

# Thermal and Structural Performance of RCC Dams under Derna Climatic Conditions: A Numerical Study

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## ABSTRACT

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The sequence of construction and the surrounding environmental conditions of Roller Compacted Concrete (RCC) dams play a significant role in the temperature distribution and the variation of stress fields within the dam body. The Bu Mansur Dam, originally designed as a conventional rockfill embankment dam, was selected in this study to verify the adopted numerical procedure. In addition, the feasibility of RCC technology is investigated as an alternative construction method to reduce project costs and enhance overall competitiveness. This study takes into account several key parameters, including the adiabatic temperature rise, the sequence of concrete placement, potential construction interruptions, the existence of internal galleries, and variations in climatic conditions. A numerical model that accounts for aging effects and temperature-dependent material properties is employed to simulate the concrete behaviour. Structural integrity with respect to crack initiation over time is evaluated using a crack safety factor. The results indicate that, due to the high ambient temperatures, combined with intense solar radiation, the occurrence of through-cracks in the Bu Mansur Dam is unavoidable in the absence of proper thermal control measures.

# أداء الحارري والسلوكي الإنشائي لسدود الخرسانة المدكوكة (RCC) تحت تأثير الظروف المناخية لمدينة درنة: دراسة عددية

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## المُخلص

تلعب مراحل تنفيذ البناء والظروف البيئية المحيطة بسدود الخرسانة المدكوكة (RCC) دورًا حاسمًا في توزيع درجات الحرارة وتطور مجالات الإجهاد داخل جسم السد. وقد تم اختبار سد بومنصور، الذي صُمم في الأصل كسد ركامي صخري تقليدي، في هذه الدراسة بغرض التحقق من دقة الإجراء العددي المعتمد. علاوة على ذلك، تم بحث جدوى اعتماد تقنية الخرسانة المدكوكة (RCC) كبديل لطريقة الإنشاء التقليدية، بهدف خفض تكاليف المشروع وتعزيز تنافسيته.

تأخذ هذه الدراسة في الاعتبار مجموعة من المعلمات الأساسية، تشمل حرارة الإماهة، وتسلسل صب الخرسانة، واحتمالية حدوث توقفات أثناء التنفيذ، ووجود الممرات الداخلية، بالإضافة إلى التغيرات في الظروف المناخية. كما تم استخدام نموذج عددي يأخذ في الحسبان تأثيرات التقدم العمري (Aging) وخواص المواد المعتمدة على درجة الحرارة، وذلك لمحاكاة سلوك الخرسانة بدقة.

وقد جرى تقييم السلامة الإنشائية من حيث نشوء التشققات مع مرور الزمن باستخدام معامل أمان التشقق. وتشير النتائج إلى أنه، نتيجة لارتفاع درجات الحرارة المحيطة مقترنة بشدة الإشعاع الشمسي، فإن حدوث تشققات نافذة (through-cracks) في سد بومنصور يُعد أمرًا لا مفر منه في حال عدم تطبيق إجراءات فعالة للتحكم الحراري.

الكلمات المفتاحية: سدود الخرسانة المدكوكة (RCC)؛ التأثيرات الحرارية؛ تحليل الإجهادات.

## 1 Introduction

The construction sequence and fluctuations in ambient temperature around roller-compacted concrete (RCC) dams play a crucial role in shaping their thermal and stress responses (Bofang & Ping, 2001). Furthermore, heat dissipation within the dam body occurs slowly, typically requiring a considerable amount of time for the internal temperature to reach equilibrium. Therefore, it is necessary to perform detailed simulations of temperature and stress distributions at different time intervals during both the construction stage and the service life of the dam (Liu & Liu 1996, Zhang et al. 2009).

Previous research has addressed these aspects using advanced numerical approaches. For instance, Bayagoob utilized the finite element method to model the thermal interaction between the RCC dam body and the reservoir, while incorporating the effects of reservoir operating conditions (Bayagoob et al, 2010). The results yielded realistic temperature contour distributions and indicated a gradual cooling rate of about 1 °C per year for the Kinta RCC dam in Malaysia. In this study, the initial temperature of the upper layers of the reservoir water was assumed to be 2 °C lower than the ambient air temperature.

The thermal response of RCC dams has been extensively studied due to its critical role in the development of temperature-induced stresses during construction and service life. Mousavi and Pasbani Khiavi (2022) conducted a comprehensive investigation using a finite element model implemented in ANSYS Workbench, integrated with a probabilistic analysis framework. The study employed Latin hypercube sampling to account for uncertainties in key material properties, including Young's modulus, thermal conductivity, and specific heat. The results indicated that thermal variations significantly influence the stress state within the dam body, particularly leading to tensile stresses during cooling periods, which may increase the risk of cracking. Moreover, the sensitivity analysis revealed that both thermal and mechanical parameters play a substantial role in governing structural response, with young's modulus identified as a dominant factor affecting tensile stress development. These findings underscore the necessity of incorporating parameter variability and environmental effects in the thermal analysis and design of RCC dams (Mousavi & Khiavi, 2022).

