Mass Concrete Temperature Control by Construction Stages for Bridge Foundation

Dr VinayagaMoorthy[1]; HamisiMaliki[2]

[1]*Bridge Engineer, SGR Project,Tanzania*
[2]*Civil /Structura lEngineer, SGR Project, Tanzania*

Abstract:

Thermal analysis is one of the main components in the design and construction of any mass concrete especially in the foundation. In this article, the heat transformation in concrete due to atmosphere and hydration process is analysed andthe way of cooling method is introduced to perform the thermal analysis of a curing system in mass concrete structures. Several typical models are selected to verify the performance of this method. The proposed method is applied to a bridge pile foundation concrete called in the pile cap for the Bridge Project, Dar es salaam, which is still under construction in Tanzania. The actual climatic conditions and thermal properties of the materials are considered in this analysis. The temperatures determined by numerical simulation are in good agreement with the actual monitoredvalues. The simulation results indicate that the proposed method can accurately simulate the hydration temperaturestage, the temperature rise along time rise, and the effect of directional changes of flow in temperature distributions. Moreover, the maximum temperature for 24 hours wasexamined shown thedevelopment in concrete and compared with foundation with the curing system.Mainly from the extreme temperature in the core of the concrete and fluctuation during the cooling process of concrete. The untimely application of water-cooling systems during hot seasons will induce extreme tensile stresses and increase the risk of cracking.

Author keywords: Foundation; Heat of hydration; Heat-fluid coupling method; Thermal analysis; Cooling pipes.

I. Introduction:

Controlling temperature-induced cracking in concrete is one of the main concerns in the design and construction of concrete of mass concrete foundation. In compacted concrete (RCC) foundation, the application of continuous casting with different-layer of concrete combined with the large use with less cement content during construction makes mass structures significantly different from conventional concrete structurewith respect to the temperature due to hydration process, cooling conditions,and the main factors affecting updraft stress. Particularly, the quickconstruction process and large size of concrete lifts will induce ahigh temperature or extreme thermal gradient within the concreteand cause significant thermal stresses during the cooling of the foundation,which are sufficient for cracking (Zhu 1999). Thus, it is necessary tosimulate and analyse the temperature and stress fields during constructionand then suggest some effective temperature control measuresto prevent cracking (Tatro and Schrader 1992; Zhu 2006).Cooling by the flow of water through an embedded cooling pipehas become a common and effective artificial temperature controlmeasure in the construction of concrete foundations. A great deal of research has been conducted to simulate thecooling effect of this water flow.Cervera et al. (2000a, b) presented a numerical procedure for thethermal and stress analysis of the evolutionary construction processof RCC foundations. This procedure took into account the ambient temperature,placing temperature, casting schedule, and, in particular,the more applicable features of the behaviour of concrete during theearly stages after construction, such as hydration, aging, creep, andfoundation age. The U.S. Bureau of Reclamation (USBR 1949) conductedresearch on the calculation of the final stage of water cooling andpresented an analytical solution using a two-dimensional (2D)program, and an approximate solution using a three-dimensional(3D) program with no heat source by using the separation-ofvariables method.The calculation of the initial stage of watercooling and obtained an analytical solution using a 2D program andan approximate solution using a 3D program with a heat sourceby using the integral transform method. The polythenepipes had fewer joints, which appeared to be more convenient thansteel pipes in construction, and four methods forcomputing the effect of cooling by non-metal pipes. In addition, the simplified analysis, and proposed methods to compute theequivalent radius and equivalent horizontal spacing of non-metal pipes. Zhu (1991) treated water cooling as negative hydration heatand presented a cooling equivalent

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algorithm based on the FEM. The water-cooling effect to every element in theFEM analysis, easily obtaining an approximate distribution of thetemperature field

The model developed in 3D FEM program to thermallyanalyse concrete structures with pipe cooling systems. Line elementswere adapted to model pipes, and internal flow theory wasapplied during the calculation of the temperature variation of thecooling water. The proposed general analytical model toaddress heat extraction from mass concrete by employing a rectangulararray of cooling pipes. In this study, an analytical solution isderived in terms of the physical parameters for heat diffusion andheat removal. The model can be employed to analyse a temperaturethe heat is removed using a rectangular pipe frame andcan provide guidance in choosing pipe sizes, pipe spacing, aggregatesof different heat diffusivity, types of cements, fresh concretetemperature. However, this technique still cannot accurately reflect the velocity andwater temperature variation rise along the flow.

