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Original Article

Comparative Analysis of CWSM Model from Engineering Point of View

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Abstract

From dam safety point of view, timely thermal analysis is very important to prevent dam from cracking. Keep in view the importance of thermal analysis of dam from engineering point of view; two models were selected to complete this comparative study. Different authors already had done studies regarding thermal analysis of dams. Different methodologies and parameters were used for thermal analysis in these models. In this article, comparison of improved HST and CWSM for thermal analysis of dam is done. This study proves that CWSM is better than improved HST model. Because of the incorporation of several sensors that may collect data from various places in an environment, dam body, sun elevation, water temperature and water pressure. So CWSM can produce measurements that are more precise.

Keywords: CWSM, Improved HST, Thermal Analysis, Concrete Temperature, Dam Analysis, 3-D Analysis

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1. INTRODUCTION

As it is well known, a variety of methods are utilized to assess the heat transfer analysis of concrete construction during the hydration phase (Afzal, et al., 2023). These methods begin with manual computing and finish with 3-D modeling. In contrast to 3-D analysis methods, manual calculation procedures are quite straightforward. Schmidt offered a concept in 1924 to address the problem of heat conduction (Afzal, et al., 2023). Using a basic averaging procedure or a graphical representation, we may solve heat conduction problems using this method. American Concrete Institute (ACI) continues to advise using Schmidt's technique to calculate thermal slopes. With the use of the finite element technique, the behavior of giant concrete structures such as dams has recently been analyzed (Afzal, et al., 2022). The answer to the problem of calculating the hydration temperature was provided by Afzal, et al., (2022).

To show how much the temperature rose as a result of the adiabatic process, they employed an exponential time function. A framework for thermodynamics by chemical reactions (thermo-chemical) was introduced, and its formulation was utilized (Afzal, et al., 2023). For studies of temperature distribution for concrete dams, the finite element method was used (Alnaggar, et al., 2017). Several researchers analyzed the causes of dam crest cracking based on measurements of long-term temperature

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data (Belmokre, et al., 2020). 3-D finite element method is used as a tool for the analysis of thermal stress and cracking (Bukenya, et al., 2014).

In the fields of thermal analysis related to non-linear and non-heat flux through a substance, taking into consideration suitable boundary conditions, the temperature has a considerable influence on the long-term reinforcing of concrete dams (Afzal, et al., 2022). Several people have spoken about the temperature directive consideration of concrete dams in arctic locations and the sensitivity analysis of thermal fields in large constructions (Chen, et al., 2003). A huge amount of research has been done recently on the temperature behavior of concrete dams, taking into account the results of applying environmental conditions (Emmons, 1943).

Some researchers have focused mainly on thorough investigations of displacements involving: concrete dam analysis based on seasonal hydrodynamic damage because of rigid load, seasonal thermal displacements of gravity dams in cold areas, the technique of dam deformation caused by thermal activities, and the connection between surface temperatures and daily changeability of structural performance (Esser & Vliegenthart, 2017). Some researchers have studied temperature-induced stresses in concrete dams, and others have examined structural cracks in dams. While another study has examined thermal characteristics in every dam, several have studied the effects of shadowing and solar radiation (Kang, et al., 2017). Following figure number 1 represent the thermal filed as descried in all this literature:

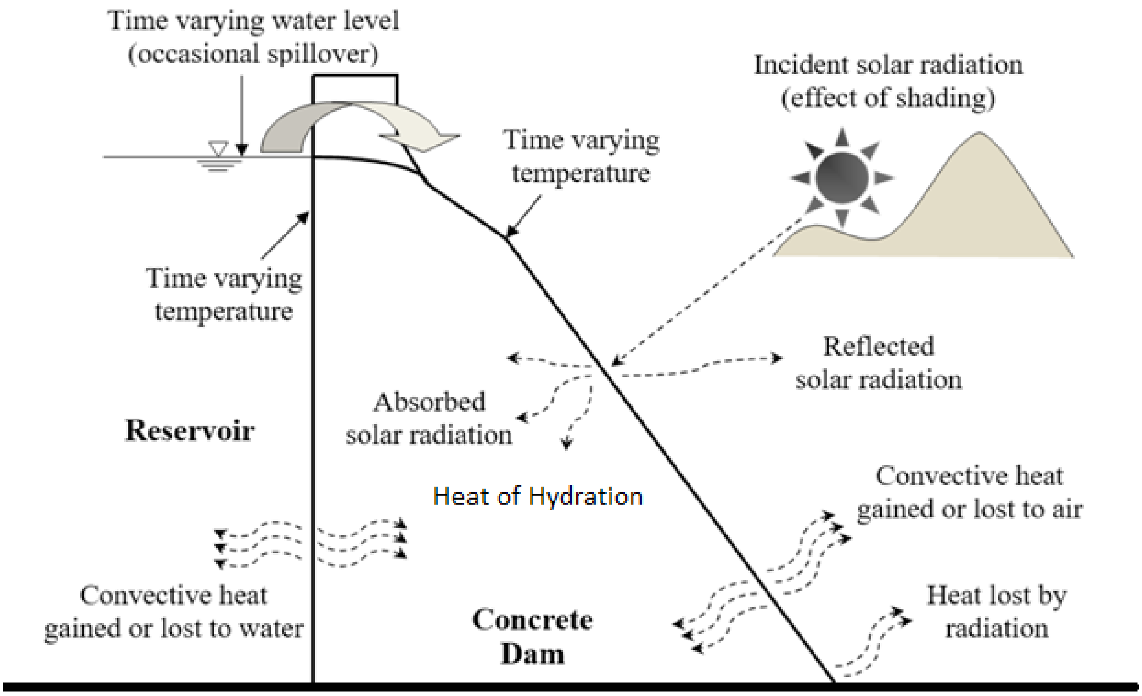

Fig. 1. Dam's Thermal Field

In comparative studies, we examine and analyze the already done work on subject matter using qualitative or quantitative methods (Léger, et al., 1996). Keep in view the importance of thermal analysis of dam from engineering point of view (Li, et al., 2021), two models were selected to complete this comparative study. Different authors already had done studies regarding thermal analysis of dams. Different methodologies and parameters were used for thermal analysis in these models. In this article, comparison of HST and CWSM for thermal analysis of dam is done.

2. MODELING OF HST AND CWSM

An improved HST (Hydrostatic Season Time) was proposed by Belmokre, A., et al (2020) for the thermal analysis of dam (Yazdchi, et al., 1999). Following was the modeling of HST:

$$f(h,s,t) = a_0 + f(h) + f(s) + f(t)f(s) \qquad 01$$

The equation above gives a description of the HST model's overall expression (1). f (h) is the function that simulates the elastic impact of hydrostatic pressure, f (s) is the temperature element, and f (t) is the permanent deformation, where a_0 is a constant.

$$= a_7 \cos\left(\frac{2\pi J}{365}\right) + a_8 \sin\left(\frac{2\pi J}{365}\right) + a_9 \cos\left(2\frac{2\pi J}{365}\right) + a_{10} \sin\left(2\frac{2\pi J}{365}\right) \qquad 02$$

A sinusoidal function, represented by equation number 02, determines the thermal element, where J is the total days throughout the year.

$$T_a = A_{air} \sin\left(\frac{2\pi}{365}J\right) + T_{mean} \qquad 03$$

Equation 02 shows the deformations caused by seasonal temperature, where T_{mean} is the annual temperature and A_{air} is the annual average temperature. Using equation 03, the following yearly temperature range T_a may be determined:

$$u(x,t) = \frac{(\bar{T}_w - \bar{T}_{air})h_{air}h_w x + \bar{T}_{air}(h_{air} + h_{air}h_w L) + \bar{T}_w h_w}{h_{air} + h_w + h_{air}h_w L} \qquad 04$$

The new analytical model assumes that the temperature of the concrete T at a point x in a cross-section of length L is the total of three thermal responses: u, v, and w. When segment L's ends are kept at a constant temperature—the mean water temperature T_w at the upstream edge and the mean air temperature T_{wair} at the downstream edge—u is the temperature in that section. The stationary solution to the issue u is given by equation 04, where h_{air}, and h_w are the circulation factors at the downstream and upstream faces, respectively.