The thermal and stress responses of the Mianhuatan roller-compacted concrete (RCC) gravity dam in China have been analyzed numerically by considering several key governing factors. These include the staged construction process, creep deformation, heat of hydration from cementitious materials, and fluctuations in ambient environmental temperature. These parameters significantly affect both the thermal distribution and the resulting stress fields within RCC dams, and therefore must be carefully considered in numerical simulations (Zhang & Zhu, 2002). For long-term performance assessment, the analysis relies on

representative environmental conditions. In this context, the mean annual air temperature together with the average annual river water temperature are adopted as boundary conditions to predict the evolution of temperature and stress fields during the dam's service life (Zhang & Zhu, 2002). A three-dimensional finite element model for integrated thermal–structural analysis of RCC dams was proposed by Noorzai. The framework considered both site-specific climatic influences and the thermal properties of the construction materials, allowing for a reliable prediction of the dam response under realistic operating and construction conditions. The structural response was evaluated using an elasto-plastic formulation, which allows for nonlinear stress–strain behaviour within the dam body. The results demonstrated that the elasto-plastic approach enhances stress redistribution and yields more realistic stress patterns compared to linear elastic analysis. Nevertheless, the study did not consider time-dependent effects such as creep and shrinkage, which could have a significant impact on the long-term performance of RCC dams (Noorzai et al. 2009)

Under conditions of elevated ambient temperatures and intense solar radiation, thermal control is a critical concern in such regions. RCC is typically placed in thin lifts over large surface areas, which promotes a noticeable rise in temperature due to cement hydration and solar radiation. In contrast to conventional mass concrete dams, RCC dams generally do not incorporate embedded cooling systems; therefore, heat dissipation is primarily limited to the exposed surfaces. Under hot climatic conditions, the upper surface may even absorb additional heat rather than release it, further intensifying the thermal build-up. Such pronounced temperature variations can lead to the development of significant thermal stresses within the dam body, which must be carefully considered in design and analysis to prevent potential cracking and long-term performance issues.

Kuzmanovic et al employed a three-dimensional finite element model to investigate the thermal and stress behaviour of RCC gravity dams under staged construction conditions. The approach simulates temperature development by accounting for heat generated during cement hydration and incorporates time-dependent material properties. The dam and its foundation are discretized into solid elements, and the construction process is modelled step-by-step, with each phase using the previous state as initial conditions. Realistic boundary and initial conditions are defined based on field data, and the model is validated against in-situ measurements. The computed temperature field is then used to evaluate thermal stresses, and different monolith lengths are examined to assess their influence on stress distribution and optimize joint spacing (Kuzmanovic et al, 2015).

The thermal behaviour of a roller-compacted concrete (RCC) dam was investigated through a transient analysis based on the finite element approach using ANSYS Workbench. The simulation replicated the construction stages by modelling the placement of

successive layers, incorporating time-dependent material properties and the heat generated from cement hydration. Heat transfer processes, including conduction, convection, and radiation, were considered alongside environmental influences such as ambient temperature and seasonal changes. Several construction conditions, particularly casting during different climatic periods, were examined to understand their impact on temperature distribution and the development of thermal stresses. The analysis demonstrated that the temperature within the dam increases initially due to hydration and then declines تدريجياً with time, with surface zones cooling more rapidly than the interior. Peak tensile stresses were found near the heel and toe areas, whereas the central region experienced comparatively lower stresses. The study further showed that large thermal gradients, especially those resulting from summer construction followed by cooler conditions, may trigger cracking. It was also concluded that managing construction practices and controlling the initial temperature of concrete can help minimize the likelihood of thermal cracking (Mousavi et al, 2017).

To evaluate the time-dependent thermal response of RCC dams, comprehensive 2D and 3D numerical simulations were implemented. The analyses incorporated realistic dam geometry, construction procedures, and temperature-sensitive material characteristics. Model validation was carried out using field data from the Platanovyssi dam, demonstrating strong agreement between predicted and measured temperatures. The results highlight the significant influence of boundary conditions and mixture characteristics on the thermal response, while also indicating that 2D models can provide sufficiently accurate predictions for phased thermal analysis (Kuzmanovic et al, 2010).

Despite the growing application of RCC dams worldwide, information regarding their thermal and structural performance under Libyan environmental conditions remains scarce. Therefore, this study presents a numerical assessment of the thermal behavior of an RCC dam located in Derna, northeastern Libya, considering local climatic effects. The analysis aims to evaluate the resulting thermal response and its implications for structural performance during the dam's lifecycle. However, this study does not include a comprehensive hydrological design or flood routing analysis, nor does it address foundation bearing capacity, which is particularly complex due to the karstic nature of the local limestone formation. The main objectives of this study are to evaluate the likelihood of crack development within the dam body resulting from temperature variations, self-weight (dead load), and hydrostatic pressures. In addition, the research aims to propose an appropriate construction sequence that minimizes thermal and structural stresses, thereby enhancing the overall performance and safety of the dam.

## 2 Computation of Thermal Field

The Taylor–Galerkin method is adopted as the numerical formulation in this study. The governing differential equations are then derived, providing the basis for the subsequent analysis (Bayagoob et al, 2010).

$$[K_t]^{(e)} \{T\}^{(e)} - [\beta]^{(e)} \left\{ \frac{\partial T}{\partial t} \right\}^{(e)} = \{F\}^{(e)} \quad (1)$$

In this formulation,  $[\beta]^e$  denotes the capacitance matrix,  $[K_t]$  represents the thermal conductivity matrix, and  $\{F\}$  denotes the global heat load vector arising from cement hydration and convective effects.

