EXPERIMENTAL TEMPERATURE MONITORING IN MOCK-UP OF THE MASS CONCRETE FOUNDATION

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Abstract. *This paper presents an experimental result to monitor temperature in mass concrete foundation slab through mock-up specimen in coordinate with various conditions of some suppliers. This result enables to control maximum temperature in mass concrete foundation along with measuring temperature difference in real construction. In addition, decreasing the thermal stress in concrete by use of cooling pipe system with the water volumes for each water temperature and cracking prediction due to thermal gradient in foundation concrete will be considered in further research. This result contributes to prove the relationship between external condition and inside temperature of mass concrete foundation.*

Keywords

Experimental temperature monitoring; mock-up; mass concrete foundation; temperature difference.

1. Introduction

The construction industry significantly develops due to the urbanization speed. Consequently, after water, concrete becomes the second most common consumed material over the world because of some its useful properties as durability, sustainability, availability, and economy [1]. Furthermore, for high-rise buildings, mass concrete is commonly used in transfer structures (slabs, beams) and foundation structures. A thermal gap between the concrete and the ambient temperature is a result of the relatively low thermal conductivity of concrete [2]. This gap shows the interaction with the surrounding environment and due to their exposure to solar radiation [3]. The temperature effect during the construction and operation time is one of factors influencing on the stress-strain state of mass concrete structures [4, 5].

The amount of hydration heat caused by the type and content of cement is one of factors that influence on the temperature regime in mass concrete structures [6]. For massive concrete foundation, the surface cracking due to reaction of cement hydration process is always a common problem at worksite. A large amount of heat will be released when Portland cement is mixed with water, especially in hot condition. Some authors also stated that in period of hydration stage and concrete hardening, the heat is exchanged between inside structural elements with outer environment until internal and external temperature balance [7].

Due to the quite large size of a massive concrete structure, after the pouring, the heat of hydration causes the internal temperature increases dramatically [8]. The magnitude and speed of heat generation of the concrete depends on the amount per unit volume of cement and pozzolana, the fineness and compound composition of cement, and the temperature during hydration of the cement plays a vital role in this process [9]. The formation of thermal stress is caused by the temperature differential between inside and outer surface of the concrete, especially massive concrete structures. Thermal cracking will occur on concrete structure surface if this stress is larger than the tensile strength of concrete. In practice, to avoid the thermal crack formation, some regulations or codes suggest the value of temperature differential between internal and surface being 20^0C and maximum temperature being 70^0C like EN 206-2013 [10].

In Ho Chi Minh City Vietnam, there is currently high-rise building project under construction that required the construction of a very large size mat foundation (about over 2,000m^2 of area and 8.5m of height) in a tropical climate. This project requires a thermal study to reliably predict the behaviour of the footing regarding heat of hydration in order to avoid the thermal crack. In this manner, a mock-up (sample) with size 2mx2mx3m of each concrete supplier and verifying concrete temperature of mock-up is implemented. A predictive calculation of water volume to decreasing the temperature differential values is also considered to lower the risk.

2. Materials and Methods

2.1. Objectives of the research

The project of high-rise building for commercial and residence purposes with over 280-meter height is located in the Ho Chi Minh City of Vietnam, with the mat foundation size of approximate 3,000m^2 of area and 4m÷8.5 m of height at pit of lift core foundation. With large volume of concrete, pouring was divided into two phases including phase 1 (1,878m^2 area and 4.5m height) and phase 2 (3,000m^2 area and 4m height). Foundation concrete was designed based on Eurocode 2 with concrete strength of C40/50 (R28 self-compacting concrete) and slump 19±2cm [11]. To prevent the temperature, increase in concrete, initial temperature of concrete before pouring is less than 30^{0}C.

The mock-up size of 2mx2mx3m was selected based on Vietnamese standard [12] and American standard [4] for each concrete supplier. There is total four concrete suppliers (first supplier, second supplier, third supplier, forth supplier) joining in real mock-up modelling to check experimental concrete behaviour before foundation construction. For the quality control of the construction work, concrete temperature of this specimen is measured continually approximate 54 hours after pouring.

