International Journal of Engineering Research
Volume No.5, Issue No.7, pp : 582-585
ISSN:2319-6890)(online),2347-5013(print)
1 July 2016

Numerical Simulation of Thermal Diffusion in Outdoor Concrete Fish Pond

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Abstract: In this research, numerical simulation of thermal diffusion in outdoor concrete fish pond was conducted. Experimental determination of temperature variation in the walls of concrete fish ponds was carried out to establish parameters for the simulation. Transient numerical simulation of the thermal diffusion across the thickness of the concrete wall was also carried out in ANSYS to determine change in temperature with time. Using the condition of inner maximum temperature of 49℃ and final outer temperature of40.691℃ for dry concrete fish pond and inner maximum temperature of 39℃ and final outer temperature of 32.077℃ for wet concrete fish pond, graphical and analytical methods were used to validate the results. From the study, the results show that the present of water in the pond reduces the effect of high temperature on the concrete fish pond. In conclusion, the thermal penetration on the concrete wall and the intermittent heating and cooling of the concrete fish pond creates the fatigue which leads to cracking. Since this heating effect was found to be critical in the empty pond, it is recommended that even after harvesting of fish from the fish pond, the pond should be filled with water to avoid thermal cracking as a result of thermal diffusion in the concrete.

Key words: Concrete fish pond, Thermal diffusion, Transient simulation and Cracks.

Introduction

Outdoor concrete ponds are normally subjected to thermal effect from solar radiation. This thermal effect is capable of causing deterioration in the concrete fish ponds especially in arid regions. Deterioration of concrete fish ponds is a stochastic process which is caused due to diverse explanatory variables such as high temperature, aggression of chlorides, aggression of carbon dioxide, aggression of sulphate and alkali-silica reaction. Mean and Younis (2014) affirmed that concrete deterioration occur when the materials are subjected to harsh weather (temperature), chemicals and bad water quality over a long period of time. During hot weather on dry concrete pond, surface contraction due to cooling is restrained by the hotter interior concrete that does not contract as rapidly as the surface. This restraint creates tensile stress that can crack the surface concrete as a result of uncontrolled temperature variation across the thickness of the concrete as shown in plate 1. Concrete members also expand and contract when exposed to hot and ambient temperature respectively. This temperature cracking is always a later age and longer term issues. Sudden cracking of concrete fish ponds lead to excessive leakage, loss of revenue, and the relatively high sunk costs incurred during the repair. The mathematical modeling of the thermal diffusion in outdoor concrete fish pond yields equation (1) as the model describing the behavior of concrete walls subjected to thermal effect.

Plate I: Cracked walls of concrete fish

$$\alpha \left[\frac{\partial^2 T}{\partial x^2}\right] = \frac{\partial T}{\partial t} \quad (1)$$

This model is a transient heat transfer in one dimension which has no close form (analytical) solution (Bergman *et al*, 2011; Holman, 2010; Çengel, 2006). Hence, numerical method becomes the best approach to an approximate solution of the equation. This model is subject to the following boundary and initial conditions:

The first boundary condition which gives the temperature as a function of distance (x) and time (t).

$$\frac{\partial T}{\partial x}(x,t) = \frac{\partial T}{\partial x}(0,t) = 0 \quad (2)$$

The second boundary condition which states that on the external wall, the conduction heat transfer must be equal to the convection heat transfer.

$$-kA\frac{\partial T}{\partial x}(x,t) = hA[T(L,t) - T_\infty]$$

$$-k\frac{\partial T}{\partial x}(x,t) = h[T(L,t) - T_\infty] \quad (3)$$

The initial condition states that at t = 0, the initial temperature (T_i) is equal to 49℃.

$$T(x,t) = T(x,0) = T_i \quad (4)$$

Numerical methods are techniques by which mathematical problems are formulated so that they can be solved with arithmetic operations (Chapra and Canale 2010). Slack *et al* (2007) defined simulation as the use of a model of a process, product or service to explore its characteristics before the process, product or service is created. The technique of simulation has long been an important tool of the designer and the purpose is to investigate and compare various proposed system configurations to help choose the best one (Hillier and Lieberman, 2001). Designing processes like the concrete ponds often involves making decisions in advance of the final process being created and so the designer is often not totally sure of the consequences of his or her decisions. To increase the confidence in the design decision, however, it is imperative to simulate how the process behaves in practice. Hence, simulation is one of the most fundamental approaches to decision making. Simulations play a pivotal role in today's research and engineering work.