The governing equation (Equation 1) is solved in the time domain using a finite difference approach, which enables a step-by-step evaluation of the temperature variation with time (Bayagoob et al, 2010).

$$([\beta] + \vartheta \Delta t [K_t]) \{T\}_{ii} = ([\beta] + \vartheta \Delta t [K_t]) \{T\}_i + \Delta t ((1 - \vartheta) \{F_t\}_i + \vartheta \{F_t\}_{ii}) \quad (2)$$

where  $\{T\}_{ii}$  and  $\{F_t\}_{ii}$  are  $\{T\}$  and  $\{F_t\}$  at time (ii) and  $\{T\}_i$  and  $\{F_t\}_i$  are  $\{T\}$  and  $\{F_t\}$  at time (i),  $\vartheta$  is a scalar parameter ( $0 \leq \vartheta \leq 1$ ) which takes the value 2/3 when using the Galerkin method (Bayagoob et al, 2010).

## 3 Temperature-Dependent Creep Stress Behavior

In the study of creep behaviour, the exponential model is frequently adopted. This model is especially suitable for numerical simulations because it eliminates the requirement to store the entire stress history, thereby simplifying the computational procedure compared to other approaches (Wu & Luna, 2001).

Creep functions can be expressed in terms of a Dirichlet series, as presented by Wu and Luna (Wu & Luna, 2001):

$$G(t, \tau) = \sum_{\gamma=1}^M \frac{1}{\epsilon_{\gamma}(\tau)} [1 - e^{y_{\gamma}(\tau) - y_{\lambda}(t)}] \quad (3)$$

$G(t, \tau)$  is Time-dependent deformation functions,  $\epsilon_{\gamma}(\tau)$  is function of one variable, called the reduced times,  $(\tau)$  is the loading age in days,  $y_{\gamma}$  is experimental function (Wu & Luna, 2001). When temperature effects are ignored, a simplified form of the Viscoelastic compliance function is commonly adopted to describe the material behaviour under time-dependent loading (Du & Liu, 1994).

$$G(t, \tau) = C(t, \tau) + \frac{1}{E(t)} \quad (4)$$

The creep compliance  $S(t, \tau)$ , it can be written as,

$$S(t, \tau) = \sum_{\gamma=1}^3 \phi_{\gamma}(\tau)[1 - e^{-S_{\gamma}(t-\tau)}] \quad (5)$$

$$\phi_1 = \alpha_1 + \beta_1 \tau^{-\delta_1}, \phi_2 = \alpha_2 + \beta_2 \tau^{-\delta_2}, \phi_3 = D e^{-S_3 \tau} \quad (5a)$$

where  $\alpha_{\gamma}, \beta_{\gamma}, \delta_{\gamma}, S_{\gamma}$  are constants determined from the experimental data.

The time-dependent elastic modulus, denoted as  $E(t)$ , is considered in this study. The formulation proposed by Conrad and colleagues has been adopted, where the model describes how the elastic modulus of roller-compacted concrete (RCC) evolves over time (Conrad et al, 2003).

$$E(t) = E_c e^{a\tau^b} \quad (6)$$

$E_c$  denotes the ultimate (final) Young's modulus, while  $a$  and  $b$  are empirical parameters of the model.

#### 4 Assessment of Structural Safety Against Cracking

Crack analysis is carried out through the evaluation of a safety factor based on a cracking criterion. This factor is determined using the following relationship, as proposed by Abdulrazeg (Abdulrazeg et al, 2013):

$$C_f = \frac{\sigma_{1ult.}(t)}{\sigma_1(t)} \quad (7)$$

A number of investigators have attempted to evaluate the concrete strength under different combination of loads.

- (i) For tension–tension loading, a constant tensile strength is typically assumed, taken as equal to the uniaxial tensile strength of concrete (de Araújo. & Awruch, 1998).

$$\sigma_{1ult.}(t) = f_t(t) \quad (8- a)$$

- (ii) For tension–compression loading conditions, a linear reduction in tensile strength is generally recommended, where the tensile capacity decreases progressively with increasing compressive stress (de Araújo. & Awruch, 1998).

$$\sigma_{1ult.}(t) = f_t(t)(1 + 0.8 \frac{\sigma_2(t)}{f_c(t)}) \quad (8- b)$$

In this expression,  $\sigma_1(t)$  and  $\sigma_{1ult.}(t)$  correspond to the maximum and permissible principal stresses of RCC, respectively. The allowable principal stress is determined according to the prevailing stress state. The parameters ( $f_t(t)$  and  $f_c(t)$ ) represent the age-dependent tensile and compressive strengths of the concrete, respectively.

The time-dependent variation of compressive strength is determined using a relationship that links the elastic

modulus to the compressive strength, as given in (American Concrete Institute [ACI], 1995).

$$E(t) = 4750 \sqrt{f_c(t)} \quad (9)$$

In this context,  $E(t)$  denotes the time- and temperature-dependent Young's modulus, as formulated in Eq. (6). The tensile strength of the RCC material is determined based on the constitutive model developed by Zdiri et al. (2008).

$$f_t = 0.214 f_c^{0.69} \quad (10)$$

Finally, the allowable principal stress is evaluated using Equation (8), taking into account that the crack safety factor is calculated from Equation (7). When the crack safety factor exceeds unity, the structural element is regarded as safe against cracking. Conversely, if the factor is less than one, cracking is expected to occur within the dam body.

#### 5 Finite Element Computational Code

The finite element program developed by Abdulrazeg was utilized in this study, incorporating the formulations described in Sections (3, 4, and 5) for thermal, creep, and cracking analyses. The structure is analysed in sequential construction stages in accordance with the construction schedule, with each stage further subdivided into a series of time intervals. Figure 1 illustrates the flowchart of the numerical algorithm implemented in the code (Abdulrazeg et al, 2013).

