Performance of Stage and Direct Method of Mass Concrete Construction in Controlling Temperature Gradient

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Abstract:- Mass concrete construction always deals with the temperature control issue since the process including the heat transfer following the oxidation process and may generate thermal crack for high temperature gradient between layers as low thermal diffusivity of concrete may generate internal restraint and resulting tensile stress at some parts of the concrete, which does not perform well in resisting tension force. Quality control and assurance of mass concrete construction among projects are unique and it is significantly recommended to arrange appropriate procedure.This paper evaluates temperature development and its gradient between layers of mass concrete construction with stage and direct method. Curing method was performed by assuring that the temperature from the concrete surface to the lower level remained similar, or may vary with no more than 20^{o}C. This curing technique performed excellent in office (stage method) and hotel (direct method) raft foundation. The trendline of those two foundations were typically similar, not to mention the time difference. Therefore, it may be expected that thermal cracking did not occur in the concrete during construction and curing phase. Moreover, should cubic polynomial interpolation is used, the behavior of temperature development shows precise result for second degree polynomials

Key-Words: -mass concrete, temperature, temperature difference, thermocouple, thermal crack.

1 Introduction

Production of concrete always engages with thermal process, i.e. heat transfer, following oxidation process in concrete mixing. It has positive correlation with concrete dimension, hence bigger dimension will result in large amount of heat transfer, higher temperature and its gradient betwen layers in concrete.It has been performed that in terms of transient heat conduction, the occurance of thermal gradient yields irreversibility in the system [1]. Low thermal diffusivity of concrete may generate internal restraint and resulting tensile stress at some parts of the concrete, which does not perform well in resisting tension force.In addition, the need of temperature control to mass concrete construction is developed into essential since high temperature gradient between infinite layers yields thermal crack in concrete [2,5,6,7,8,9,10]. Thus, since concrete surface cools down rapidly and the concrete core does conversely, thermal cracking will occur [2,5]. Some terms of thermal effects have been developed to capture the appropriate heat transfer phenomena, including thermal effusivity and diffusivity [3,4].

As stated in [10], in terms of concrete, hot weather is a simultan combination among high temperature, low humidity and high wind speed. Therefore, some techniques have been developed in maintaining those factors in control during mass concrete construction e.g. including fly ash and other pozzolan material that may reduce time of hydration.It is realized that behaviour of cementitios composites is vital in oxidation process and has elicited various sophisticated mathematical models with its algorithms [11]. Boundary and intial temperature will determine heat transfer process behaviour in the concrete slab [11,12]. Moreover, boundary conditions have considerable effect, while the initial condition might be avoided for large time interval. For that reason, selected method will involve these parameters.

One of the generally simple approach in preventing thermal cracking is by keeping temperature difference between surface and core of concrete not more than 20^{o}C [13,14].This might be attained by controlling the increase in the internal temperature of concrete during hydration reaction e.g. providing the insulating material on the exposed concrete surface environment to minimize the temperature difference between the core and the surface of the concrete. Another technique is by adding superplastisizer as water reducer .

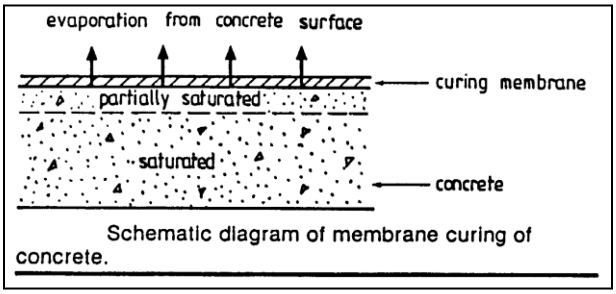

Fig 1. Curing method in maintaining temperature

In addition, large scale construction of mass concrete relies on supply capacity. This is determined by capacity of batching plant, traffic, quality control and quality assurance during construction. Every part of this typical project need to be carefully examined. As construction duration is relatively long, details and contigency plan should be properly organized. In the big city with erratic traffic condition like Jakarta, Indonesia, ready mix concrete delivery from batching plant to project site may cause irregular concrete quality arriving on the site. Should the ready mix concrete truck arrive longer than specified concrete setting time, the concrete must be rejected to be included in the construction. Concrete setting time is varied between 6 and 11 hours, depended on concrete strength and the admixtures. Not only the travel time, but also slump test [15] of concrete after arriving at the site should be considered as quality control and assurance requirement in mass concrete construction. Temperature of fresh concrete should also meet the requirement in [16] where the temperature should be less than 35^{o}C. In accordance with the volume, stage method ussually may be conducted in the night, in low traffic condition. On the other hand, direct method needs days to finish. Therefore, excellent management system, both batching plant and project site, should be performed during the process. Risk analysis should be carefully scrutinized, then the loss can be minimized. Furthermore, cold joint should be prevented to be exist in the mass concrete construction. Strict monitoring in travel time is expected to avoid this to ensue. However, reinforcement should be installed to minimize the risk in terms of number of cold joint that probably take place during construction.