$$v(x,t) = \frac{A_{air}h_{air}}{2} = S_p e^{i\omega t}.\frac{\sqrt{\frac{\omega}{2\chi}}(1+i)\cosh\left\{\sqrt{\frac{\omega}{2\chi}}(1+i)(L-x)\right\} + h_w \sin h\left\{\sqrt{\frac{\omega}{2\chi}}(1+i)(l-x)\right\}}{\left(\sqrt{\frac{\omega}{2\chi}}(1+i)S_P + h_{air}C_P\right)\left(\sqrt{\frac{\omega}{2\chi}}(1+i)S_p + h_w C_P\right) - h_{air}h_w} +$$
$$S_n e^{i\omega t}.\frac{\sqrt{\frac{\omega}{2\chi}}(1+i)\cos h\left\{\sqrt{\frac{\omega}{2\chi}}(1+i)(L-x)\right\} + h_{w}{}_{Sin}h\left\{\sqrt{\frac{\omega}{2x}}(1+i)(L-x)\right\}}{\left(\sqrt{\frac{\omega}{2\chi}}(1+i)S_n + h_{air}C_p\right)\left(\sqrt{\frac{\omega}{2\chi}}(1+i)S_n + h_w C_p\right) - h_{air}h_w} \qquad 05$$

Eq. 05 provides the second term v, which is the solution to a heat transfer issue where the downstream endpoint is forced to operate at a temperature of $A_{air}\sin^{\omega t}$ while the upstream end is forced to operate at zero.

$$w = \frac{A_w h_u}{2} = S_p e^{i\omega t}.\frac{\sqrt{\frac{\omega}{2\chi}}(1+i)\cosh\left\{\sqrt{\frac{\omega}{2\chi}}(1+i)x\right\} + h_{air}\sin h\left\{\sqrt{\frac{\omega}{2\chi}}(1+i)x\right\}}{\left(\sqrt{\frac{\omega}{2\chi}}(1+i)S_P + h_{air}C_P\right)\left(\sqrt{\frac{\omega}{2\chi}}(1+i)S_p + h_w C_P\right) - h_{air}h_w} +$$
$$S_n e^{i\omega t}.\frac{\sqrt{\frac{\omega}{2\chi}}(1+i)\cos h\left\{\sqrt{\frac{\omega}{2\chi}}(1+i)x\right\} + h_{air}{}_{Sin}h\left\{\sqrt{\frac{\omega}{2x}}(1+i)x\right\}}{\left(\sqrt{\frac{\omega}{2\chi}}(1+i)S_n + h_{air}C_p\right)\left(\sqrt{\frac{\omega}{2\chi}}(1+i)S_n + h_w C_p\right) - h_{air}h_w} \qquad 06$$

The equation above 06, w is a solution to a thermal issue in section L where the downstream edge is forced to operate at zero degrees and the upstream edge is forced to operate at a temperature equivalent to $A_{air}\sin^{\omega t}$. In the equation, A_w the annual amplitude of water temperature stands in for the concept.

$$f_{(s,v,w)} = a_7 \cos\left(\frac{2\pi J}{365}\right) + a_8 \sin\left(\frac{2\pi J}{365}\right) + a_9 \cos\left(2\frac{2\pi J}{365}\right) + a_{10} \sin\left(2\frac{2\pi J}{365}\right) + v + w \qquad 07$$

Throughout its service life, the temperature of concrete is changed by heat fluxes created on surfaces exposed to air and water, as similar heats T_{eq} and Tw, respectively. The processes responsible for these heat flows include circulation, short-wave radiation, and solar radiation. Nevertheless, the HST model does not account for T_{dif}, the temperature gap between T_{eq} and T_a, and T_w, the water temperature. To solve this problem, we suggest enhancing the HST model by adding v and w to the thermal element (Equation 07) while maintaining its simplicity. To account for T_{dif}, we calculate v at the position of the swinging sensing tables, where T_{dif} is imposed as the downstream face's boundary condition. We consider that the deformations caused by the factor u are harmonic. This model is referred to as the "Improved hydrostatic-season-time" model (IHST).