At each time step, a thermal analysis is first performed to determine the temperature distribution, followed by the evaluation of the equivalent hydration age. This parameter is then employed to estimate both the elastic modulus and the creep compliance. Subsequently, the corresponding thermal and creep-induced loads are calculated and incorporated into the stress analysis. Based on the results of the structural analysis, the safety of the dam is evaluated at the same time step (Abdulrazeg et al, 2013).

#### 6 Analysis of Bu Mansur Roller Compacted Concrete Dam

Bu Mansur dam has been designed and constructed in north-eastern Libya (Figure 2) in a mediterranean climate area (maximum temperature rises to 40 °C, over a seasonal temporary Wadi with rushing floods, which have caused many natural disasters, the most recent being Storm Daniel. The dam initially was constructed as rockfill dam. The dam has a maximum height of 75 m and a crest length of 330 m. In this study, roller-compacted concrete (RCC) technology was adopted and evaluated as an alternative construction method.

Based on the available Literature, the preliminary design of the dam to determine the dimensions is based on height of the dam which will be evaluated based on reservoir capacity, topography, and hydrology. In the present study, the height is determined as 75.0 m as the previous height. Base width (B) is typically related to height using empirical formulas, 0.7 to 0.8 H. Top width (T), often between 3–10 m, depending on road access or walkway. Upstream and downstream face slopes is usually vertical on upstream and sloped (e.g., 0.7H:1V) on downstream (U.S. Bureau of Reclamation, 1976). Thus, the proposed dimensions are shown in figure 3.

### 6.1 Characteristics of Materials and Site Conditions

The material properties of roller-compacted concrete (RCC), conventional vibrated concrete (CVC), and the rock foundation are presented in Tables 1 and 2. Due to the lack of experimental results, the parameters used in this study were derived and estimated based on values reported in previously published literature (Pazhouhab Consultant Engineers, 1999).