Materials and Methods

This study was conducted at the hatchery complex of National Institute for Freshwater Fisheries Research (NIFFR), located in Kanji (New Bussa), Niger State, Nigeria located on latitude $9°52'N$ and on longitude $4°32'E$. The complex has two hundred and twenty (220) different sizes of concrete fish ponds which were used for the study. Plate II shows the outdoor concrete ponds used in the study. In this study, the temperature variations of the concrete fish ponds were determined using thermometer. Mathematical and structural models of concrete fish pond were also developed, analyzed and simulated using ANSYS software package.

Plate II: NIFFR outdoor concrete ponds

The result of the simulation was validated graphically by picking the conditions of the external surfaces of the concrete wall using ***Heisler's chart*** (Çengel and Boles, 2006)

Results and Discussions

Figure 1 shows the structural modeling of the concrete fish pond in ANSYS. The results for the transient numerical simulation of the wall of dry concrete fish pond as shown in figure 2 with the temperature ranging from 49℃ on the inner wall to 40.691℃ on the outer wall while figure 3 shows the transient numerical simulation of the wall of wet concrete fish pond with the temperature ranging from 39℃ on the inner wall to 32.177℃ on the outer wall. Figure 4 shows the graph of temperature penetration across the wall thickness. The graph started from 49℃ which is the maximum temperature along the vertical axis (TEMP) and drops down to 40.691℃ across a thickness of 0.225m along the horizontal axis (DIST).

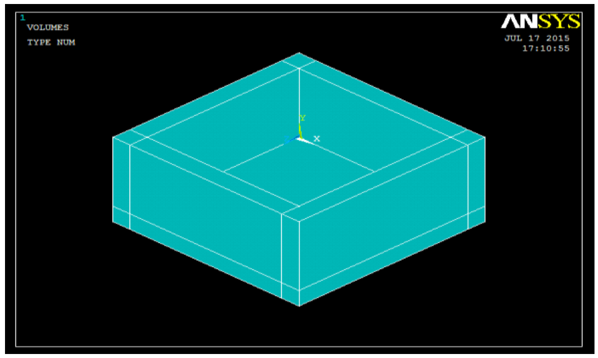

Figure 1: Structural model of concrete fish pond

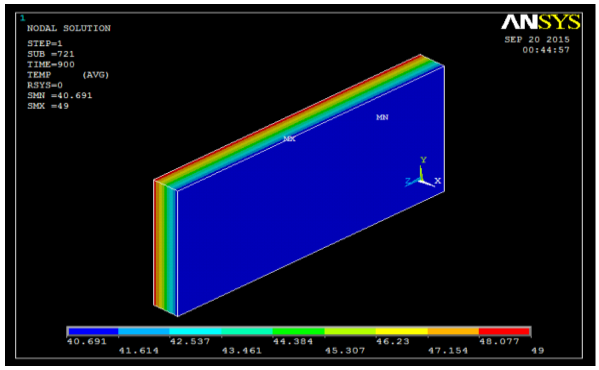

Figure 2: Transient simulation of the dry concrete fish pond.

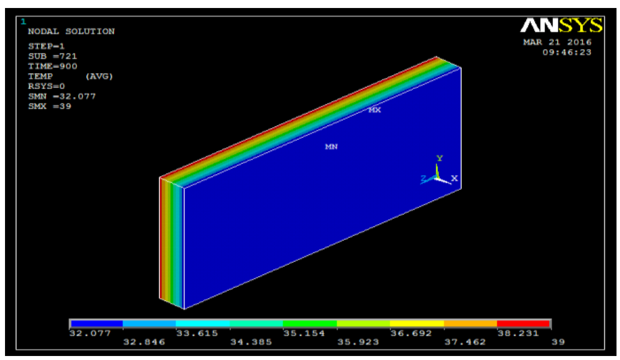

Figure 3: Transient simulation of the wet concrete fish pond

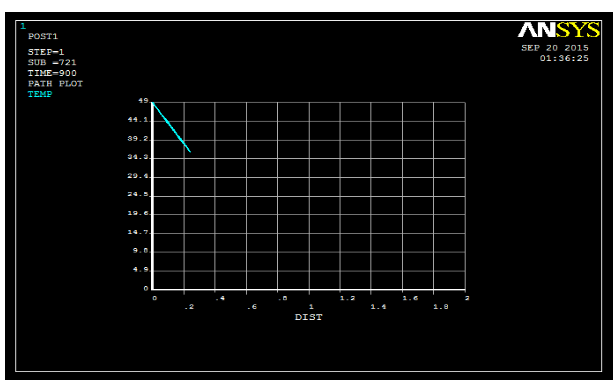

Figure 4: The graph of temperature penetration across the concrete fish pond

The behaviors of all points in the concrete wall follow this trend until a steady state condition is reached. However, the steady state temperatures for points differ from point to point. Figure 5 and 6 show the animation of transient simulation at 128.131 seconds for dry and wet concrete fish pond. The dry concrete fish pond shows that the temperature has penetrated further from 39.657℃ to 38.323℃ while the wet concrete fish pond does not show any significant change in temperature. These means that the present of water in the pond reduses the temperature variation on the concrete while the dry concrete experences significant change in temperature variation and this leads to cracks in concrete fish ponds.