A new model for thermal analysis was proposed by Afzal, et al., (2023) named as CWSM (Complex

Wireless Sensor Model) (Yuan & Wan, 2002). Following was the modeling of CWSM:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{\rho c}{\lambda}\frac{\partial T}{\partial t} \qquad 08$$

When T is the temperature (K), x, y, and z are in Cartesian coordinates (m), ρ is the density, c is the absolute temperature, λ is the temperature coefficient, and t represents the time.

$$q_s = Iacos\theta_s \qquad 09$$

Whilst q_s is the energy flux density of solar absorbed radiation by the solid (W/m2), is the energy flux density of solar energy absorbed at the surface of the Earth (W/m2), a is the solar absorptivity of the surface, and is the angle of incidence of the sun's rays (o).

$$I = I_{sc}k_T \qquad 10$$

$I_{sc}$is transparency factor, which is influenced by environmental seasonal changes and the length of the radiation passage through the atmosphere, and is solar constant (on average 1,350 W/m2).

$$cos\theta_s = -cos\delta_s cos\Omega\, sin\alpha\, cos\tau_s\, sin\Phi + cos\delta_s sin\Omega\, sin\alpha\, sin\tau_s + sin\delta_s cos\Omega\, sin\alpha\, cos\Phi + cos\delta_s cos\alpha\, cos\tau_s\, cos\Phi + sin\delta_s cos\alpha\, sin\Phi \qquad 11$$

As opposed to declination, which is the angle between the equatorial plane and the direction of the sun, azimuth, which is the normal to the plane as measured clockwise from the earth, and hour angle, which are all determined by the following:

$$\tau_s = (12 - u)15^o \qquad 12$$

Although the hour angle varies at a rate of 15°/h, the time of day is expressed using 24-hour notation.

$$cos\theta_s = -cos\delta_s cos\tau_s\, cos\Phi + sin\delta_s\, sin\Phi = sin\beta s \qquad 13$$

From the above eq we can calculate the horizontal plan (a = 0°) solar elevation angle β_s

$$cos\alpha_s = \frac{sin\delta_s - sin\beta_s sin\Phi}{cos\beta_s cos\Phi} \qquad 14$$

The solar azimuth angle which is (a_s)

$$if\ T_s > 0\ (u < 12, in\ the\ morning) \rightarrow as < 180^o \qquad 15$$

$$if\ T_s < 0\ (u > 12, in\ the\ afternoon) \rightarrow as > 180^o \qquad 16$$

$$K\,T + C\,T_t = F \qquad 17$$

In contrast, K is the matrix of thermal conductivity, T is the vector of nodal temperature, C is the matrix heat of capacity, T_t is the time derivative of temperature, and F is the vector of external action.

Comparison of Both Model Based on Factors

The HST model was proposed for the monitoring of dam. To analyze the dam's state and assure its long-term safety and stability, the improved Hydrostatic-Season-Time Model considers various aspects. This model considers different factors like Hydrostatic Pressure which means Measures dam wall water pressure. Secondly Seasonal changes, according to authors' point of view seasonal fluctuations might damage the dam. Temperature and precipitation affect dam wall water levels and pressure. The Geological Factors were also taken into consideration; the dam's condition may depend on the area's geology. Monitoring soil stability and seismic activity may impact the dam's stability. According to HST construction materials also have a significant impact on dam safety because dam's strength depends on the concrete and structure.

The CWSM for real-time dam temperature monitoring would likely employ multiple parameters to offer an accurate temperature estimate. This model is technology based model with advance capabilities of artificial intelligence and IoT (Internet of Things). The model use sensors created especially for monitoring dams. These sensors would be positioned throughout the dam in different spots to provide a complete picture of the temperature conditions. The sensors are also capable of Wireless Communication: Sensors would utilize wireless communication to provide data to a central monitoring system. This would allow real-time monitoring and rapid response to temperature problems. The Complex algorithms and data analytics tools would examine sensor data. This model also watch the Environmental Factors and their impact on dam body: The dam's temperature might be affected by numerous environmental conditions. Weather and sun radiation may impact the dam's temperature. The complicated wireless sensors model would combine technology and data analytics to deliver a real-time dam temperature measurement. This would allow immediate response to avoid possible difficulties and guarantee the dam's long-term safety and stability.

3. DISCUSSION AND CONCLUSION

Monitoring the temperature is the most important method for avoiding cracks in concrete dams. This is due to the high frequency of concrete fractures that are produced by variations in temperature. Thermal analysis of concrete dams involves the study of the temperature distribution in the dam structure under different thermal conditions. This analysis is important to evaluate the thermal behavior of concrete dams and to ensure their safety and durability. Different phenomenon are involved in the thermal analysis of concrete dams as shown in figure number 2; like Dam body Temperature, Environmental stress, Boundary conditions, Water/Reservoir Temperature, Heat of hydration, Thermo-Physical properties, Thermo-Chemical properties and finally the Thermal modeling.