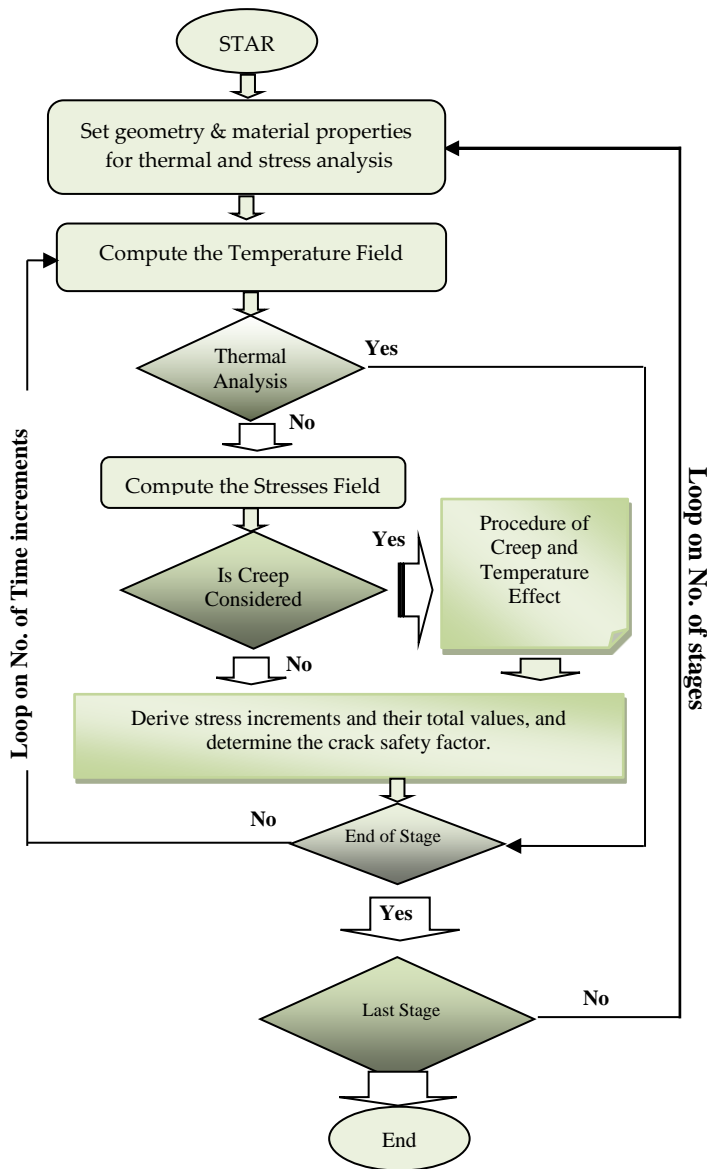


Fig. 1: Program flow chart

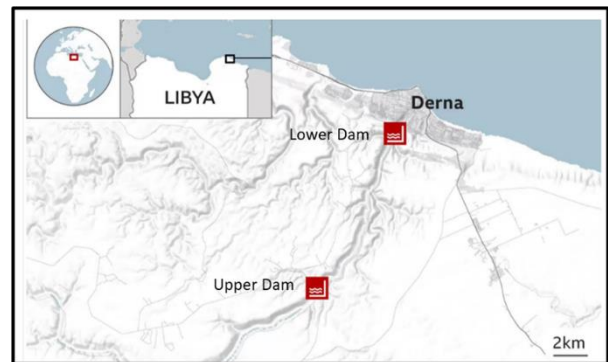


Fig. 2: Site Location and Vicinity Description

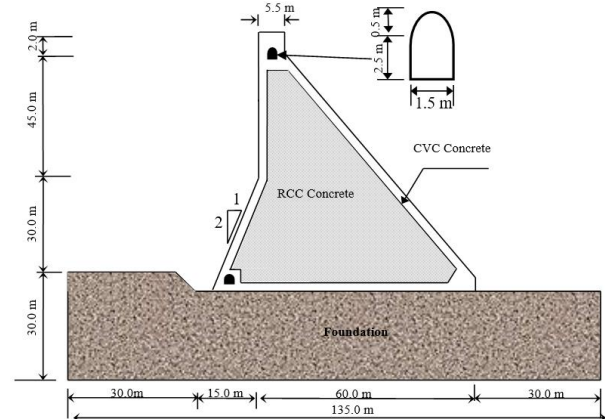


Fig. 3: Structural Geometry for Bu Mansur RCC Dam

**Table 1:** Thermal and Mechanical Properties

Material	unit	RCC	CVC	Rock
Thermal conductivity coefficient	W/m °C	2.80	2.80	2.70
Convective heat transfer coefficient	W/m <sup>2</sup> °C	15.250	15.250	15.250
Heat capacity	J/kg°C	1256.0	1256.0	1256.0
Material density	kg /m <sup>3</sup>	2400.0	2400.0	2700.0
Young's Modulus	KN /m <sup>2</sup>	1.67E+6	1.67E+6	0.6E+6
Poisson's Ratio	-	0.180	0.180	0.30

**Table 2:** Creep Characteristics of RCC and CVC Materials

Material		$\alpha$	$\beta$	$\delta$	D
CVC	1	0.35494	0.48368	0.35361	.....
	2	3.7335	-0.186	0.012486	.....
	3	-2.5644	0.13786	0.032642	0.83509
RCC	1	0.058864	0.38362	1.356	.....
	2	7.4729	-11.115	0.08919	.....
	3	-5.2079	7.9619	0.078675	4.2808

In addition, the environmental temperature data recorded at the site, as presented in Table (3), were incorporated into the thermal analysis to simulate heat transfer by convection. These temperature records were obtained from the NASA database (NASA, 1995).

**Table 3:** Average Air Temperature

Month	Air Temperature °C
Jan	14.4
Feb	14.1
Mar	15.8
Apr	18.2
May	19.8
June	22.8
July	25.8
Agu	26.8
Sep	26.9
Oct	23.1
Nov	19.3
Dec	14.3

## 6.2 Construction Sequence

The construction timeline is based on a comparable project documented in the literature, namely the Sungai Kinta RCC Dam (GHD Sdn Bhd, 2002), to ensure practical relevance. Adjustments have been made to align the schedule with the specific geometry of the dam considered in this research. In addition, construction activities are planned to be suspended during the peak summer months of July, August, and September due to high temperatures. The detailed proposed construction schedule is presented in Table 4.

**Table 3:** Average Air Temperature

Lift Height (m)	No. Of days	Lift Height (m)	No. Of days
1.5	58	39.0	34
3.0	97	42.0	32
6.0	46	45.0	38
9.0	44	48.0	36
12.0	39	51.0	27
15.0	37	54.0	26
18.0	36	57.0	24
21.0	35	60.0	22
24.0	34	63.0	20
27.0	32	66.0	17
30.0	38	69.0	14
33.0	36	72.0	12
36.0	39	75.0	12

## 6.3 Finite Element Modeling

Finite element model of the dam body, foundation, and reservoir is shown in Figure 4. The analysis is performed using eight-node isoparametric elements. The mesh discretization of the dam body is designed to accurately simulate the staged construction process.

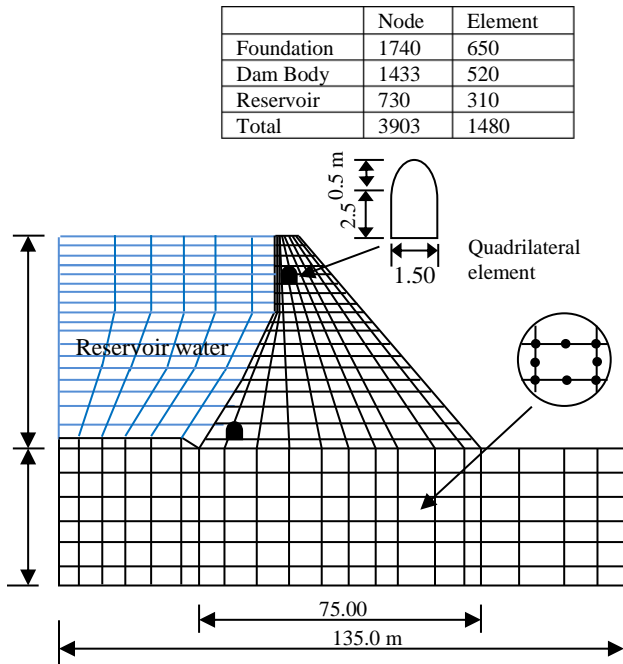


Fig. 4: Finite Element Modeling of the Dam-Foundation-Reservoir Interaction System