In terms of the existence of cold joint, there are only two approaches; first, permitting the existence of cold joint then continuing to the next layer (stage method). Second, precluding cold joint between layers (direct method). Direct method offers shorter duration of construction than stage method, where sometimes it is highly required for late project on its time schedule. Conversely, stage method suggests lower risk in thermal cracking in mass concrete construction than direct method. Hence, additional cost is needed to meet the quality control and assurance during the project. This paper focuses on describing temperature measurement and its analysis of two construction methods of mass concrete. The construction was part of Ciputra World Building Project that consists of three main tower i.e. office, hotel and apartment. It is merely at office and hotel's raft foundation (mass concrete) that will be discussed in this paper.

This paper is organized as follows. Section 2 discusses about how the two methods i.e. Stage and Direct method are performed in detail, from the preparation until the insulation phase, including the temperature measurement strategies. Next, section 3 elaborates and analyzes the result from temperature control in every layer of mass concrete. Then, section 4 encapsulates important things from previous section. Finally, the last two sections are recommendations for future research and credits.

2. Methodology

Two different method of mass concrete construction were carried out in this project i.e. stage and direct method. Stage method was conducted at office tower, while direct method was conducted at hotel and apartment tower.

Stage method is construction of raft foundation with interval time between layers. The next mix is performed until the core temperature of concrete starts to show downward trendline. It took 3-4 days to complete the costruction of the next layer. Cold joint is expected to exist in this method. Therefore, shear connector, longitudinal bar, is required during construction to assure that all layers will still work together and compatibility principle remains germane to be considered. And thermocouples were installed at the bars to control temperature at core and surface for each layer.

At the raft foundation of office tower, the total volume of concrete to be mixed was 9500 m^3 splitted into three stages i.e. first stage (2672 m^3), second stage (2672 m^3) and the third stage (4156 m^3) with total area was 2925 m^2. The target compressive strength was 35 Mpa and the admixtures component is as shown on table 1.

Table 1. Material Composition on Office Raft Foundation

No	Grade	fc' 35 Mpa
1	COMPOSITION FOR 1 CuM (SSD Condition)	
	Water	180 lt
	Cement	366 kg
	Fly Ash	59 kg
2	ADMIXTURE	
	Retarder	0.2 - 0.4%
	Superplastiziser	-
	Other	-
3	AGGREGATES	
	Fine Aggregates	640 kg
	Coarse Aggregates	1080 kg

Fig 1. Side View of Office Raft Foundation

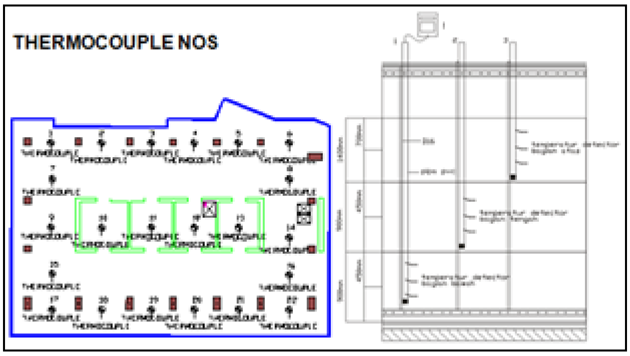

Fig 2. Layout of Thermocouple at Office Raft Foundation

On the other hand, direct method is construction of raft foundation without interval time between layers. Cold joint is not expected to exist in this method. The core temperature still indicates upward trendline but the temperature is still considered low when the next layer construction phase is started.

At the raft foundation of hotel tower, the total volume of concrete to be mixed was 15013 m^3 splitted into four stages i.e. first stage (1045 m^3), second stage (4433 m^3), third stage (3323 m^3) and the last stage (6212 m^3) with total area was aproximately 3725 m^2. The target compressive strength was 35 Mpa and the admixtures component is as shown on table 2.

