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TEMPERATURE CONTROL ON MASS CONCRETE IN BUILDING FOUNDATION

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ABSTRACT

The design of multi-storey buildings currently growing in both height and size. To compensate for these growths, it is necessary to design a larger and deeper foundation. This causes more mass concrete use in the foundation construction. Mass concrete has a special characteristic than ordinary concrete. Mass concrete can produce very high hydration heat because of the very large casting volume. If not well controlled, this heat of hydration can cause cracks in the concrete. Several methods can be used to control the heat of hydration that occurs, such as the use of ice as a part of batch water, the use of water flow in embedded pipe, additives such as fly ash and others. The combination of using ice as part of the batch water and water flow in embedded pipe to control the heat of hydration was used in this study. After this method was applied in mass concrete casting, concrete temperature checking conducted for several days. Temperature checks indicate that the method has been successfully managed to keep the heat of hydration that occurs in the concrete remains below the safe limit.

Key words: Mass Concrete, Hydration Heat, Foundation, Ice, Water Flow, Concrete Crack, Concrete Temperature.

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1. INTRODUCTION

According to American Concrete Institute, mass concrete is defined as any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking (ACI,1996) [1]. Mass concrete is widely used in dam structures, foundation pile caps, machine foundations and other structures requiring large concrete volumes. Mass concrete has special characteristics compared to other concrete work that is thermal behavior. Temperatures generated by chemical reactions in concrete mortar with large concrete masses will be very high.

There are four main points to consider in designing a mass concrete. The first is the availability of concrete, concrete mixer truck and concrete pump in sufficient quantities. This is to keep the concrete pouring not stopped due to lack of supply, resulting in a cold joint on the concrete. The second is a good mix design, so that the initial temperature of the concrete can be pushed as low as possible. The third is the cooling and insulation planning of the system, to keep the temperature difference in the concrete within the boundary. The fourth is the temperature evaluation that occurs on the concrete after the concrete casting.

Indonesia is a developing country, which is currently focusing on infrastructure development. Hundreds of buildings, seaports and toll roads built by the government in the last 4 years. This development resulted in the growing demand for concrete and the development of concrete technology in Indonesia. To carry out the construction of the building effectively and efficiently, foundation design using mass concrete as a pile cap are widely used in Indonesia. Implementation of this method would require a good and comprehensive design. Where all aspects of preparation, implementation and evaluation shall be conducted in accordance with the standards of applicable regulations.

The planning and construction of mass concrete foundations is a complex thing, because many factors and many parties involved. For this reason, this research paper is expected to provide guidance on the construction phase of mass concrete foundation. In this research, the case study is a multilevel building in Surabaya, Indonesia. In this research paper, will be explained about the methods of planning, implementation and evaluation used in the construction of mass concrete foundations.

2. LITERATURE REVIEW

The mass concrete was first used in the construction of the dam in America in early 1930. At that time many dam was built with a large wall thickness, so it takes concrete with a very large volume. In the mass concrete construction, there is a lot of damage in the form of cracks on the wall of dam that has been completed. From the results of the current study, it was recorded that high temperature rise due to cement hydration, correlated directly with the level of crack that occurred. To do special research about mass concrete, ACI Committee 207, Mass Concrete, was organized in1930 for the purpose of gathering information about the significant properties of mass concrete in dams and factors which influence these properties (ACI,1996) [1].

To ensure that the results of mass concrete work properly, control of the concrete temperature must be performed. According to ACI 207.1R-96 [1], there are four element to consider in mass concrete construction, are:

- Cementitious material content control, where the choice of type and amount of cementitious materials can lessen the heat-generating potential of the concrete;

- Precooling, where cooling of ingredients achieves a lower concrete temperature as placed in the structure;
- Post cooling, where removing heat from the concrete with embedded cooling coils limits the temperature rise in the structure; and
- Construction management, where efforts are made to protect the structure from excessive temperature differentials by knowledgeable employment of concrete handling, construction scheduling, and construction procedures.