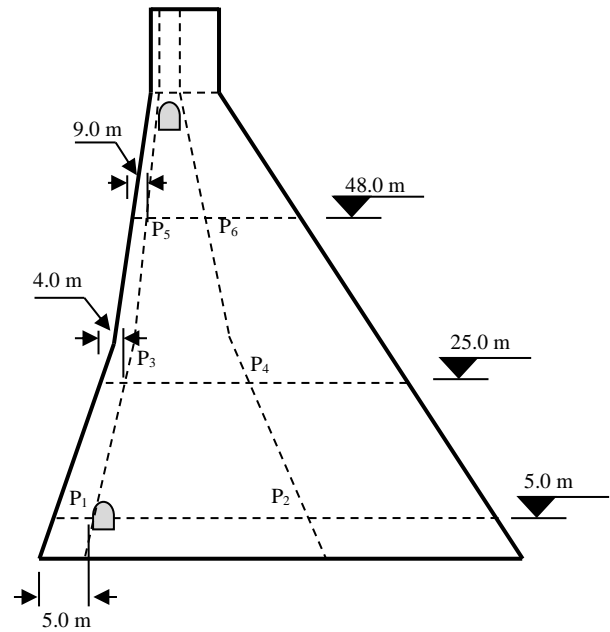


Fig. 5: Spatial Distribution of Temperature Monitoring Points

## 7 Result and Discussion

### 7.1 Thermal Distribution During Construction

To illustrate the temperature evolution within the dam body during construction, temperature histories at selected locations along different elevations (as shown in Figure 5) are presented in Figure 6, specifically at elevations 5.0 m, 25.0 m, and 48.0 m. The results indicate that the temperature rises initially due to the heat of hydration, reaching a peak approximately 10 days after placement. The highest recorded temperature is about 49°C, observed in the inner region of the dam (roller-compacted concrete zone). This behaviour is attributed to the relatively higher placing temperatures of RCC as well as the greater thermal insulation provided by the massive volume in this region compared to other parts of the structure.

The temperature contour at the completion of construction (Figure 7) indicates that the highest temperatures are concentrated in the central core of the dam, with a peak value of approximately 40 °C. Moving toward the external surfaces, the temperature progressively declines until it nears the ambient air temperature. Furthermore, a localized region of elevated temperature is identified near the crest, where values reach around 50 °C. This pattern can be attributed mainly to the increased heat generation from cement hydration in this zone compared to other parts of the dam.

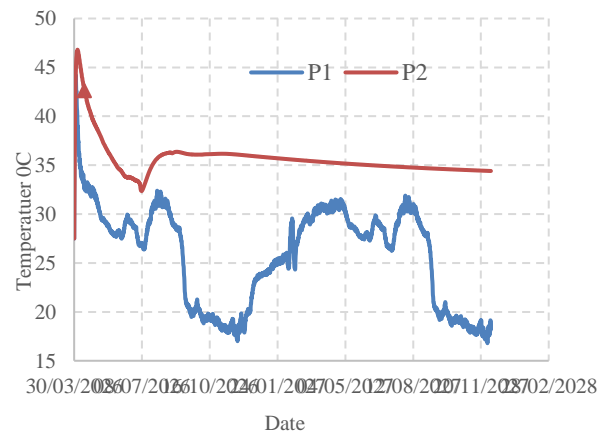
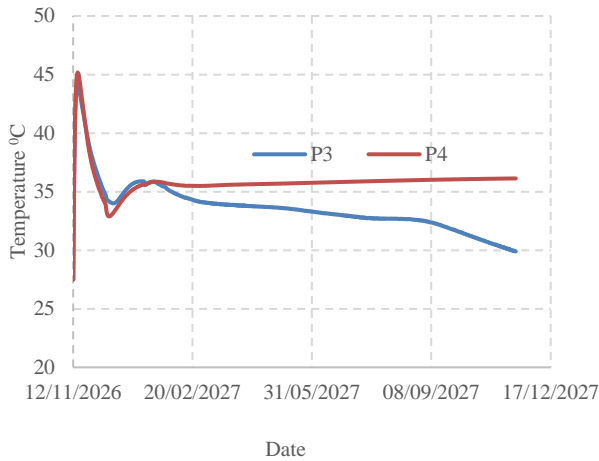
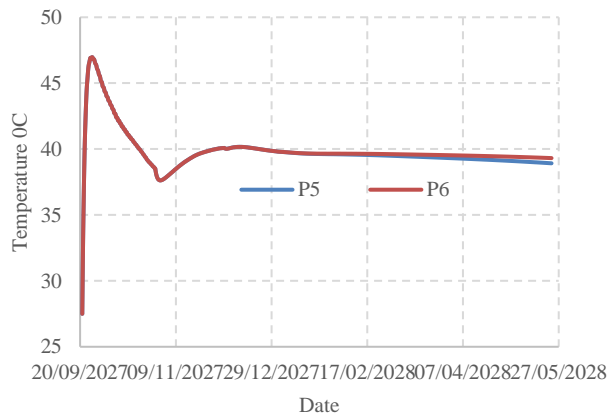


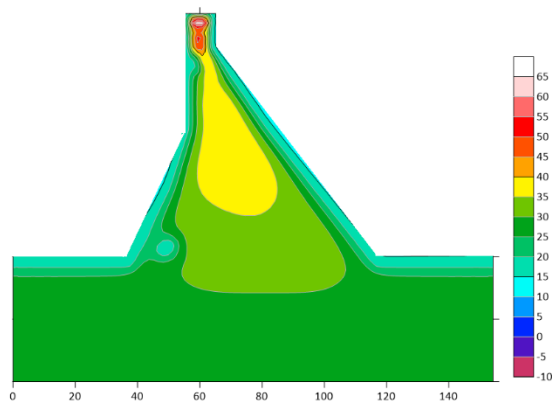
Fig. 6(a): Temperature variation at Elevation of 5.0 m



