	1.00	10	0.8 %
Density, t/m^3	2.24	2.00	-
Moisture content, %	0.02	0.5 max	3.0 % max
Chemical Compound	% by Wt.	BS 3892	ASTM C618
Silicon dioxide, SiO_2	61.30	-	total 70 % min
Aluminum oxide, Al_2O_3	29.30	-	
Ferric oxide, Fe_2O_3	4.60	-	
Calcium oxide, CaO	1.11	10 % max	10 % max
Magnesium oxide, MgO	0.59	-	-
Titanium dioxide, TiO_2	1.78	-	-
Manganese, Mn_2O_3	0.03	-	-
Sulfur trioxide, SO_3	0.14	2 % max	5 % max
Potassium oxide, K_2O	1.00	-	-
Sodium oxide, Na_2O	0.22	-	-
Loss on Ignition, LOI	0.80	7 % max	6.0 % max

2.3 Mixture Proportioning

According to ACI 207.5R, there are three different mixture design procedures; (1) proportioning RCC to meet specified limits of consistency, (2) relying on trial mixture tests to select the most economical aggregate-cementitious materials combination, and (3) proportioning RCC using soils compaction concepts. Among the three procedures, the trial mixture tests was adopted in the current study as this method is suitable for all types of aggregates and there is a minimum and maximum limit for both cement content and w/cm ratio. Moreover, the evaluation tests are similar to that of conventional concrete. Concrete mixtures were designed to be a no-slump concrete using absolute volume method.

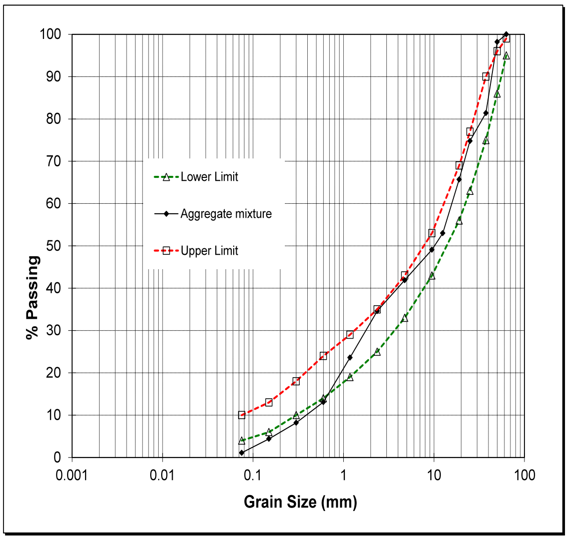

Fig. 1: Aggregate gradation used for RCC

Two groups of concrete mixtures were designed with w/cm materials ratio of 1.0 and 0.9. Each group contains six mixtures with different fly ash replacement percentages as presented in Table 3. The lower specific gravity of fly ash compared with that of Portland cement means that when replacement is based on mass, a larger volume of fly ash is added than the volume of cement removed [16-17]. During lab work, it was noticed that concrete mixtures containing Cm of 120 Kg/m^3 and w/cm = 0.9 have low paste content and are found difficult in casting, handling, and compaction. Therefore, it was decided to discard mixes No. 10-12.

Table 3: Details of concrete mix proportions

Mix No.	W/Cm	Weight per unit volume (kg/m^3)						
		cm		W	Coarse Agg.			S
		C	FA		Size 6	Size 2	Size 1	
1	1.0	150	0	150	528	464	211	908
2		75	75	150	522	459	209	897
3		60	90	150	520	458	208	895
4		120	0	120	554	487	221	952
5		60	60	120	549	483	219	944
6		50	70	120	548	482	219	942
7	0.9	150	0	135	538	473	215	924
8		75	75	135	531	467	213	914
9		60	90	135	530	466	212	912
10		120	0	108	562	494	225	966
11		60	60	108	557	490	223	957
12		50	70	108	556	489	222	956

2.4 Mixing, Casting, and Curing Procedure

The various components of the mixture are weighted. A dry blend of the cement and fly ash was first prepared outside the mixer. The cement and fly ash were blended together by hand, in a container, until a homogeneous color was obtained. The coarse aggregates, size 6 followed by size 2 followed by size 1 were firstly put in the mixer followed by sand and Cm. These components were dry-flipped in blender for 90 seconds. The amount of water was added to be distributed during the continuous mixing of different components for a period of 30 seconds. Afterwards, the mixing continued for another 90 seconds. The mixer was stopped and the materials sticking to the mixer walls and shafts were downloaded and removed using an iron bar, [18-19]. Finally, the mixing process was resumed for another 90 seconds to reach total mixing time to 5 minutes "300 seconds". After mixing, concrete was released from the mixer and remixed manually to assure the homogeneity of the concrete. Then, slump and unit weight tests were carried out on fresh concrete. Concrete was placed in the oiled steel moulds for the preparation of samples and they were filled in three layers with each layer vibrated with an internal vibrator. Because of the relatively low paste content of RCC mixtures, all moulds were finally vibrated on a shaking table by using just the vibration time needed for good compaction (until the casting surface shows slight traces of bleeding) and the settlement of the final surface were made. Immediately after casting, the top surface of the specimens was covered with a plastic sheet to reduce the rate of water evaporation until demoulding. Samples were extracted from the moulds after 24 hours and all the specimens were put in the water curing basin until the time of testing. Specimens were prepared and tested according to ASTM standards.