The objective of this work is to present an accurate and applicableprediction method for the analysis of the cooling effect exhibited bypipes in mass concrete structures. This work accounts for the followingfactors: concrete properties, ambient conditions, convection coefficient function, heat source, casting schedule, and, in particular, theactual pipe cooling system. Additionally, it considers the pipe layout(pipe sizes and spacing), the cooling water velocity, the inlet temperatureand water-temperature rise along the flow, and the thermalproperties of cooling pipes by using a numerical simulation. Thus,the prediction of the thermal fields associated with cooling pipes canbe successfully used in practice.

In this study, the heat-fluid is introduced toperform the thermal analysis of pipe cooling systems in massconcrete structures and is applied to an actual RCC foundation. A 3D FEManalysis is conducted using heat-fluid elements in the FEM program to verify the rationality and applicability of theheat-fluid coupling method, a comparison with several widely usedmethods is presented. Furthermore, this method is applied to verifyand predict the distribution of temperature during the initial stageof the cooling process of the railway viaduct bridge pylon foundation.

Basic Formulations and Solution Approach ofTemperature Field

Based on the energy balance principle, the general partial differentialequation governing heat flow in a 3D solid medium is expressed where the concrete temperature; The initial transient temperature can be represented as;

$$T = To\,(x, y, z)$$

Simulation of Water Cooling with the Heat-FluidCoupling Method

In the entire FE model, concrete is simulated by 3D solid elements,and cooling water pipes are simulated by heat-fluid elements, asshown in Fig. 1. Each heat-fluid element has four nodes, consisting

of two primary (I, J) and two supplemental (K, L) nodes. Thecoupling of the additional nodes of the heat-fluid element and thenodes of the concrete solid element are used to simulate the convectionheat of water and concrete.
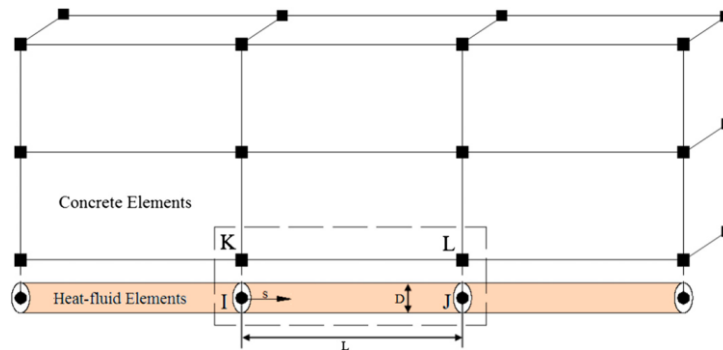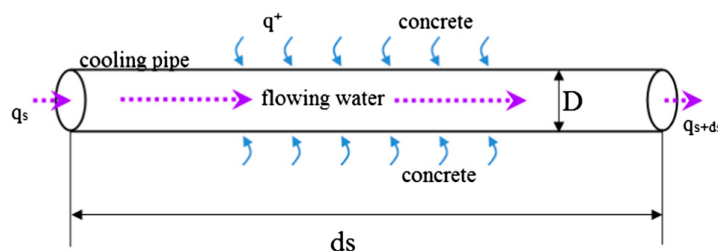