**Fig. 6(b): Temperature variation at Elevation of 25.0 m**



**Fig. 6(c): Temperature variation at Elevation of 48.0 m**



**Fig. 7: Thermal Distribution in the Dam at the End of the Construction Phase**

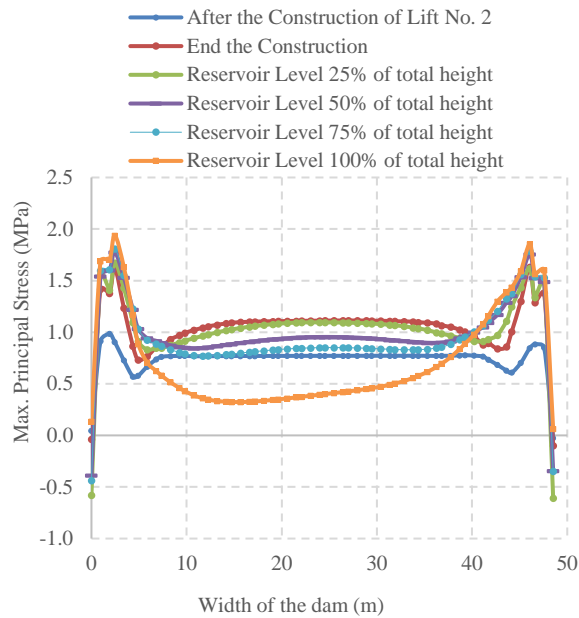
### 7.2 Temperature Control

In mass concrete structures, the temperature gradient between the interior and the exposed surface is typically recommended not to exceed 20 °C (Neville, 2012), based on the allowable tensile strain capacity at early ages. Given an average site temperature of 20.1 °C, the corresponding permissible internal concrete temperature range is approximately 40.1°C. However, the construction stages of the dam exhibited relatively high thermal responses, with predicted peak temperatures exceeding 45 °C in all lifts. This increase is primarily attributed to elevated RCC placing temperatures, hot climatic conditions, and the effect of direct solar radiation during the summer period. As a result, the allowable temperature limit is exceeded in several stages, indicating the need for implementing appropriate thermal control measures throughout the construction process. Various techniques can be applied to reduce temperature rise in RCC dams, such as:

- i. Use of ice flakes in RCC mixing water to lower the initial placing temperature of concrete.
- ii. Reduction of cement content, while still satisfying the required mechanical and durability properties, which helps decrease heat generated from hydration (Hajilikhani, 2003).
- iii. Construction pauses between lifts, which are particularly important in hot and dry climates. These delays help dissipate accumulated heat from previous layers and avoid placing concrete during peak temperature conditions.

### 7.3 Stress Analysis

To examine the stress distribution across the width of the foundation block, Figure 8 presents the results at the end of construction and for different reservoir levels. The curves follow a consistent trend, with tensile stresses concentrated near the upstream and downstream faces, while the central region exhibits a relatively lower and more uniform distribution. At the end of construction, the maximum tensile stress is approximately 1.8 MPa at the downstream face, mainly due to self-weight and thermal effects. As the reservoir level increases, this maximum stress rises to about 2.0 MPa due to hydrostatic loading, which induces bending and leads to a redistribution of stresses along the base.



**Fig. 8: Distribution of Maximum Principal Stress Along the Lift No.2**

**7.4 Crack Prediction**

The crack safety factor was examined across the width of Lift No. 7 at the upstream side, downstream side, and central section, with its evolution monitored after the completion of construction (. The findings reveal that the edge regions surpass the permissible limits, indicating a greater tendency toward cracking and classifying them as critical areas. On the other hand, the central portion demonstrates a continuous increase in the safety factor as construction progresses, which is mainly due to the growing influence of self-weight that contributes to improved overall stability.

**Table 4:** Assessment of Safety Factors Along the Lift No.7

Date	I/C			Downs tream side
	Upstream Side	central section		
8/1/2026	1.39	0.69	0.67	<b>0.6</b>
8/27/2026	1.14	0.91	0.89	<b>0.55</b>
9/20/2026	1.65	1.02	0.99	<b>0.59</b>
10/12/2026	1.18	1	1.0	<b>0.56</b>
11/1/2026	<b>0.69</b>	1	1.02	<b>0.44</b>
11/18/2026	<b>0.64</b>	1	1.03	<b>0.4</b>
12/2/2026	<b>0.64</b>	1	1.03	<b>0.39</b>
12/14/2026	<b>0.67</b>	1	1.03	<b>0.37</b>
12/23/2026	<b>0.7</b>	1	1.03	<b>0.37</b>
12/23/2026	<b>0.75</b>	1	1.03	<b>0.36</b>

**8 Conclusions**

Following the catastrophic flooding in Derna in September 2023, which was triggered by extreme rainfall and led to the failure of two upstream dams with more than 5,000 casualties, the need for robust risk-informed infrastructure design has become increasingly critical. In this context, this study investigates RCC technology as a cost-effective and competitive alternative for dam construction. A two-dimensional finite element approach is utilized to model the temperature field and stress distribution in the dam during both the construction phase and operational period under hot and dry climatic conditions. The concrete behaviour is represented using a viscoelastic constitutive model that accounts for ageing and temperature-dependent material properties. The structural performance with respect to crack initiation over time is evaluated through a crack safety factor criterion.