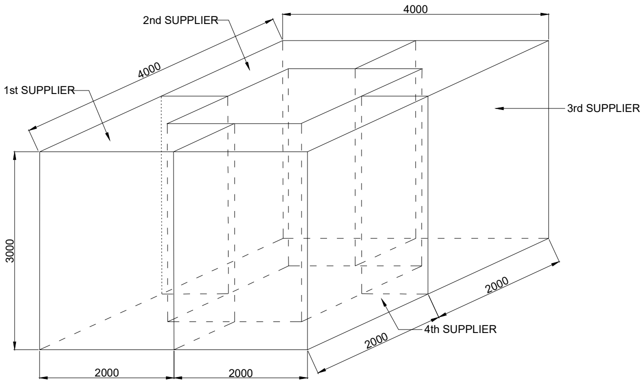


Fig. 1: Three dimensions (4x4x3m) of mock-up for four concrete suppliers.

Three concrete suppliers used low heat of hydration cement and one supplier used Portland cement combined to fly ash (type C). Therefore, concrete components are similar. Additionally, three supplier used Andesite rock while the rest used Granite rock. The superplasticizer additive of generation 3 (Polycarboxylate-ether) and additive extends the setting time (Lignosulphonate) were used in this mock-up of all suppliers.

Tab. 1: The chemical characteristic of fly ash (type C).

No.	Characteristic	Unit	Value
1	Loss on ignition (LOI)	%	0.15
2	Sulfuric trioxide content (SO_3)	%	0.47
3	Silicon dioxide content (SiO_2)	%	52.30
4	Aluminium oxide content (Al_2O_3)	%	24.90
5	Iron oxide content (Fe_2O_3)	%	14.10
6	Sodium oxide content	%	0.67
7	Particle composition - Retaining on 45 µm sieve	%	7.92
8	Carbon content	%	0.70
9	Density	g/cm^3	2.40

Tab. 2: The characteristic of low heat of hydration cement.

No.	Characteristic	Unit	Value
	Physical items		
1	Compressive strength	MPa	
	- 03 days		17.70
	- 07 days		26.80
	- 28 days		39.50
2	Mass density	g/cm^3	2.93
3	Fineness test – specific surface	m^2/kg	434.00
4	Normal consistency	%	30.50
5	Setting time	min.	
	- Initial set		155
	- Final set		205
6	Expansion of mortar exposed to water at 14 days	%	0.008
7	Autoclave expansion	%	0.06
8	Air content of mortar	%	10.20
9	Chloride content	%	0.07
10	Heat of hydration	KJ/kg	
	- 07 days		239
	- 28 days		282
	Chemical items		
1	Sulfuric trioxide content (SO_3)	%	2.53
2	Insoluble residue content (RI)	%	0.59
3	Loss on ignition (LOI)	%	0.74
4	Silicon dioxide content (SiO_2)	%	27.98
5	Calcium Oxide content (CaO)	%	48.31
6	Aluminium oxide content (Al_2O_3)	%	10.57
7	Iron oxide content (Fe_2O_3)	%	1.57
8	Magnesium Oxide content (MgO)	%	4.12
9	Total of equivalent Alkali content (Na_2O 0.658K_2O)	%	0.43

Tab. 3: Mix proportion for one cubic meter of concrete.

Supplier	Cementious Content		Water (l)	Sand (kg)	Crush sand (kg)	Stone 5-13 (kg)	Stone 5-20 (kg)	Silica fume PPI admixture (kg)	Admixture		W/C (%)	Notes
	Cement (kg)	Mineral content (Fly ash – kg)							(1) – ml/100kg cement	(2) - mL		
1st	400	-	165	520	355	-	960	20	1500	6000	0.39	Low heat cement
2nd	420	-	158	530	360	-	980	-	1300	4300	0.38	Low heat cement
3rd	430	52	152	515	277	264	791	-	4506	1352	0.35	PC + fly-ash
4th	430	-	159	525	370	-	975	-	1100	4730	0.37	Low heat cement

2.2. The measurement procedure

All faces of the concrete mock-up are insulated so that they are not affected by external environmental condition, as an adiabatic temperature rise. Moreover, the mock-up test data also supports specific heat of the concrete (q), rate of adiabatic temperature as well as maximum adiabatic temperature of the concrete. These data are used to calculate crack index due to thermal gradient in the concrete foundation. The specific heat, rate of adiabatic temperature and maximum adiabatic temperature of the concrete do not depend on the size of the concrete mock-up, it mainly depends on cement type and cement content in the concrete mix proportion.