Typical construction practices used to control temperature changes within concrete structures include according to ACI.207-4R.1993 [2] are:

- Cooling batch water
- Replacing a portion of the batch water with ice
- Shading aggregates in storage
- Shading aggregate conveyors
- Spraying aggregate stockpiles for evaporative cooling effect
- Immersion of coarse aggregates
- Vacuum evaporation of coarse aggregate moisture
- Nitrogen injection into the mix
- Using light-colored mixing and hauling equipment
- Placing at night
- Prompt application of curing water
- Post-cooling with embedded cooling pipes
- Controlled surface cooling
- Avoiding thermal shock at form removal
- Protecting exposed edges and comers from excessive heat loss

In the design of reinforced concrete elements, there is a temperature change to be considered is the difference between concrete peak temperatures achieved during initial hydration (usually within the first week) and the minimum temperature of the concrete. An increase in initial hydration temperature can produce stress on the concrete. At this early age, the modulus of elasticity of the concrete is small, so the pressure caused by the temperature rise is not significant. The level of heat generated from the concrete depends on the amount of cement and pozzolan volume (if any), the composition and the fineness of the cement. The hydration temperature is influenced alternately by the amount of heat lost or obtained as regulated by the size of the member and the exposure conditions (ACI,1995) [3].

One of the most widely used pozzolan material, as cementitious material in concrete mix is fly ash. With the use of fly ash as a cementitious material, the use of cement in the concrete mixture can be reduced, so that the hydration temperature of the concrete can also be reduced. For use in concrete, ASTM C618 specifies the requirements for Class F and Class C fly ashes and Class N for raw or calcined natural pozzolans. According to “ACI Concrete Terminology,” fly ash is “the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal systems” (ACI, 2008) [4]. The use of fly ash as a cement replacement material in the concrete mixture has a maximum limit. For fly ash Class F recommended percentage is 15 - 25% of the weight of cementitious material. As for Class C fly ash, the recommended percentage is 20-35% of cementitious material (ACI,1993) [5].

In general, there is a limit of temperature in the mass concrete to prevent heat, crack the concrete and maintain the durability of the concrete. The maximum permissible temperature limit on concrete is usually taken at 70 ° C. While the temperature difference between the center and the maximum concrete surface is 20 ° C. However, in many cases, the temperature limit is determined by each project (Soo Geun, 2010) [6].

The approximate temperature of concrete at placement can be calculated from the temperatures of its ingredients by using the following equation (PCA, 2003) [6]

$$T\ initial = \frac{0.22(Ta.Ma + Tc.Mc) + Tw.Mw + Twa.Mwa}{0.22(Ma + Mc) + Mw + Mwa}$$

Where:

$T_{initial}$ = temperature of the freshly mixed concrete, °C

Ta, Tc, Tw, and Twa = temperature in °C of aggregates, cement, added mixing water, and free water on aggregates, respectively

Ma, Mc, Mw, and Mwa = mass, kg, of aggregates, cementing materials, added mixing water, and free water on aggregates, respectively

The approximate maximum temperature of concrete can be calculated from the weight of cementitious materials by using the following equation:

$$Tmax = Tinitial + \left(T\ rise\ x\ \frac{Equivalent\ cement\ content}{100}\right)$$

Where:

T_{max} = maximum temperature of concrete, °C

$T_{initial}$ = temperature of the freshly mixed concrete, °C

T_{rise} = rise of temperature per kg equivalent cement content 12 °C

One method of mass concrete temperature control is by using embedded pipe cooling. This system was first attempted at Hoover Dam development in America and is widely used today (Townsend ,1981) [7]. This system consists of steel pipes arranged to form pipelines and cold water drained inside. This water is designed with a certain flow rate and temperature so that it can reduce the peak temperature that occurs in the mass concrete.

3. METHODS

3.1. Studi Area

This study will be conducted on building construction in Surabaya, Indonesia. Mass concrete reviewed in this study is the foundation of the building, with a thickness of 1.5 to 2 m. The dimensions of the foundation are 70 x 40 m as shown in FIG. 1.

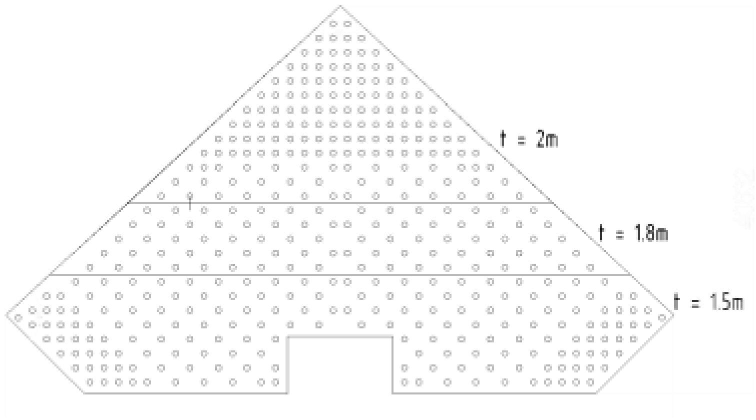

Figure 1 Mass Concrete Foundation Layout

3.2. General Work Requirements

Mass Concrete Volume : 2710 m3

- Cement : 667.5 tons
- Sand : 2273.6 tons
- Stone : 3005.3 tons
- Fly Ash : 203.25 tons