Methodology of mass concrete construction in hotel raft foundation was based on temperature analysis and evaluation on office raft foundation.

Table 2. Material Composition on Hotel Raft Foundation

No	Grade	fc' 35 Mpa
1	COMPOSITION FOR 1 CuM (SSD Condition)	
	Water	185 Lt
	Cement	400 Kg
	Fly Ash	68 Kg
2	ADMIXTURE	
	Retarder	1030 ml
	Superplasticiser	-
	Other	-
3	AGGREGATES	
	Fine Aggregates	611 Kg
	Coarse Aggregates	1049 Kg

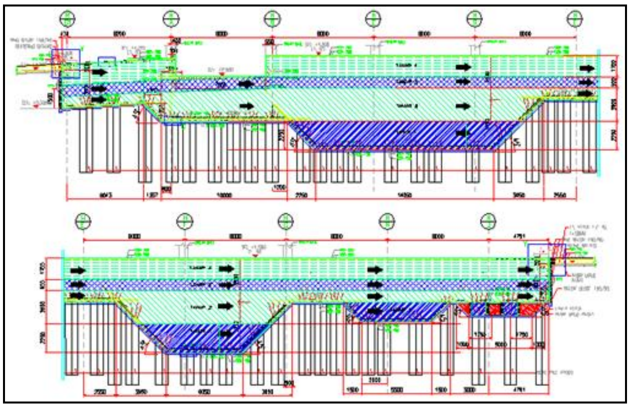

Fig 3. Side View of Hotel Raft Foundation

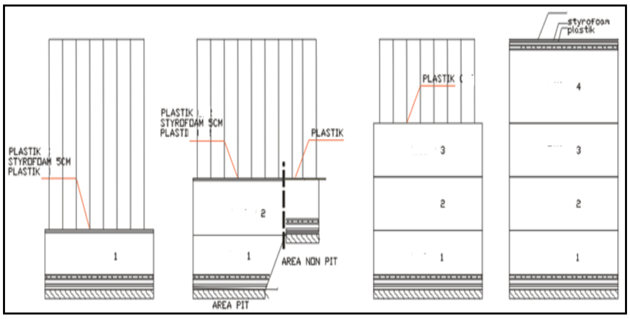

Fig 4. Curing Stage of Hotel Raft Foundation

3. Result & Discussion

In the office raft foundation,there were four types of thermocouple arrangement based on their distance to each other, and it was labelled A, B, C and D. Fig 5-8 demonstrates the temperature measurement in every representative point on the bar where the thermocouple was being attached.