Fig. 2: Temperature sensor and reader equipment AUTONICS T4WM.

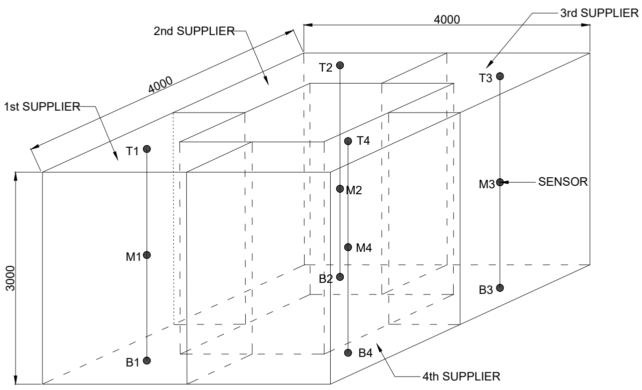


Fig. 3: Location of the sensors in mock-ups.

For four suppliers, sensors are located at three locations including top surface, medium and bottom closed to ground. By this way, they can be accuracy representative results to provide heat transfer in mass concrete. The middle of layout is a intersection of concretes from four suppliers and this place was not considered so there was not any measurement equipment. The mockup has suitable sizes which satisfies TCVN 305-2004 [12].

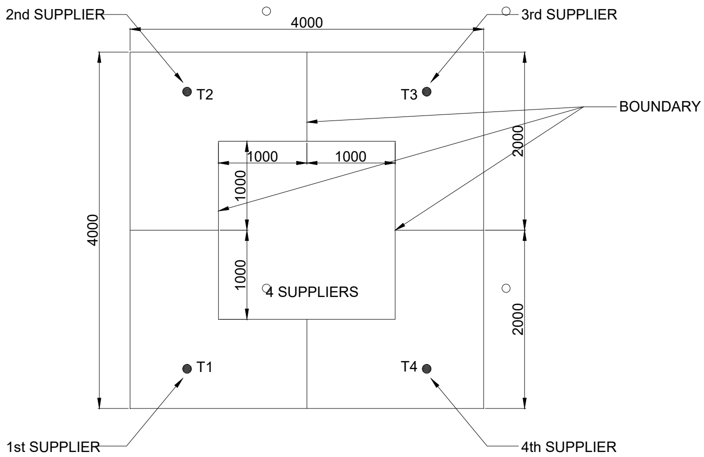


Fig. 4: Layout of the sensors on the top of mock-ups.

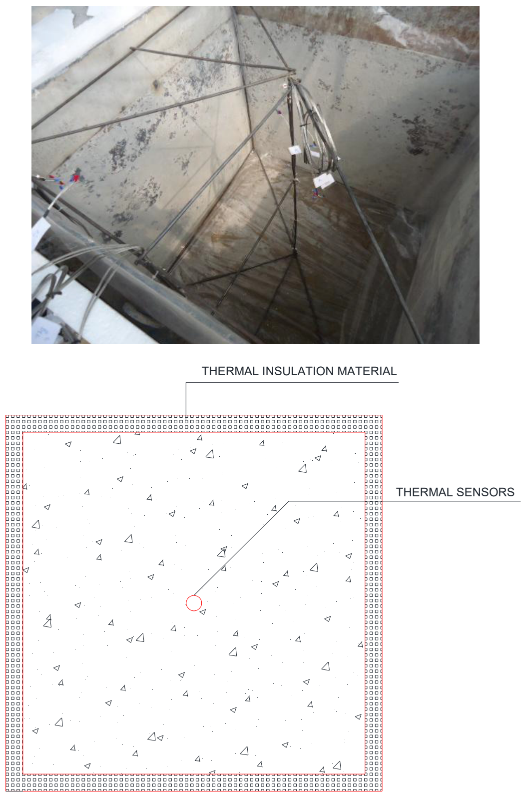


Fig. 5: The restraint condition of mock-ups.