2.5 Test Specimens

The compressive strength was measured at ages of 3, 7, 28, 90 and 180 days after concrete casting on cube specimens (150 x 150 x 150 mm). While splitting and flexural strength were done at ages of 28 and 90 days on cylinders (150 x 300 mm) and prismatic specimens (100x100x500 mm), respectively. The static young’s modulus and water absorption were measured only at age of 28 days. All was undertaken using the facilities of Department of Construction materials, CRI, NWRC, MWRI, according to the specifications provided by ESS.

3. LAB. RESULTS AND DISCUSSION

3.1 Fresh Concrete Properties

The properties of fresh concrete are measured in terms of slump and unit weight. The measured values of slump confirmed that all concrete mixtures have zero-slump as being designed. As plotted in Fig. 2. It is clear that using fly ash, as a partial replacement of cement, has no significant effect on the unit weight of fresh concrete for both examined w/cm ratios. However, unit weight of RCC mixtures with w/cm of 1.0 is marginally higher than that of w/cm of 0.9. In addition, unit weight of RCC is found directly proportional to the total cementitious materials content of concrete.

3.2 Hardened Concrete Properties

3.2.1 Compressive strength

It can be concluded that the obtained compressive strength, f_c is inversely proportional with the fly ash percent as drawn in Figs. 3-4. In other words, increasing the FA replacement ratio decreases f_c of concrete. Moreover, f_c values for concrete mixtures containing FA are always smaller than the corresponding values of concrete containing only OPC. These results are valid for all investigated w/cm ratios, cementitious materials content and testing ages.

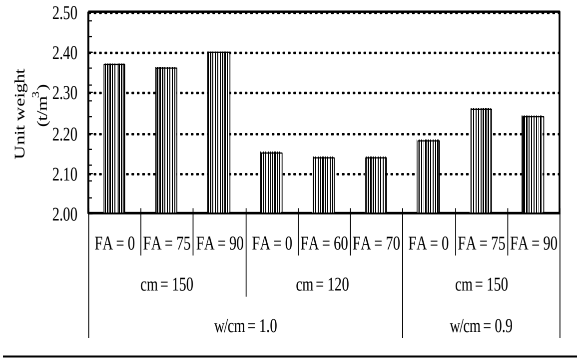

Fig. 2: Unit weight of studied mixtures

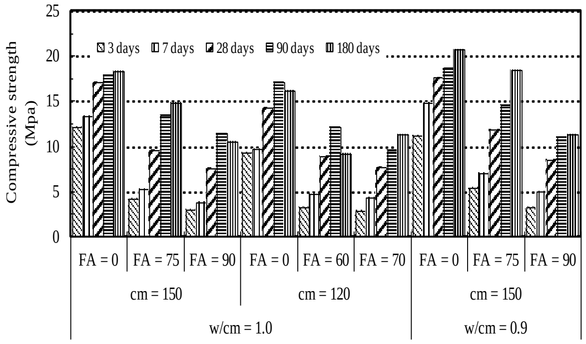

Fig. 3: f_c of the studied mixtures

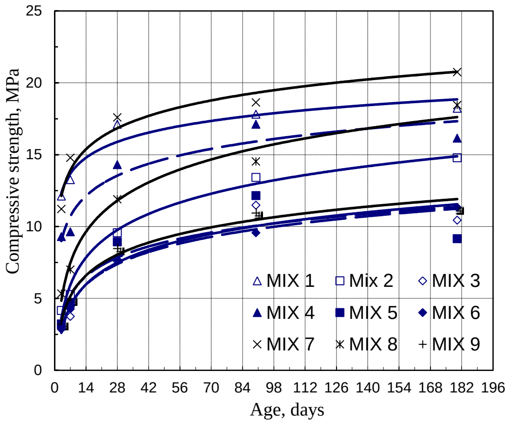

Fig. 4: f_c versus concrete age

3.2.2 Strength development rate

The ratio of 90-day compressive strength to the 28-day one (f_{c-90}/f_{c-28}) is illustrated in both Table 4 and Fig. 4. The f_c values, at 90 days after casting, for concrete mixtures containing only OPC ranged from 105 to 120 % of 28-day strength. While the corresponding ratio for RCC mixtures containing OPC and FA ranged from 122 to 151 %. This observation agrees with the findings illustrated by [20]. As expected, increasing the FA replacement ratio increases the (f_{c-90}/f_{c-28}) ratio, which can be attributed to the long-term fly ash pozzolanic reaction.