In light of the present analysis, the following conclusions can be stated:

Interruptions or scheduled delays in the casting process are necessary under hot–dry climatic conditions, as they help reduce the heat of hydration and prevent concrete placement during periods of excessive ambient temperature, thereby improving thermal control during construction.

Higher tensile stresses tend to develop along the dam boundaries, with the most critical concentrations observed at the downstream face. Consequently, this region requires special attention during both design and construction stages to ensure adequate structural safety and crack resistance.

**References**

Abdulrazeg, A. A., Noorzai, J., Mohammed, T. A., & Jaafar, M. S. (2013). Modeling of combined thermal and mechanical action in roller compacted concrete dam by three-dimensional finite element method. *Structural Engineering and Mechanics*, 47(1), 1–25. <https://doi.org/10.12989/sem.2013.47.1.001>.

American Concrete Institute. (1995). Building code requirements for structural concrete (ACI 318M-95). ACI.

Bayagoob, K. H., Noorzai, J., Jaafar, M. S., Thanoon, W. A., & Abdulrazeg, A. A. (2010). Modelling heat exchange between RCC dam and reservoir. *Proceedings of the ICE – Engineering and Computational Mechanics*, 163, 33–42.

Bofang, Z., & Ping, X. (2001). Method for stress analysis simulating the construction process of

- high concrete dams. *Journal of Dam Engineering*, XII, 243–260.
- Conrad, M., Aufleger, M., & Malkawi, A. (2003). Investigations on the modulus of elasticity of young RCC. In L. Berga (Ed.), *Proceedings of the 4th International Symposium on Roller Compacted Concrete (RCC) Dams* (pp. 729–733). Madrid, Spain.
- de Araújo, J. M., & Awruch, A. M. (1998). Cracking safety evaluation on gravity concrete dams during the construction phase. *Computers & Structures*, 66, 93–104.
- Du, C., & Liu, G. (1994). Numerical procedure for thermal creep stress in mass concrete structures. *Communications in Numerical Methods in Engineering*, 10, 545–554.
- GHD Sdn Bhd. (2002). SUNGAI Kinta dam RCC: Study of restrictions on RCC temperature (Stage 2). Malaysia.
- Hajilikhani, M. R. (2003). Modifying construction methods of Zirdan RCC dam. In L. Berga (Ed.), *Proceedings of the 4th International Symposium on Roller Compacted Concrete (RCC) Dams* (pp. 273–276). Madrid, Spain.
- Kuzmanovic, V., Savic, L., & Mladenovic, N. (2015). Thermal-stress behaviour of RCC gravity dams. *FME Transactions*, 43, 30–34. <https://doi.org/10.5937/fmet1501030K>
- Kuzmanovic, V., Savic, L., & Stefanakos, J. (2010). Long-term thermal two- and three-dimensional analysis of roller compacted concrete dams supported by monitoring verification. *Canadian Journal of Civil Engineering*, 37(4). <https://doi.org/10.1139/L10-004>.
- Liu, N., & Liu, G. T. (1996). Spectral stochastic finite element analysis of periodic random thermal creep stress in concrete. *Engineering Structures*, 18, 669–674.
- Mousavi, M., Khiavi, M. P., & Ghorbani, M. A. (2017). Thermal analysis of roller compacted concrete dams. In *Long-Term Behaviour and Environmentally Friendly Rehabilitation Technologies of Dams*. <https://doi.org/10.3217/978-3-85125-564-5-117>
- Mousavi, S. M., & Khiavi, M. P. (2022). Thermal analysis of roller compacted concrete dam utilizing a probabilistic model. *Mathematical Problems in Engineering*, 2022, Article ID 3781989. <https://doi.org/10.1155/2022/3781989>
- NASA. (1995). RETScreen solar radiation data. <https://eosweb.larc.nasa.gov/sse/>
- Neville, A. M. (2012). *Properties of concrete* (5th ed.). Pearson
- Noorzaei, J., Bayagoob, K., Abdulrazeg, A., Jaafar, M., & Mohammed, T. (2009). Three-dimensional nonlinear temperature and structural analysis of roller compacted concrete dam. *CMES: Computer Modeling in Engineering & Sciences*, 47, 43–60.
- Pazhouhab Consultant Engineers. (1999). *Technical report of Zirdan roller compacted concrete dam*.
- U.S. Bureau of Reclamation. (1976). *Design of gravity dams: Design manual for concrete gravity dams*.
- Wu, Y., & Luna, R. (2001). Numerical implementation of temperature and creep in mass concrete. *Finite Elements in Analysis and Design*, 37, 97–106.
- Zhang, G., & Zhu, B. (2003). Thermal stress simulation and possible crack analysis of Mianhantan RCC dam. In L. Berga (Ed.), *Proceedings of the 4th International Symposium on Roller Compacted Concrete (RCC) Dams* (pp. 603–609). Madrid, Spain.
- Zhang, X., Li, S., Chen, Y., & Chai, J. (2009). The development and verification of relocating mesh method for the computation of temperature field of RCC dam. *Advances in Engineering Software*, 40, 1119–1123.
- Zdiri, M., Oueddou, M. B., & Néji, J. (2008). Theoretical and experimental study of roller-compacted concrete strength. *Magazine of Concrete Research*, 60, 469–474.