2.3. Mixing procedure and specimen preparation

Four suppliers were noted as 1st supplier, 2nd supplier, 3rd supplier and 4th supplier. Three of them used lower heat cement and the rest used Portland cement combined with fly ash type C (density of 2.4g/cm^3, carbon content of 0.7%). Thus, the adhesive components of suppliers are compatible and suitable with requirements for mass concrete.

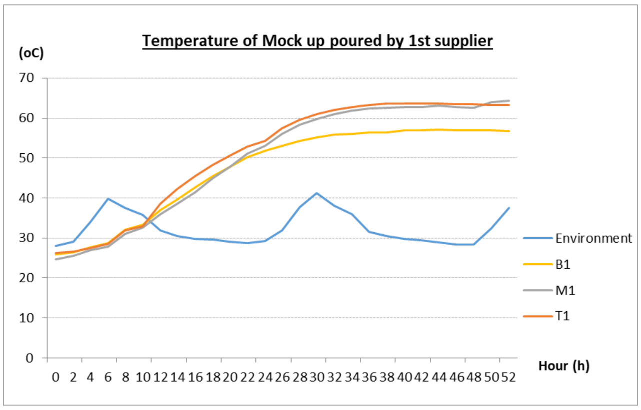
On the other hands, three suppliers used Andesite rock with humidity diffusion coefficient of concrete using Andesite rock being 0.096m^2/day and other used Granite rock with humidity diffusion coefficient of concrete using Granite rock being 0.092m^2/day. Hence, there is no difference regarding humidity diffusion coefficient in cooling process for foundation concrete using fresh concrete from suppliers.

All suppliers use the third-generation superplasticizer admixtures (Polycarboxylate-ether – PCEs) with a relatively low dosage approximate 0.15–0.3% by cement weight and retarding admixtures (Lignosulphonate – LS) to gain the rate of stiffening or setting of the concrete being 15 hours. Therefore, the chemical admixture use of suppliers is appropriate and no affect to concrete properties.

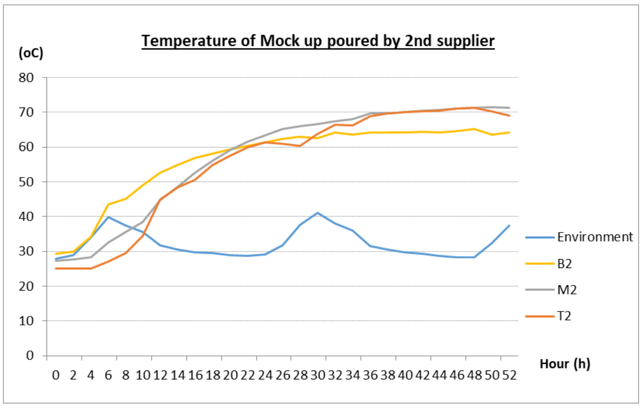
3. Results and Discussion

3.1. The analysis results

Four fresh concrete suppliers poured concrete at the same time at 6:00am and temperature measurement also commenced two hours later. Besides, external condition was also considered through measurement of environment temperature. A tropical country as Vietnam, the hottest temperature reaches approximate 40^{0}C at 2:00pm.