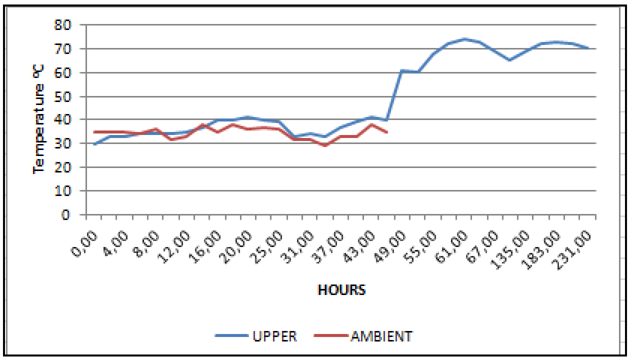

Fig 5. Temperature Measurement Type A in Office

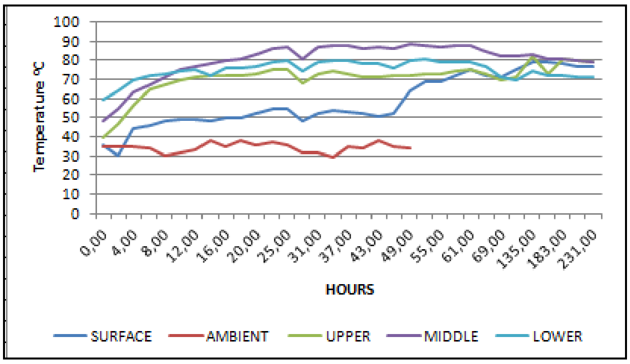

Fig 6. Temperature Measurement Type B in Office

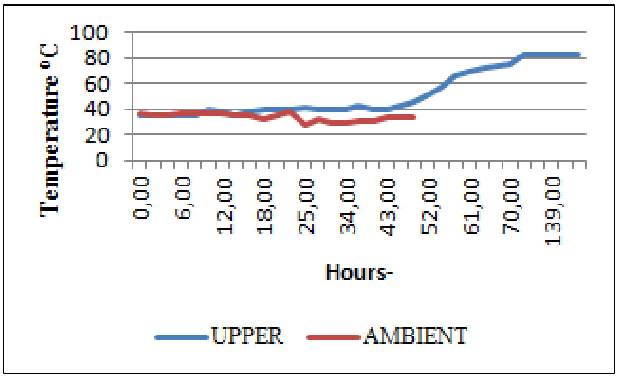

Fig 7. Temperature Measurement Type C in Office

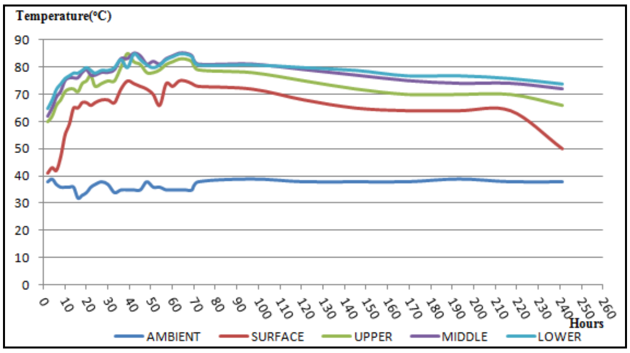

Fig 8. Temperature Measurement Type D in Office

It can be seen from the figure 8 that until approximately 70 hours following the construction, the temperature generally increased with some variation. Then, the temperature shows slightly downward trendline and stable at some extent. It was expected that the temperature in the concrete was uniform, and might vary for not more than 20 ^{o}C difference between adjacent layer levels i.e. surface-upper, upper-middle, middle-lower. However, the temperature difference between surface level and surrounding area could not be included in the evaluation since there were mixing plastic and styrofoam on top of the surface separated interaction between those two temperatures. Should the temperature difference close to 20 ^{o}C, all the engineers and supervisor is required to remain vigilant until the time difference decreases.

Based on results in office area, it is obviously clear that to maintain time difference in control for direct construction method, for the same thickness of mass concrete, it is necessitate to perform next layer construction not more than 20 hours after previous layer, not only for preventing thermal cracking, but also assuring that cold joint is not formed during construction.