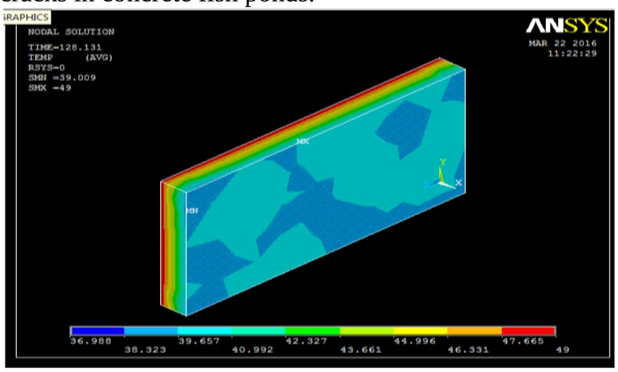

Figure 5: Animation of transient simulation at 128.131 sec. for dry concrete pond.

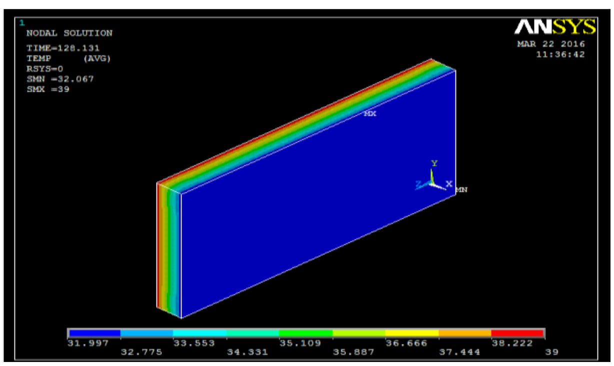

Figure 6: Animation of transient simulation at 128.131 sec. for wet concrete fish pond

From *Heisler's chart* for plane wall (b) Temperature distribution.
Calculating for the type of curve to use,

$$\frac{X}{L} = \frac{X_6}{L} = \frac{L}{L} = 1$$

Therefore, using curve where $\frac{X_6}{L} = 1.0$;

$$\theta = \frac{T - T_\infty}{T_0 - T_\infty}$$

$$\theta = \frac{T_2 - 37}{49 - 37}$$

From the graph,

$$\frac{1}{B_I} = \frac{k}{hl}$$

$$B_i = \frac{hl}{k}$$

$$B_i = \frac{20x0.225}{2.0} = 2.25$$

Therefore, if $B_i = 2.25$ then;

$$\frac{1}{B_i} = \frac{1}{2.25} = 0.44$$

From the graph, at $\frac{1}{B_i} = 0.44$ on curve 1.0,

$$\theta = \frac{T_2 - T_\infty}{T_0 - T_\infty} = 0.3$$

$$\frac{T_2 - 37}{49 - 37} = 0.3$$

$$T_2 - 37 = 0.3(12)$$
$$T_2 - 37 = 3.6$$

$$T_2 = 37 + 3.6 = 40.6$$

Hence, $T_2 = 41℃$

Conclusion

The thermal penetration on the concrete and the intermittent heating and cooling of the concrete create the stress and strain which leads to cracking which is in form of fatigue in concrete walls thereby causing deterioration on the concrete fish pond. Since high temperature are found to be the major factor causing cracks on concrete fish pond, fish farmers are adviced to always have water in the concrete fish ponds irrespective of absence of fish in the pond.

Thermal analysis is one of the most important analyses that should be done for every reinforced concrete structures to provide the engineer with a means of predicting excessive tensile stresses and strains, which could indicate possible cracking, thereby, allowing the designer to take appropriate measures to limit or control such potential cracks.

Acknowledgement

I wish to express my profound gratitude to National Institute for Freshwater Fisheries Research (NIFFR), for their support in providing materials used for this study and also my supervisor for all his assistance during this research.

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Table 1: Material properties used for the simulation (Saetta, 1995).

	Material Properties	**Values Adopted**	
Structural	Elastic Modulus	E_c	30Gpa
	Poisson's Ratio	v	0.2
	Density	ρ	24kN/m^3
Thermal	Thermal conductivity	k	2.0W/m.°C
	Specific heat capacity	c	1000J/kg
	Density	ρ	24kN/m^3

Table 2: Range of convective heat transfer coefficient for air (Long and Sayma, 2009)

Nature of Flow	**Fluid**	**h(W/m^{2}K)**
Surfaces in building	Air	1-5
Surfaces outside building	Air	5-150