Table 4: Effect of fly ash on strength development, f_{c-90}/f_{c-28} ratio

Mix No.	W/ Cm	Cm (Kg/m^3)	FA (Kg/m^3)	Ratio (%)
1	1.0	150	0	105
2			75	140
3			90	151
4		120	0	120
5			60	136
6			70	124
7	0.9	150	0	106
8			75	122
9			90	129

3.2.3 Tensile strength

Tensile strength in terms of splitting and flexural strength was illustrated in Fig. 5 and Fig. 6, respectively. It is obvious that concrete mixtures containing OPC and FA had smaller splitting tensile and flexural strength values than the corresponding values of mixtures containing only OPC. Increasing the FA replacement ratio decreases both splitting tensile and flexural strengths of concrete. This observation is clear for all examined w/cm ratios, cementitious materials content, and testing ages adopted in the current study. Moreover, the examined tensile strength is directly proportional to the total cementitious materials content.

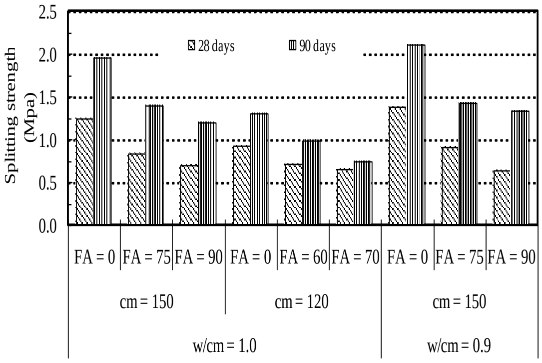

Fig. 5: Splitting strength of studied mixtures

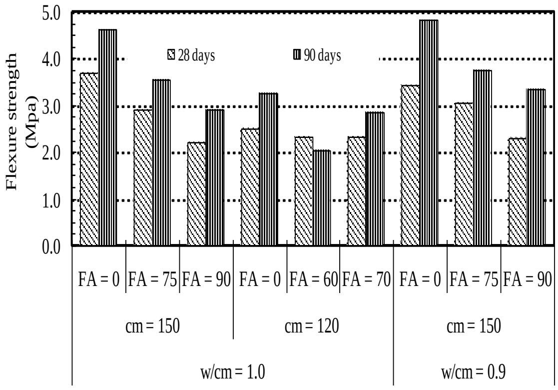

Fig. 6: Flexural strength of studied mixtures

3.2.4 Elastic modulus

Static elastic modulus of concrete was measured at 28 days after casting and plotted in Fig. 7. Generally, it can be noticed that elastic modulus values of concrete containing OPC only are higher than those of concrete containing OPC and FA. Similar findings were reported [20].

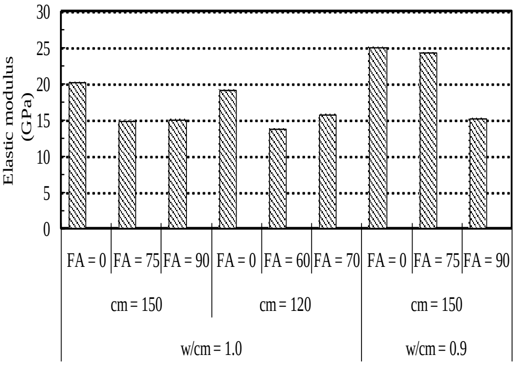

Fig. 7: Static elastic modulus of concrete

3.2.5 Concrete absorption

Calcium hydroxide, CH, liberated by cement hydrating is water-soluble and may leach out of hardened concrete, leaving voids for the ingress of water. Through its pozzolanic properties, fly ash chemically combines with calcium hydroxide and water to produce C-S-H, thus reducing the risk of leaching calcium hydroxide [15]. Additionally, the long-term reaction of fly ash refines the pore structure of concrete to reduce the ingress of water [21], and the results of mixtures containing FA as 50% cement replacement ratio verifies this result. Despite this fact, water absorption percent values of concrete containing OPC and FA are more or less comparable to those values of concrete containing only OPC as shown in Fig. 8. The reason may due to the relatively low cement content, and consequently, there is a reduced amount of CH for pozzolanic reaction of fly ash. Moreover, water absorption was measured at 28 days while the greatest influence of fly ash on permeability occurs within the first 2 to 20 months [13].

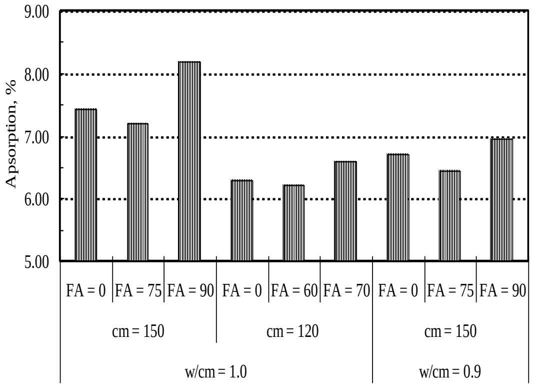

Fig. 8: Water absorption of concrete

4. MODEL CONSTRUCTION

Materials selection and proportioning of RCC dam mixtures is controlled by design requirements, availability of materials, and planned placement procedures [22]. In this study, the following procedures are followed for constructing RCCD model.

4.1 Quality Assurance Tests

The Quality Assurance, QA, tests were carried out on both fine and coarse aggregate to determine their physical, mechanical properties as well as chemical composition and finally determination of the global grading curve for the combined aggregate with respect to the upper and lower boundaries of the grading listed in ACI 207.5R, [13]. The grading curve for the combined aggregate is verified as was previously shown in Fig. 1.