Implementation time : 72 hours
Number of Ready-mix Company used : 2
Ready-mix capacity (Company 1) : 1810 m3
Ready-mix capacity (Company 2) : 900 m3
Target speed of 1 batching plant : 30 m3 / hour
Number of "Concrete Pump" : 4 units + 2 units stand by
Truck Mixer

- Ready-Mix Company 1 : 25 Units
- Ready-Mix Company 2 : 25 Units

3.3. Mass Concrete Pouring Plan

Ready-Mix Company 1

Total pouring targeted is 1810 m^3 in 72 Hours
Number of Concrete Pump (CP) use : 2 Concrete Pump
Casting speed per Mixer Truck (MT) 7.5 m^3 : 30 minutes
Number of Mixer Truck use : 25 Truck
Cycle time of 1 Mixer Truck : 30 minutes (Concrete pour to CP) + 20 minutes (cleaning) + 90 minutes (Trip to batching plan) + 90 minutes (Process in batching plan) + 90 minutes (Travel back to project location) = 320 minutes
Number of Mixer Truck Trip : 241 trip

Ready-Mix Company 2

Total pouring targeted is 900 m^3 in 72 Hours
Number of Concrete Pump (CP) use : 2 Concrete Pump

Casting speed per Mixer Truck (MT) 7.5 m^3 : 30 minutes
Number of Mixer Truck use : 25 Truck
Cycle time of 1 Mixer Truck : 30 minutes (Concrete pour to CP) + 20 minutes (cleaning) + 90 minutes (Trip to batching plan) + 90 minutes (Process in batching plan) + 90 minutes (Travel back to project location) = 320 minutes
Number of Mixer Truck Trip : 120 trip

3.4. Mass Concrete Temperature Control Method

To keep the temperature at this concrete casting has a difference between concrete core and concrete surface <20 ° C, and to keep maximum concrete temperature < 70 ° C, necessary steps is needed. Where in this work is divided into 2 steps namely precooling and post cooling.

Mixed design with a mixture of fly ash and cold water (Precooling)

Use mix design with the following mixture so that the initial temperature of the concrete can be lowered. Mix design for fc'30:

Water Cement Ratio	: 0.43
Cement	: 250 kg
Fly Ash	: 75 kg (30%)
Sand	: 839 kg
Gravel	: 1109 kg
Water	: 150 kg
Water temperature (used ice water)	: 7 'C
Slump	: 10 ± 2 cm
Admixture : Type D: 0.72 kg, Type F	: 4.1 kg
Calculated fresh concrete temperature	: 30 ° C
Calculated peak concrete temperature	: 65.7 ° C

Surface Insulation (Post Cooling)

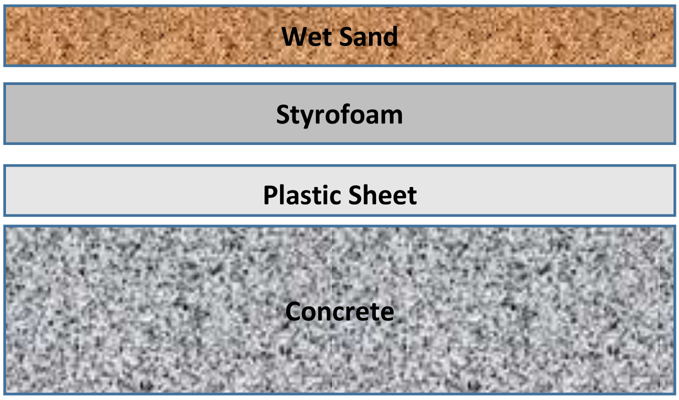

Figure 2 Surface Insulation

Surface insulation is performed as soon as the concrete surface hardened (1.5 hours of concrete pour time). Surface insulation is done by covering the surface area of concrete with a layer of plastic, 2 cm Styrofoam and wet sand with a thickness of 20 cm. Surface insulation is performed for 14 days, or after concrete temperature difference < 20 ° C. After surface insulation is removed, proceed with curing using water or wetted cloth.