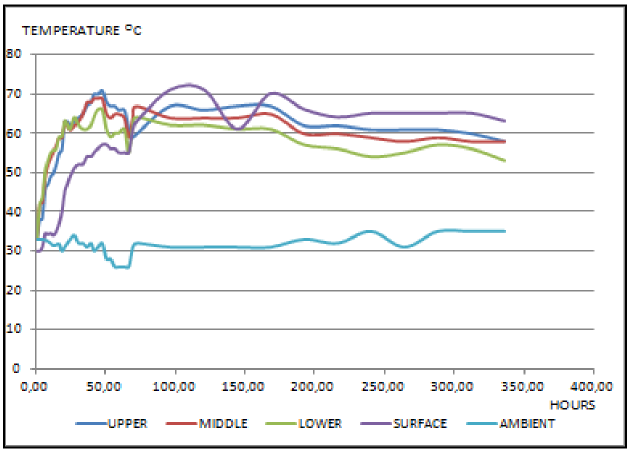

Fig 9. Temperature Measurement Type A in Hotel

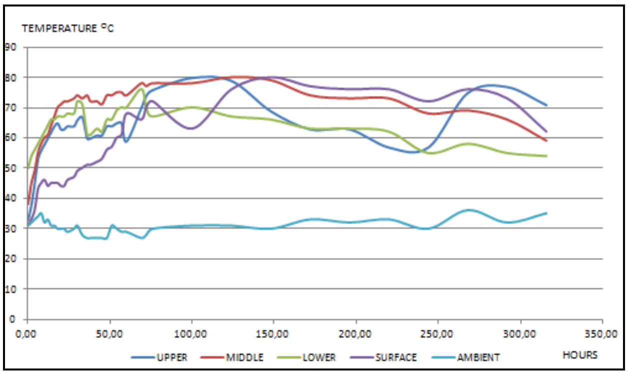

Fig 10. Temperature Measurement Type B in Hotel

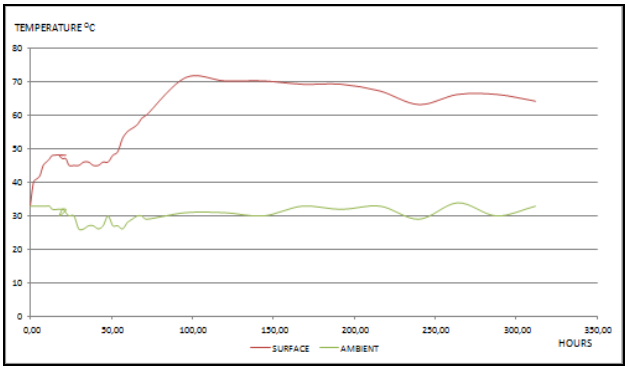

Fig 11. Temperature Measurement Type C in Hotel

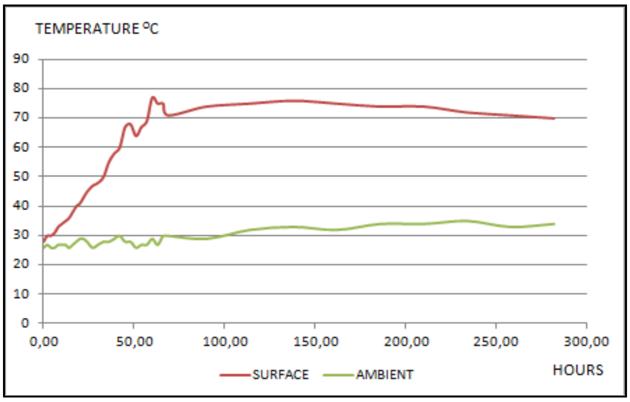

Fig 12. Temperature Measurement Type D in Hotel

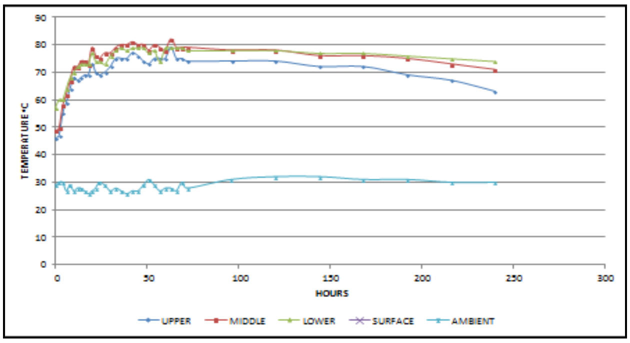

Fig 13. Temperature Measurement Type E in Hotel

With previous technique mentioned, the results of the mass concrete construction in hotel raft foundation are demonstrated on figure 9-13. There were 5 (five) types of thermocouple installation. It can be clearly seen from the figures that temperature development in hotel area follows not only the trendline of each layer at office area, but also the time difference between layers that sustains under the limit.

Direct method has more advantages in terms of time in construction than stage method. However, the preparation, especially in quality control and quality assurance need to be carefully scrutinized because cracks in the core will absolutely have consequence in cost for repairing and additional time for construction.

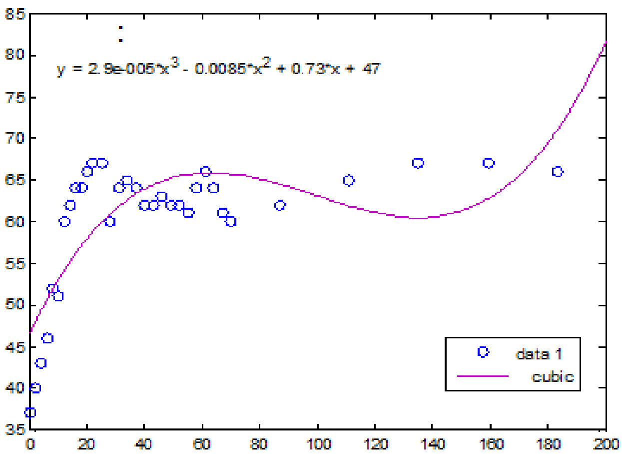

Fig 14. Cubic Interpolation of Upper Temperature Type A

It can be seen from figure 14-17, simple interpolation approach using cubic spline method in predicting temperature development during specified time. From type A-D, each type similar behavior that the constant for third degree is significantly small. Therefore, second degree polynomial can be used as starting approach model, with limited consideration, since it is needed complete parameters to determine precise and accurate behavior of temperature development in mass concrete construction.