(a)



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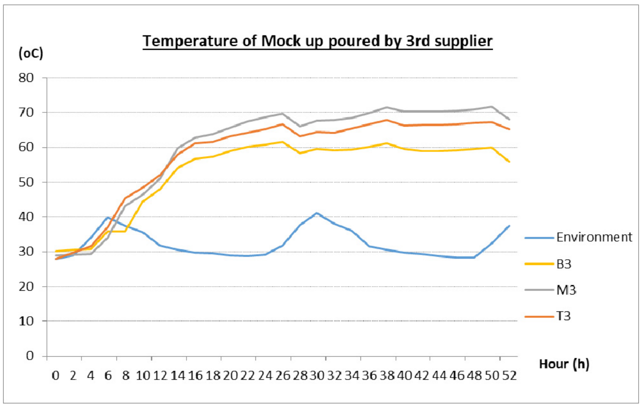
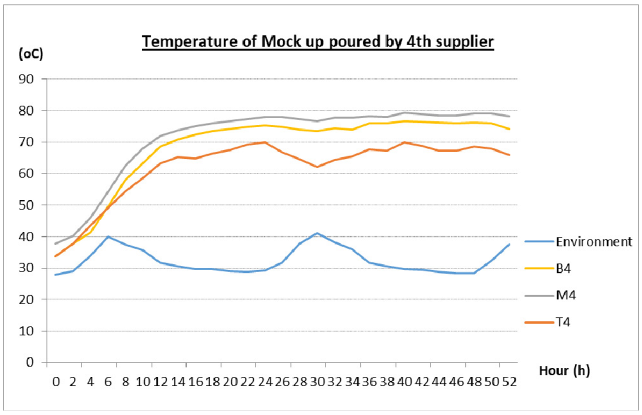


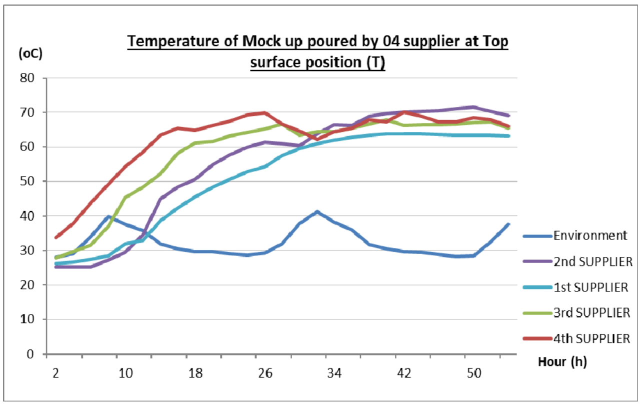
(c)



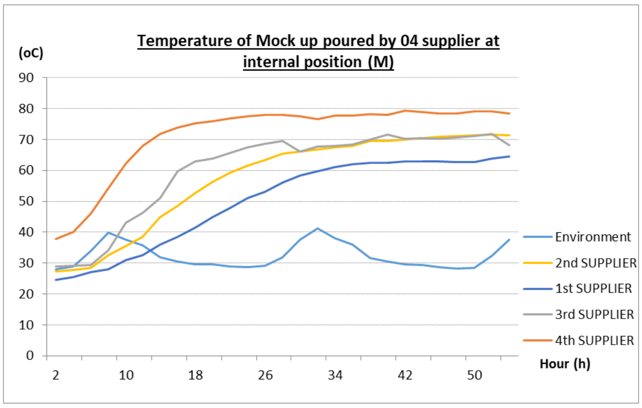
(d)

Fig. 6: Chart of temperature change over time with four suppliers.

Based on these results, heat of bottom (B) and surface (T) position of mock-up are lower than the rest (M). On the other hands, concrete heat increases rapidly from 4 hours to 12 hours after pouring and from since after 20 hours, heat nearly stops to go up.



(a)



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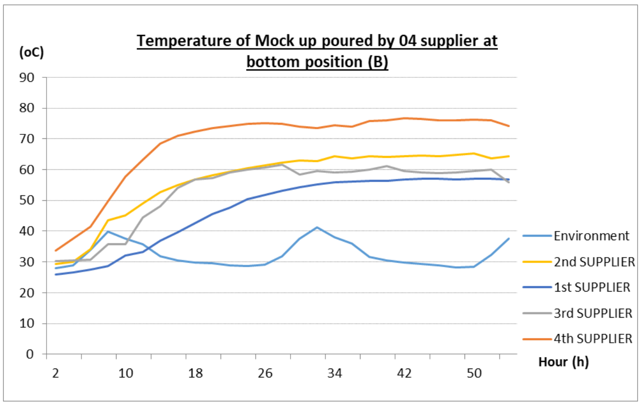

(c)

Fig. 7: Chart of temperature of four suppliers at top surface (T), internal (M) and bottom position (B).