4.2 Design of RCC Mixture

The mixture must be proportioned and designed to provide the strength, durability, and impermeability necessary to meet all design requirements for stability and performance, [22-23]. As previously discussed, various procedures for mixture proportioning have been developed at CRI material laboratory. Based on the lab experimental results, the proportions of the examined mixture No 9 having 75 Kg fly ash as a partial replacement (50 %) of cement content and w/cm of 0.90 are selected for constructing the RCCD model.

4.3 Pre-Construction Stage

Before constructing RCCD model, some of trial slabs, as shown in Figs. 9-10, are casted in the site to firstly confirm both slump and strength as well as to define the procedure of the compaction process provided by the soil compactor machine as well as measure its efficiency.

Fig. 9: Trial slabs compacted with soil compactor

Fig. 10: Verification of no slump

4.4 Consideration for Layer Thickness and No of Passes Selection

The benefits of thicker or thinner lifts should be optimized. Thicker lifts mean fewer lift joints and fewer potential seepage paths, but thinner lifts allow the joints to be covered sooner with better bond potential. Thinner lifts are generally more suited to smaller jobs and thicker lifts more suitable on larger jobs, [22-26]. Maneuverability, compactive force, drum size, frequency, amplitude, operating speed, and required maintenance are all parameters to be considered in the selection of a roller.

4.5 Lifts Thickness and Minimum No. of Passes

The minimum number of passes for a given vibrating roller to achieve specified compaction depends primarily on the RCC mixture, lift thickness, and type of a compactor machine. Experience shows that lift thickness will be governed more by spreading efficiency than by compaction requirements. Tests were performed in test fills prior to the early stages of dam construction to determine the minimum number of passes required for full compaction using the design mixture and the planned lift thickness as shown in Fig. 11. Three to six passes of a double-drum vibratory roller will achieve the desired density for RCC lifts in the range of 150mm to 450mm thick, [22], while it reported by [23] that the thickness of the lifts normally ranges from 150 to 900 mm, however, in the U.S. a lift thickness of 300 mm is often used. This assumes compaction in a timely manner and with appropriate equipment since overcompaction or excessive rolling actually reduces the density and should be avoided which is proved in Fig. 12. A number of slabs with the same proportions are casted and examined with the purpose of determining the optimum thickness of layer as well as the required number of passes provided by soil compactor machine needed to get the satisfactory compaction. Therefore, different lifts thickness of 200, 250, 350 mm and No of passes of 4, 6, 8, 10 for every thickness are examined for this purpose. Sand cone test is conducted to define the dry concrete density after compaction. As a result of this investigation as clearly observed in Fig. 12, a 20 mm layer thickness and 6 as No of passes are followed to construct the RCC dam model. Moreover, some core samples are extracted from the trial slabs by the drilling machine shown in Fig. 13, while Fig. 14 presents photos for some of these extracted cores.

Fig. 11: Conducting sand cone test for measuring compaction efficiency

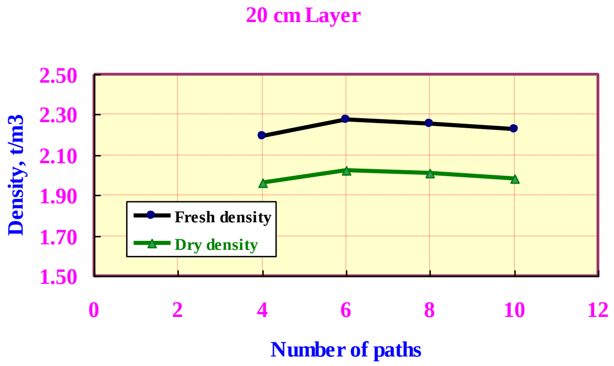

Fig. 12: Results of sand cone test

Fig. 13: Drilling concrete core machine

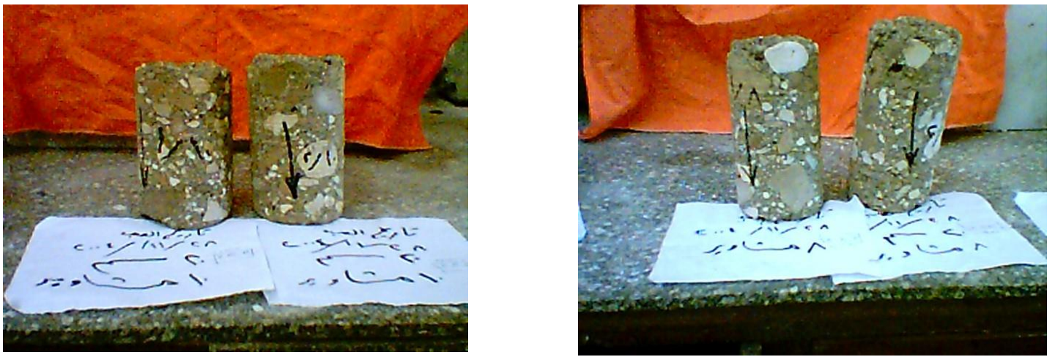

Fig. 14: Samples of the cores extracted from the trial slabs

4.6 X-Section of RCC Dam

The dam model is hydraulically designed to determine its different dimensions taken into considerations the different situations that will be faced based on the model scale and the allowable space for its application. The RCC dam with a dimension of 3600 mm height, 3500 mm base width, 500 mm top width, and the back slope of 1:1 is chosen to be executed for the dam model construction. Fig. 15 describes the designed cross section of the dam with its different dimensions.