Installation of Pipe Cooling System (Post Cooling)

Pipe cooling is done by flowing cold water into the iron pipe has been installed within the concrete. Pipe cooling is done until the concrete temperature drops to at least 15 ° C from the peak concrete temperature. The embedded pipe layout can be seen in Fig.3. The pipe used is a 1.5 " diameter black steel pipe and 1.5 mm thickness. The arrangement of pipes is divided into 3 zones, where each zone has different concrete thickness and pipe configuration. Their respective water pumps service the pipelines of each zone, having their own inlets and outlets. The arrangement of pumps and tanks that drain water in each zone can be seen in Fig.4.

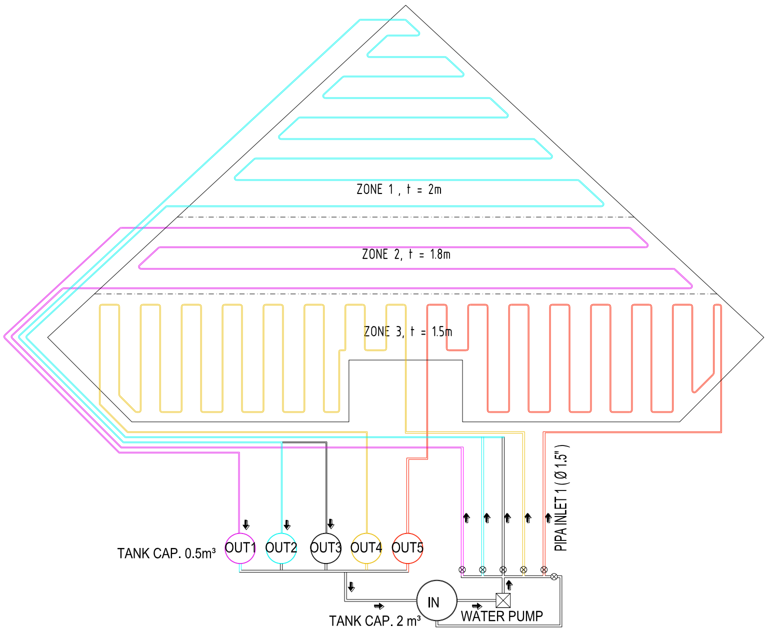

Figure 3 Embedded Pipelines Layout

Figure 4 Embedded Pipeline Installation

The inlet of this pipe cooling system comes from a tank with a capacity of 2 m3. The water at this reservoir will be pumped with a High Pressure Pump to the 5 inlets available. This inlet tube will be equipped with a temperature gauge thermometer. The water in this inlet tank will be cooled with ice cubes. Water from 5 outlets will be accommodated at a 0.5 m3 capacity tank. Water entering at the reservoir will be measured in temperature. It will then be flowed back to the inlet tank for recirculation.

Installation of Closed Tents

The installation of a cover tent aims to prevent raindrops at the time of casting. In addition, the installation of tents cover also aims to prevent the heat of sunlight, so that the concrete temperature can be reduced. Closing Tents can be assembled by themselves using pipes and tarpaulins, or rent a cover tent with a 6x6 m module.

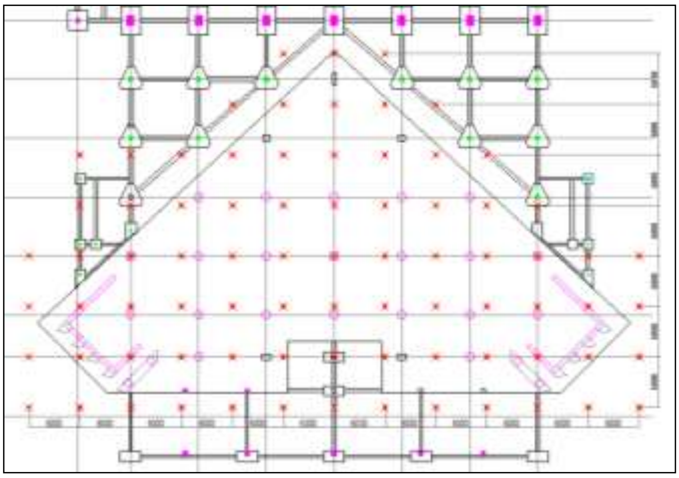

Figure 5 Tent Column Position

Figure 6 Tent Installation at Site

Concrete Temperature Monitoring

To ensure the temperature difference in concrete <20 'C, the temperature in the concrete must be controlled with thermocouple installed in the concrete. Thermocouple is installed on 3 layer thickness and 6 point, so the amount of thermocouple is 18 pieces. Thermocouple measurements are performed every two hours for the first 24 hours, and every 3 hours for the next 24 hours. Measurements are made for 5 days, or when the concrete has reached a constant temperature.