After comparison of results, it shown that concrete procedure by first supplier was better than others and forth supplier should be considered their construction method and aggregates in reality.

3.2. Discussion

Pouring temperature plays a very important role in the hydration process of a massive concrete structure. It is stated that the higher placing temperature of the concrete mixture, the higher the maximum temperature at the middle of the mock-up is reached. Figure 8 shows the effects of placing the temperature of mock-up concrete on the concrete hardening temperatures. As can be seen, the maximum temperature at the internal position (M) of the mock-up decreased when the initial temperature varies from 33.7^{0}C down 24.6^{0}C. It is apparent that the temperature at middle of massive concrete structures go up fast and reaches the peak around 40 hours after placing and then it intends to go down by time. This trend is also similar to another research [13]. At the middle point, the heat is more accumulated because the centre is surrounded by the volume of concrete with low thermal conductivity [14].

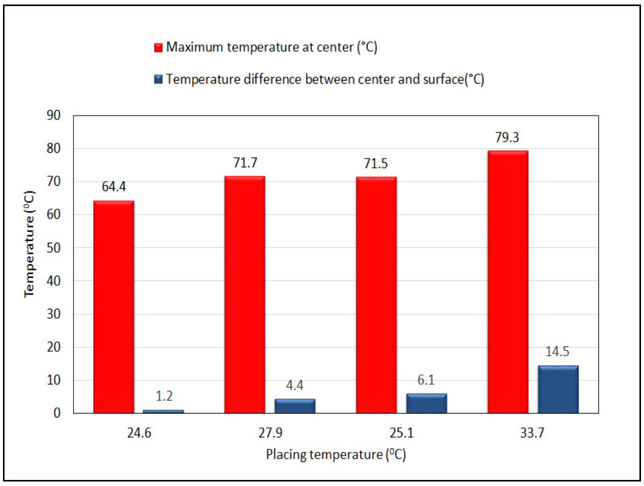

Fig. 8: The relationship between the pouring temperature and the maximum temperature, the temperature difference in the mock-up.

On the other hand, the temperature difference between the centre and the surface of mock-up differs and depends on the initial temperature of the concrete mixture, the ambient temperature and mixture components. When placing temperature of a specimen changes from 24.6^{0}C to 33.7^{0}C, the temperature difference varies from 1.2^{0}C to 14.5^{0}C. In this experimental study, temperature differences of all mock-ups were lower than allowance value of 20^{0}C due to using the low heat hydration cement and fly ash in concrete mixtures. However, the maximum temperature of three mock-ups from three suppliers were higher than allowance value of 70^{0}C, excepting 1st supplier. Thus, this is a addition clue to choose the right construction conditions and supplier. Moreover, in the tropical country like Vietnam, it is so hard to control the initial temperature being lower than 25^{0}C. Consequently, to avoid thermal cracking in massive concrete, cooling water pipe system should be considered. Based on this temperature measurement data, there are the time calculations to pump cool water in the massive concrete foundation. Following ACI 207.2R-07 [15] and temperature profiles of mock-ups, there are nine segments from first segment to nineth segment with assumptions of minimum temperature of environment being 25^{0}C and final temperature of concrete is 45^{0}C.

4. Conclusion

Experimental results of mock-up presented in this paper have supported the assumption of relationship between pouring temperature and maximum temperature of specimens. Additionally, it also verifies the theory of heat transfer in mass concrete due to external condition (environment temperature), hydration heat development and volume change of concrete. Moreover, computational models are also qualified exactly, and it is useful to provide vital information for cracking propagation calculation and crack width due to temperature [13]. In future, these results will help the contractor to manage concrete pouring method of mass concrete and use appropriate material component for foundation structure. This fact can be used in further research.

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