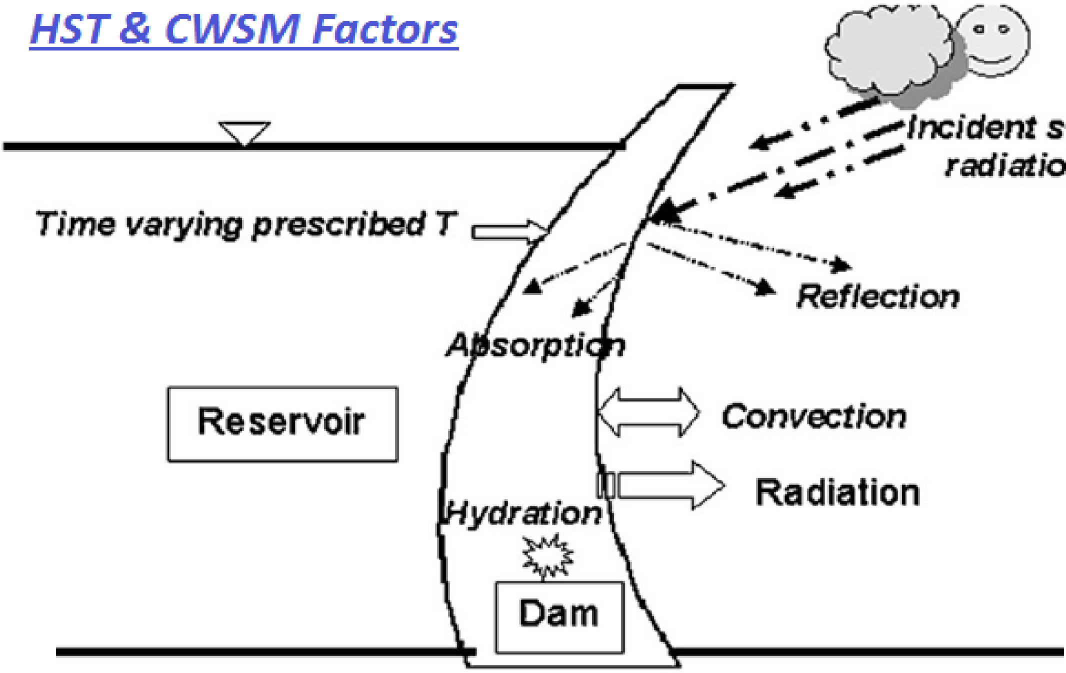

Fig. 2. Combined factors used in HST and CWSM

After the thermal modeling, the analysis is done on the base of factors taken into consideration in thermal modeling so that Mitigation measures can be defined. Based on the thermal analysis, mitigation measures can be developed to prevent or minimize the effects of thermal stresses on the dam. These can include measures such as cooling systems, insulation, or changes to the design or construction of the dam. Overall, thermal analysis is an important tool in ensuring the safety and durability of concrete dams. By understanding the thermal behavior of the dam under different conditions, engineers can take steps to prevent or mitigate potential problems, ensuring the long-term stability of the structure.

Throughout the course of the last few years, the emphasis of the attention of some studies has been on the environmental influence, while the attention of others has been on the temperature of the reservoir, the body temperature of the dam, and the pressure and stress of the dam. The CWSM model, on the other hand, is a sensing model, and it is emphasis on constant temperature monitoring during both the construction and operation of a dam. CWSM is better than HST because it has humidity, temperature, pressure, irradiance, and sun sensors in addition to other types of factors used in HST, so that it can monitor the changes that occur in a variety of factors. It is possible to monitor and assess the influence that temperature, humidity, water pressure, heat of hydration and solar radiation has on the dam by using the CWSM, as this model used IoT based intelligent vigilance system based on token ring topology. Overall, CWSMs can offer significant advantages for dam monitoring with respect to scalability, flexibility, and accurate and timely data.

Competing Interests

The authors have declared no competing interests.

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