4.7 Instrumentations

Instruments should be installed at selected locations throughout the dam and its foundation so that measurements can be taken to monitor the structure's behavior during construction and subsequent operation. The number, type, and location of instruments installed during construction of RCC dams become a concern in that they may hamper rapid placement, thereby increasing construction costs. The designer, with a clear understanding of the project's purpose, can design an inexpensive but functional instrument package and layout to provide immediate and long-range dam and foundation behavioral data, [22].

Embedded instruments can be used to determine temperature, strain, stress, and hydrostatic pore pressure, and to measure cracks. Twelve (12) thermocouples were installed in the RCCD during construction in a predetermined grid will provide continuous temperature data during and after construction. As shown in Fig. 15, thermocouples were cited into 5 in the bottom third of the dam, another 5 along the top third of the dam, while another 2 thermocouples were distributed as one in the middle height of the dam and the last one embedded at the top of the dam (crest). Piezometers were also installed to measure the water depth (i.e. judge dam permeability) along the dam at the bottom layer of the dam and distributed along the whole width of the dam as shown in Fig. 16. Moreover, to measure the bond strength between the different dam lifts, 2 electrical strain gauges were bonded on two steel bars; one horizontal and one inclined as described in Fig. 16; and installed at the interface between layers 11 and 12. Finally, 4 electrical strain gauges were bonded to the exterior concrete surfaces and a cell pressure was installed in front of the dam to measure the front pressure that the dam will face.

Fig. 16 illustrates all these kinds of instrumentations. Instruments associated with RCC dams were read at prescribed intervals for an extended period of time after construction to build an historical structural behavior record. Immediate attention will be required to determine if the readings were made correctly, or the instruments need to be maintenanced. It is advisable to provide the owner of the dam with information about the minimum and maximum readings expected for each instrument.

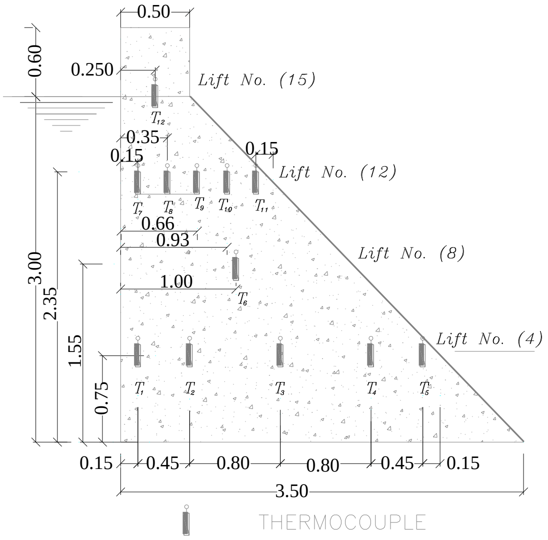

Fig. 15: Thermo-couple instrumentations used for RCCD

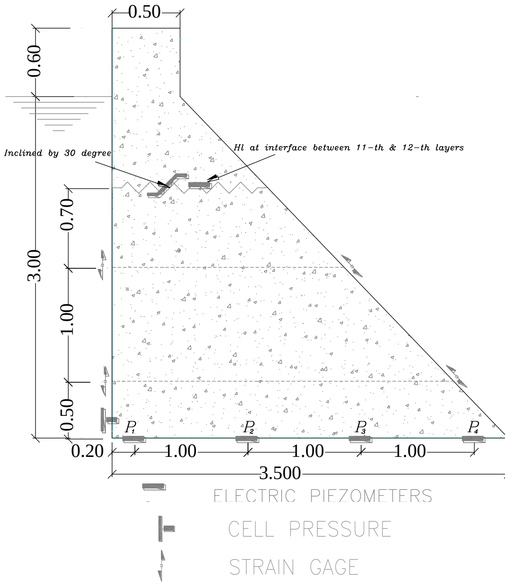

Fig. 16: Piezometers, strain gauges, cell pressure instrumentations used for RCCD

4.8 Placing and Spreading

Firstly, as described in Fig. 17, the placement of concrete is conducted using the gutter. Then, for the concrete homogeneity purposes, the concrete is remixed to overcome segregation problems as shown in Fig. 18.

A preferred technique of placing RCC is to push an advancing face of each lift progressing from one abutment to the other, [22]. The lift extends from the downstream to the upstream face. Soil compactor equipment, (Fig. 9), has proven to be best for spreading RCCD model. It is fast, sufficiently accurate, and contributes to uniformly compacted RCC. By careful spreading, a soil compactor may remix RCC and minimize the segregation that occurs in dumping. Careful attention should be given to assure that remixing is occurring and that the soil compactor is not simply hiding segregated material. Each RCC mixture will have its own characteristic behavior for compaction depending on temperature, humidity, wind, plasticity of the aggregate fines, overall gradation, and the maximum-size aggregate, [22-24]. Furthermore, Fig. 19 shows constructing the RCCD into lifts of 200 mm thickness, while Figs. 20-22 describes how the formwork was strengthened during the concrete placement process and no formwork removal for the previous casted lift until it was completely covered by the next two subsequent lifts.