Installation of thermocouple mounted on top, middle and bottom position of concrete thickness. Thermocouple is mounted on a PVC pipe bound to the reinforcing steel. The outer end of the thermocouple probe is labeled according to position in the concrete and wrapped in plastic to avoid getting wet. The outer end of the probe will be connected to the digital thermometer for temperature readings. The measurement of outer air temperature and temperature in inlet and outlet tanks is done simultaneously with thermocouple measurements.

Figure 7 Thermocouple and Digital thermometer

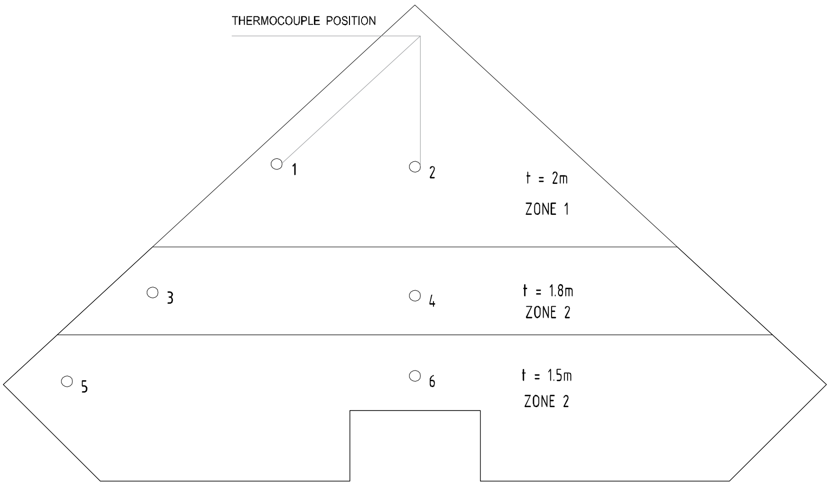

Figure 8 Thermocouple Position

4. RESULT AND DISCUSSION

Mass concrete temperature evaluation is based on measurements made over 5 days. From the measurement results, then evaluated whether the temperature difference is still below 20'C (delta max). It also analyzed whether the maximum temperature exceeds the safe temperature of 70'C . The results of the measurement evaluation are presented in the following graphs.