Fig. 1. Heat-fluid element geometry

Fig. 2. Concept diagram of energy conservation principle

Simulation analysis of finite element procedure
Project Overview:
This foundation is for bridge main span foundation project in Dar es salaam, Tanzania. It has main span length of 150m and 7.2m height(Above the ground). The foundation thickness 3500mm and 2500mm of soil base for the analysis. Fig 1 displays plan layout of foundation and temperature measuring point.
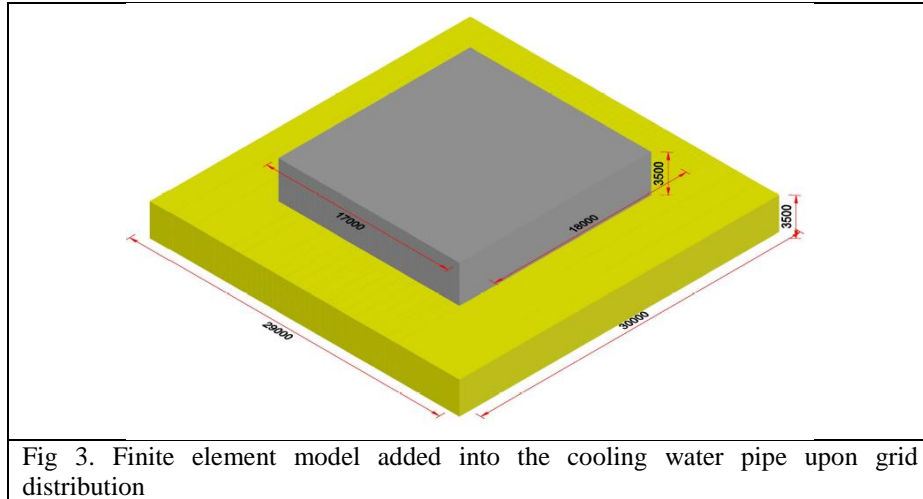

Fig 3. Finite element model added into the cooling water pipe upon grid distribution

The following temperature control measures are adopted for the project: One layer of straw mat orgunny bag immersed in water for a long time is first laid on the external surface of concrete; then twolayers of dry straw mat are laid for heat insulation; the covering materials are increased or reducedaccording to the temperature gap; the cooling water pipe is set up in the concrete. Fig 4A is layout ofcooling water pipe.

The following temperature control measures are adopted for the project: totally seven layers were considered, each layer is 500mm. totally eight construction stages were considered with cumulative time of one hour for each pouring.The cooling water pipe is set up in the concrete shows in layout (Fig 4A) ofcooling water pipe.
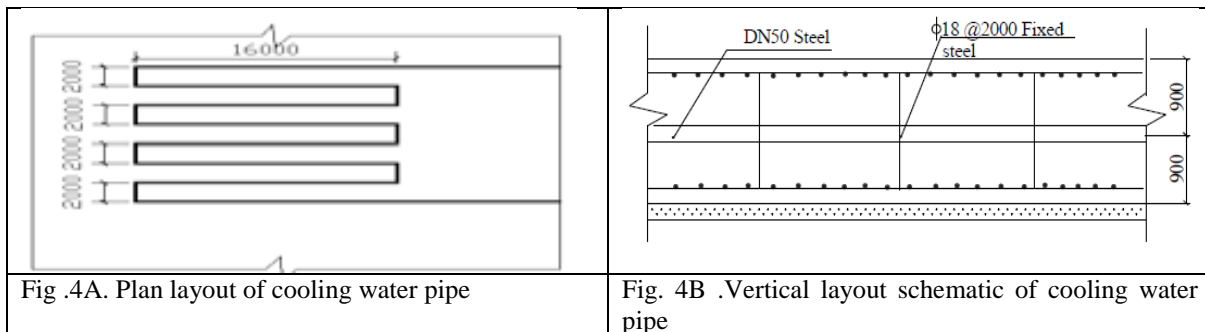

Fig .4A. Plan layout of cooling water pipe

Fig. 4B .Vertical layout schematic of cooling water pipe

Construction Methodology
Foundation concrete will be casted in single pour. It will be casted in layer by layer. Each layer thickness will be 0.5 m and time taken to complete every single layer will be 1 hour. Time required to complete one single footing will be around 8 hours.

Description	Thickness of foundation casted at each stage	Total thickness casted	Cumulative time taken
Stage 1	500 mm	500 mm	1 hour
Stage 2	500 mm	1000 mm	2 hours
Stage 3	500 mm	1500 mm	3 hours
Stage 4	500 mm	2000 mm	4 hours

Stage 5	500 mm	2500 mm	5 hours
Stage 6	500 mm	3000 mm	6 hours
Stage 7	500 mm	3500 mm	7 hours
Stage 8	-	3500 mm	8 hours

Analytical procedure of finite element procedure:
The article adopts structural analysis finite element software MIDAS/FEA to implement valuesimulation analysis to the large-volume concrete temperature field and temperature stress. It can bedivided into the following three procedures:

Model establishment and necessary parameter confirmation.
This process mainly includes the material features related to time such as creep, dry shrinkage andelastic modulus and setup of boundary.