Fig. 17: Placement of concrete by gutter

Fig. 18: Remixing the concrete manually

Fig. 19: Layering dam into 20 cm layers-thickness

Fig. 20: Concrete placement into one of dam-layers

Fig. 21: No formwork removal for the previous casted layer

4.9 RCCD Curing

After RCC has been placed and compacted, the lift surface must be cured and protected from weather just as for concrete placed by conventional methods. The surface must be maintained in a moist condition, or at least so that moisture does not escape. It should also be protected from temperature extremes until it gains sufficient strength. During placing, a brief and very light rain or mist can be tolerated provided that equipment does not track mud onto the RCC or begin to work moisture into the surface so that the compacted RCC is damaged. As soon as damage is evident or the roller begins to pick up material on the drum, placing should be stopped. When conveyors are used for delivery and little or no vehicular traffic is required on the RCC, construction can continue into slightly wetter weather, [22]. This may require a very slight decrease in the amount of mixture water used because of the higher humidity and lack of surface drying. During construction, the compacted surfaces of RCC lifts should be maintained in a damp condition but without ponded water. The surface may be covered with plastic or other means to prevent loss of moisture. Fig. 23 shows the used plastic as enclosure for covering the concrete lift immediately after casting to protect it from rain and sun.

Fig. 22: Strengthen formwork during placement

Fig. 23: Plastic covering for casted layers

Fig. 24: Installing piezometers, electrical strain gauges, and pressure cell

Fig. 25: RCC dam after construction completion in its final shape

Each RCCD should be evaluated for its exposure conditions and material properties. The hydration heat generated by the RCC mass and the continuous placing sequence can combine to allow placing in very cool weather, [26-27]. Therefore, the current RCCD model is constructed in winter at the end of December and the construction is completed on January 15. Fig. 24 shows photos of some instrumentations installed as a part of monitoring system of the dam such as piezometers, electrical strain gauges, and pressure cell. Fig. 25 describes photos for RCC dam in its final form after its construction completion.

5. RCCD THERMAL ANALYSIS

The principal changes in volume associated with massive placements of concrete result from the changes in temperature that occur during the life of the dam. Drying shrinkage is limited to the exposed surfaces of the mass. Autogeneous changes in volume are normally inconsequential. They are primarily dependent on the quality and quantity of the cementitious materials used but may also be influenced by aggregates, [22]. A disadvantage of RCCD is that it may have a poor resistance to tension and may crack from the thermal strains along the major axis of the dam following the cooling down of the dam. Cracking of the mass will occur when restraint of the change in volume exceeds the strain capacity of the concrete, [27-29]. Thermal strains are the major cause that leads to wide cracks that possibly can affect the overall performance of concrete dams. These thermal cracks are mainly vertical and thus are perpendicular to the axis of the dam. The structural consequences of these cracks may not be significant for a gravity straight dam. However, they can be very undesirable for gravity/arch dams in which part of the load is transferred horizontally; then cracks could lead to an unsafe gravity section due to an interruption of the path of arch action. By decreasing the monolithic action of the entire structure, cracks can reduce the ability of the dam to resist settlement, and vibrations from earthquakes and live loads and waves. Cracks also increase seepage volume through the dam. This seeped water may contain chemicals that weaken the strength of concrete and its chemical bindings that are one of the main reasons for concrete to have its strength, [28]. The principal factors affecting cracking are the peak internal temperature reached soon after placement, the average annual ambient temperature to which the mass will eventually cool, creep, the modulus of elasticity, and the degree of restraint acting at the crack location. These cracks appear during the first or second winter season and generally initiate at exposed surfaces adjacent to the foundation where restraint is the greatest. From there, they will propagate inward and upward with continued cooling of the mass. If the change in volume is sufficiently large, the cracking will penetrate the full thickness of the dam and become a source of leakage. Figs. 26-32 illustrate the measured temperatures and its distribution inside the RCCD for different external climate temperatures.

Analyzing the thermal results that plotted in Figs 26-32, it can be clearly observed that on the early ages after RCCD completion, the temperature distribution inside the dam core are found (14^o) smaller than that of the whole dam perimeter which adjacent to the surrounding climate temperature (18.6^o) as can be seen in Fig. 26, whereas in the following monitored temperatures drawn in Figs. 27-28, the temperatures values inside the dam core raised a little bit from 15^o to 20^o and the same trend is noticed from the two figures since the surrounding climate temperatures was the same (15^o). With increasing the age of the dam, it is observed from Fig. 29 and Fig. 30 representing the day and night since the average weather temperatures was ranged from 30.33^o at day light and 23.2^o at night, the measured temperatures inside the dam core are less than that of the outside temperatures. They were minimized from 30.33^o to 18^o and from 23.2^o to 19^o at day light and night respectively. The obtained results are fantastic and unexpected. Fig. 31 confirms this result since the monitored temperatures inside the dam is more or less comparable with that of the outside temperatures to range from 17.5^o-19.54^o. However, at night the temperatures inside the dam are increased from 11.31^o to 21.5^o making the dam keeping its temperature to be as the same day light one.