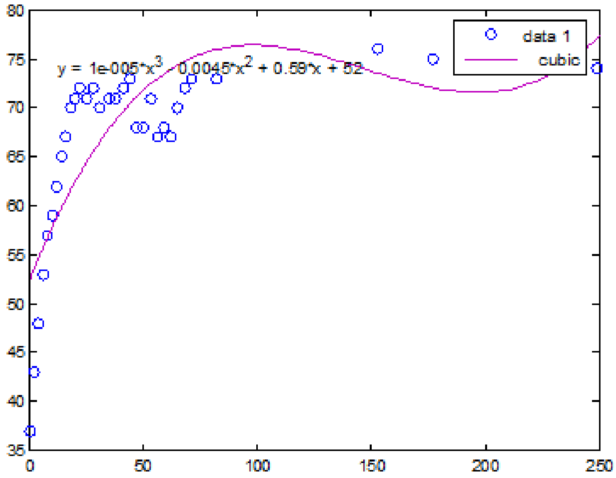

Fig 15. Cubic Interpolation of Upper Temperature Type A

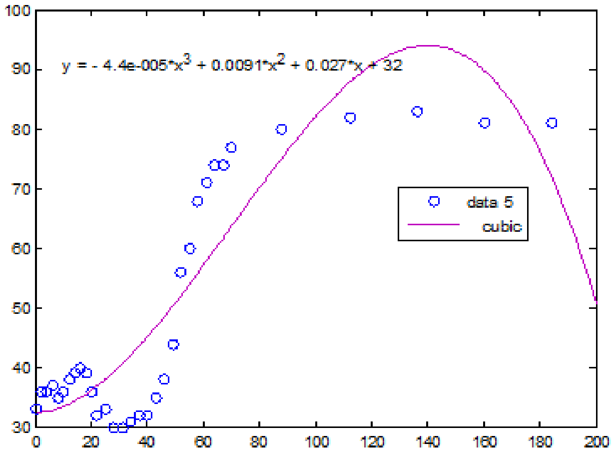

Fig 16. Cubic Interpolation of Upper Temperature Type C

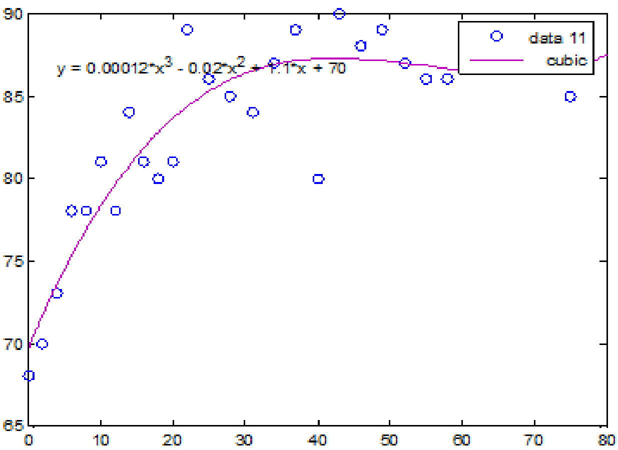

Fig 17. Cubic Interpolation of Upper Temperature Type D

4. Conclusion

Temperature control is of paramount importance in precluding thermal cracking in the mass concrete. Curing strategy in maintaining temperature and humidity superbly performed in this construction.

Athough the temperature hit 80-90°C, the temperature difference was still under 20°C. For that reason, thermal cracking is expected not occur in the concrete. Study on stage method (office raft foundation) generated strategies on determining construction method in direct method especially in terms of thickness and the field resources management. Excellent preparation can be concluded from the trend comparison between office and hotel temperature of mass concrete.

Based on the cubic polynomial interpolation, constant on third degree polynomial does not have significant value. Then, it can be concluded that second degree polynomial will give precisely simple equation.

5. Further Study

To gain complete information with regard to temperature distribution in the mass concrete, numerical study in modeling temperature behaviour is required. Although the simple polynomial model has been developed, the formulation is far from accurate since it does not involve related physical and mechanical properties of concrete in determining the temperature model. The boundary trend has been provided in this paper, and the trend formulation may be established. Hence, diffusion rate and mass transfer pertinent to differential equation may be predicted during construction.

Moreover, since thickness also one feature in temperature development in the mass concrete, it is also required to be included in the analysis. This will give valuable impact to constrction industry.

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