Analysis of temperature stress process.
This process mainly includes the setup of temperature, distribution of heat source and setup ofconstruction simulation time. It mainly includes the temperature change graph and temperature stress change graph.

Procedure model establishment
The mass concrete and natural foundation is selected and adopted as the calculation object formodelling; the concrete thickness is 1.8m and 2.7m; the length is 38m and width is 46m; the soil thicknessis 3m, length is 42m and width is 54m. Axis Z is along the thickness direction, axis X is along the lengthdirection and axis Y is along the width direction.

Table: material property for concrete

Density	25 kN/m3
Grade of Concrete, Fck	40 MPa
Elastic modulus, Ec	35000 MPa
Allowable tension stress	3.0 MPa
Allowable compression stress	14 MPa

Table: material property for concrete

Density	78.5 kN/m3
Fy	500 MPa
Es	200000 MPa

The grid is distributed according to the concrete shape; the Mass concrete foundation (thickness of 3.5m) length and width direction includes 17m and 18m respectively; the mass concretefoundation (partial part with a thickness of 0.5m) length and width direction includes 8 units and 9 unitsrespectively.

The initial and boundary conditions
Environmental temperature: Average daily temperature is 21ºC.Initial concrete temperature: The measured model entry temperature of concrete is 22 ºC—28ºC;in order to reflect the possible maximum temperature, 28 ºC is adopted for the procedure analysis.
Flowing temperature of cooling water: The measured temperature is 19 to 22 ºC, 21ºC is adopted.The concrete surface, surrounding steel model and air contact surface is treated according to boundary conditions; the natural foundation and foundation contact surface is treated according to boundary conditions; the contact is good and natural foundation is simulated into a structure withcertain specific heat and heat transmission rate.The natural foundation is treated as follows: The side and lower bottom of natural foundation adopt thefixed natural foundation temperature (22ºC); the model is established for the restriction conditionsaccording to the body unit: general support restriction conditions are adopted.

Thermal parameters of concrete foundation and natural foundation:
Table 2.The material and thermal characteristic parameters

Description	Unit	Foundation	Subsoil
Specific heat	Kcal/kg/°C	1046.5	837.2
Rate of heat conduction	Kcal/m/hr/°C	9627.8	7116.2
Ambient temperature	°C	25	-
Casting temperature	°C	20	-
Thermal expansion coefficient	-	11.6×10^{-6}	-
Heat source function coefficients	K (°C), a (no unit)	K=33.97, a=0.605	-
Density	kg/m^3	2400	1800
Poisson's ratio	-	0.2	0.2

II.   Results and Discussion:

In this analysis, the major cause for thermal stresses is due to the temperature differences within the concrete mass resulting in internal constraints.Recapping the overview, Internal Constraints are caused by unequal volume changes. Initially, cooling surface and warm inner parts cause tension at the surface and compression at the inner parts. At a later stage after the rise in temperature due to heatof hydration reachesthe peaklevel, the cooling (contracting) inner parts relative to the surface causetension in the inner parts and compression at the surface. The magnitude of the stresses is proportional to the temperature differences between the inner parts and surface. It isalso anticipatedthat the two concrete masses of two separate pours of different ages will exhibit different heat transfer characteristics.

It will analyse the characteristics of thermal stresses in concrete by reviewing the results of heat of hydration analysis for 15Hours reflecting construction stages by graphic and contour results.

1.   Max temperature = 36 degree
2.   Max tensile stress < Max allowable stress
3.   Temperature variation for inner core and outer surface

III.   Conclusions:

The study aimed at characterizing the hydration phenomenon of early stage concretes is proposedin this work. It emphasizes the role of temperature to describe the evolution of thehardening process. After the analytical formulation of the hydration and heat transfer derivations,a consistent numerical solution based on the Finite element technique for the mass concrete. Then, in order to consider structural applications dealing with the thermal problems,the same constitutive relationships are considered within a general Finite Element (FEM) procedure.Numerical comparisons without cooling pipe system and with cooling pipe system tests performed for rapid hardeningcement-basedconcretes establish the soundness and capability of the given application.

So the mass concrete with cooling pipe is reduced the temperature from core surface by 38%, it can realize dual control of temperature and temperature stress; it is feasible as an auxiliary method of temperature control and management wide application in the similar projects.

The simulation analysis of finite element procedure can realise the integration between modern technical measures of actual project.