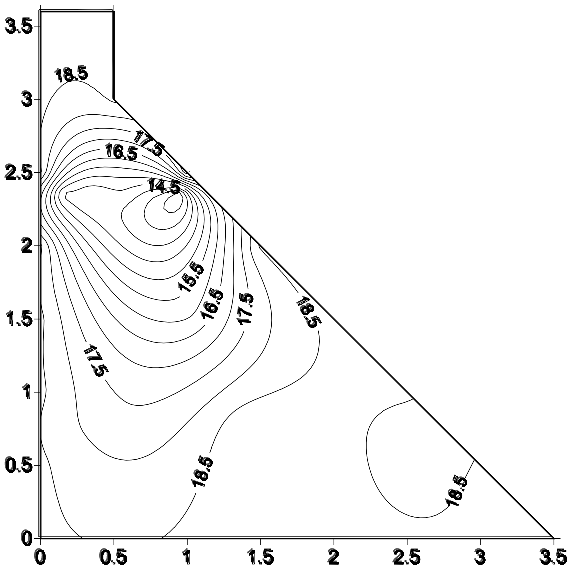

Fig. 26: Thermal distribution along the dam at air temperature of 18.6º (16/1)

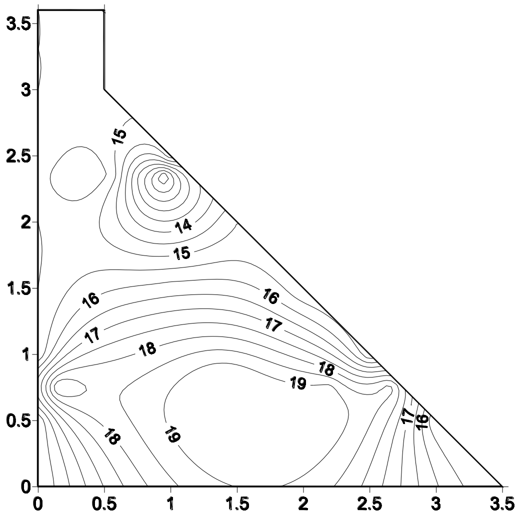

Fig. 27: Thermal distribution along the dam at air temperature of 15º (17/1)

All these great temperatures findings may be due to one or all of these reasons:

1. By using natural pozzolans, fly ash in the concrete in massive dam construction, it is possible to achieve a reduction of the temperature rise without incurring the undesirable effects associated with very lean mixtures; i.e., harshness, bleeding, tendency to segregate, and tendency to increase permeability.
2. Use of natural pozzolans, fly ash in the concrete can reduce the thermal stresses by the reduction of the heat of hydration in mass concrete structures.
3. Improved sulfate resistance and reduction of alkali-aggregate reaction provided by proper incorporation of pozzolans into concrete mixtures are other important considerations in the construction of massive concrete dams.
4. The low early RCC elasticity modulus may reduce temperature-related cracking.

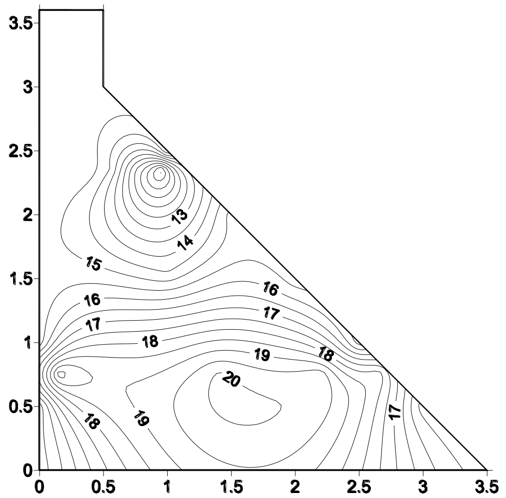

Fig. 28: Thermal distribution along the dam at air temperature of 15.2º (18/1)

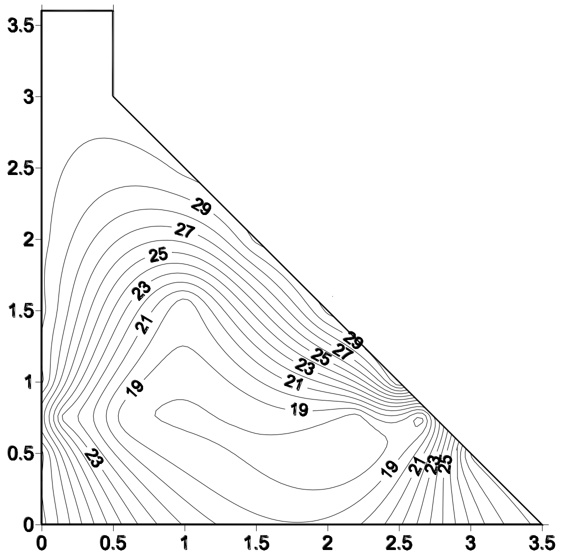

Fig. 29: Thermal distribution along the dam at air temperature of 30.33º (29/1 day)