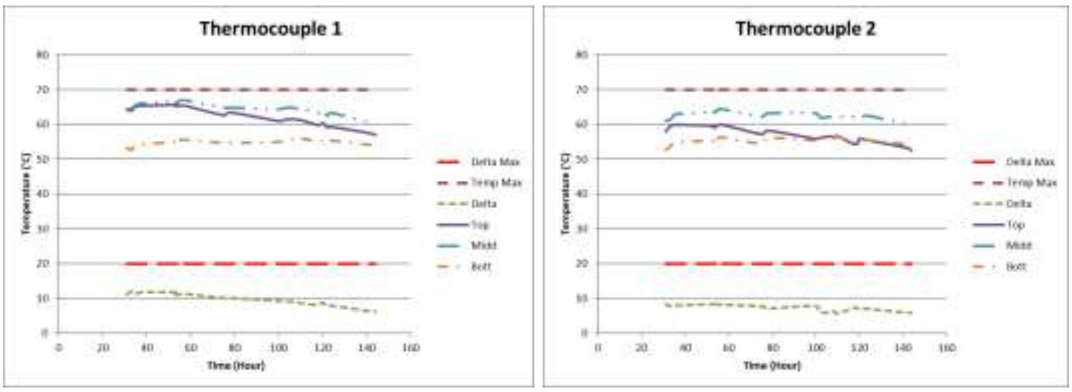

Figure 9 Thermocouple 1 and 2 Result

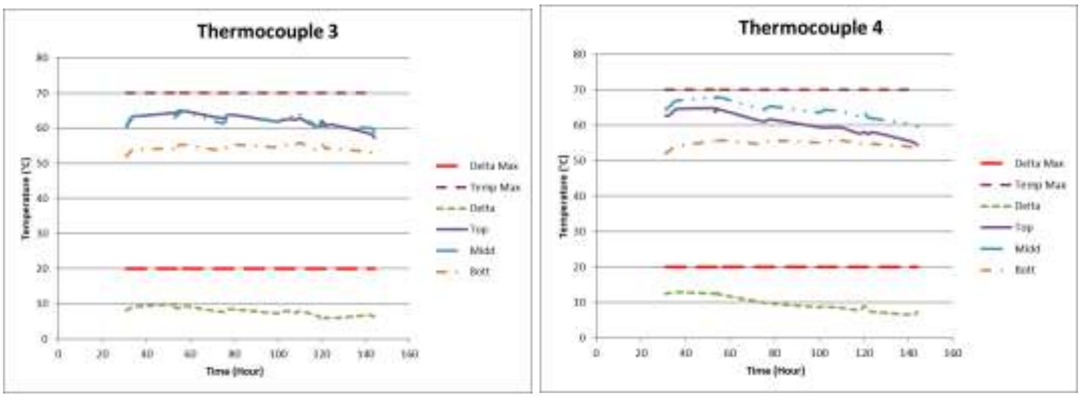

Figure 10 Thermocouple 3 and 4 Result

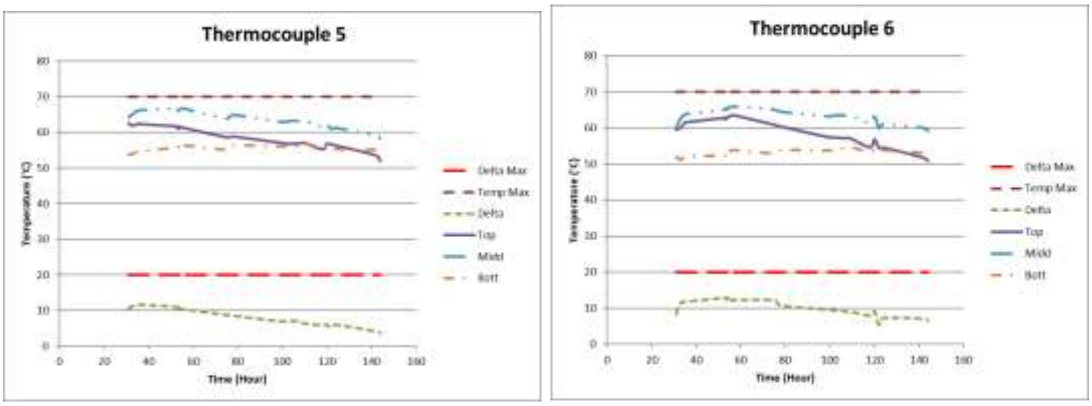

Figure 11 Thermocouple 5 and 6 Result

From the graph in fig.9-10, there is a reading of three layers of thermocouple located on the top, middle and bottom layers of the foundation. Of the 6 thermocouple positions installed, all show that the middle layer is the position with the highest temperature. Nevertheless, with the temperature control measures that have been performed, the maximum temperature that occurs remains below the maximum limit of 70 C. From the measurements on the three layers, the bottom layer is the area where the lowest temperature occurs, this is because the bottom layer has a direct contact with soil that the heat can be absorbed.

The temperature difference between the highest and lowest temperatures can be kept below the limit. So the danger of excess temperature on concrete casting can be avoided. The maximum temperature that occurs is 68 C, slightly above the prediction that has been done that is 65 C. But in general the temperature control plan and calculations that have been done, can succeed in accordance with the planned.

5. CONCLUTIONS

From the temperature, measurements that have been made can be concluded as follows:

- From the temperature measurement, it shows that the increase of concrete temperature occurring in the mass concrete foundation is still below the maximum temperature limit (maximum measurement temperature 68 'C <Maximum Temperature limit of 70'C).
- The measurement results show that the highest and lowest temperature difference on this mass concrete foundation, below the permissible temperature difference (Maximum temperature difference measurement 13 'C <Maximum Temperature limit of 20 ° C).

- Maximum Temperature occurs at approximately 60 hours (3 days) after the casting and began to decrease the temperature after the 5th day.
- All systems that have been planned to control the temperature of the concrete can function properly and with satisfactory results.

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