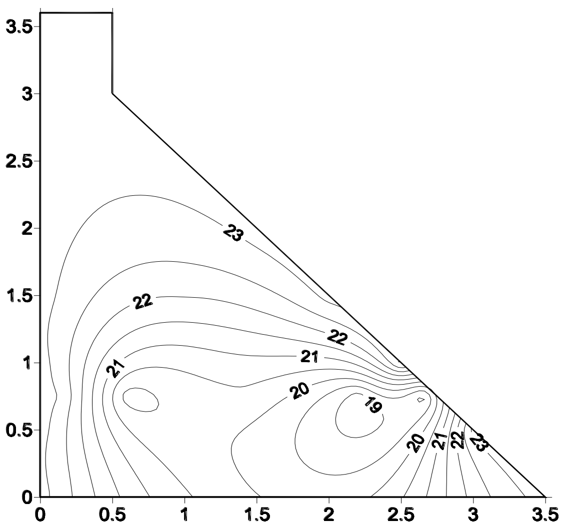

Fig. 30: Thermal distribution along the dam at air temperature of 23.2º (29/1 night)

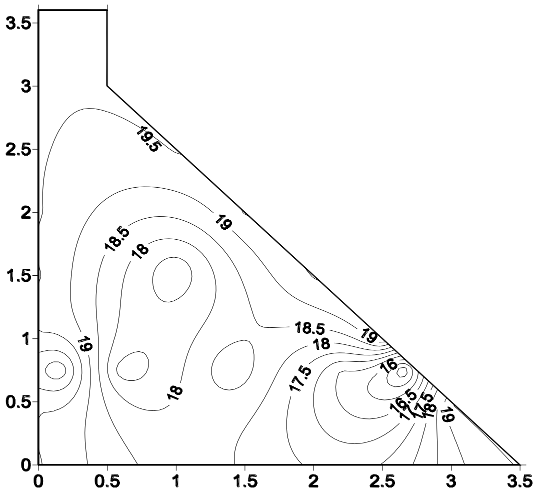

Fig. 31: Thermal distribution along the dam at air temperature of 19.54º (2/2 day)

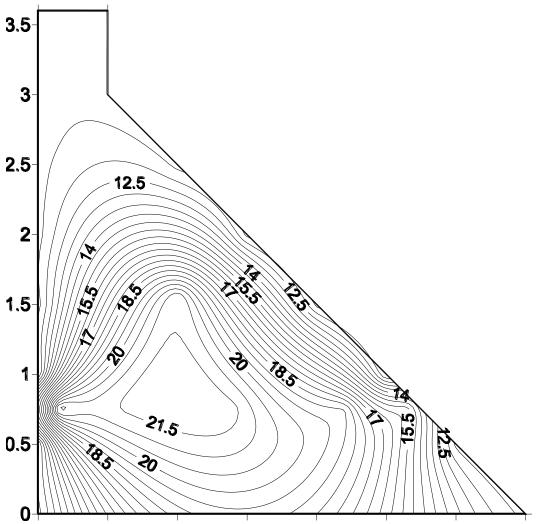

Fig. 32: Thermal distribution along the dam at air temperature of 11.31º (2/2 night)

6. SUMMARY AND CONCLUSIONS

In this research, the effect of fly ash on the properties of fresh and hardened concrete is presented. For fresh concrete, slump and unit weight tests were performed while the measured properties of hardened concrete included compressive strength, tensile strength, (splitting and flexural), static elastic modulus, and water absorption. The appropriate design mix was selected and applied in the construction of the dam model in the first stage of this study. Furthermore, this paper introduces the sequences of constructing RCC dam as well as installing the different devices (through the overall monitoring system applied for the dam) at selected locations throughout the dam and its foundation. Different measurements were taken to monitor the structure's behavior during construction and after construction. Results of thermal analysis for the dam are also presented. On the light of the obtained results of the investigated concrete mixtures, the following conclusions may be drawn:

1- Roller compacted concrete mixtures can be designed and produced using the available local Egyptian materials.
2- Fly ash, through its pozzolanic and cementitious properties, is a suitable replacement material for Ordinary Portland cement to reduce cement usage without invading concrete properties and can contribute to strength gain and may improve performance of fresh and hardened concrete.
3- By using natural pozzolans, fly ash in massive concrete dam construction, it is possible to achieve a reduction of the temperature rise without any undesirable effects such as bleeding, tendency to segregate, and tendency to increase permeability. It reduces the thermal stresses by reducing the heat of hydration in mass concrete structures.
4- Use of fly ash and provide a maximum of aggregate and a minimum amount of cement while developing the required properties often results in low early

modulus of elasticity of RCC that may reduce temperature-related cracking and finally leads to durability improvement and finally a reduction in the cost of concrete construction.

5- Results are promising and more measurements and further researches are still needed to be carried out to implement RCC in dam construction.

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