Monolithic pouring of the foundation slab of the 632 m high tower

Shanghai Tower

The Shanghai Tower, a 632 m high building, is the highest one in China and the second highest in the world. The foundation raft of high-rise buildings is usually a huge mat with cast-in-place mass concrete. It is a structural member that transfers loads from the building to the foundation base. To keep the integrity of a massive raft is a key issue both in design and construction phase. The key point to obtain a monolithic foundation raft is via continuous pouring of concrete without providing construction joints. This would definitely invoke a problem on how to mitigate hydration heat accumulated in mass concrete during pouring of concrete. Preventing thermal cracks is critical for large concrete members and this project presentation shows how is dealt with this issue in the Shanghai Tower foundation.

To control volume variations due to release of hydration heat, guidelines such as the Code for Construction of Mass Concrete (GB50496-2009) [1] and others provisions (EC 2) [2] give limitations on pouring of concrete, for example, a maximum volume of poured concrete per unit time and a minimum interval between pouring of each batch. Research interests are raised worldwide to explore measures to avoid thermal cracks in mass concrete. Accordingly, many construction approaches aimed at decreasing hydration heat and controling of heat accumulation in a massive raft have been developed in practice. For example, the pre-installed pipe system method was applied in the 13 500 m^3 mat foundation of Jinmao Tower building [3] and layered construction in the 9 m thick foundation raft of the World Financial Center [4]. This method increases project costs and complicates the construction procedure. Some projects such as Petronas Towers in Kuala Lumpur, Malaysia, were executed by continuous pouring in 54 hours [5]. Excel Warehouse Project

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1 Pumping concrete for the foundation of the Shanghai Tower
2 Location and surrounding of the Shanghai Tower
credits: Courtesy to Shanghai Center
3 Foundation raft of main building: (a) plan, (b) section [mm]

[6] and Abu Dhabi's Landmark Tower [7] also used this method. For the foundation of Shanghai Tower, more than 60,000 m^3 of concrete had to be poured continuously, with no construction joints or post-cooling measures, for high-speed construction and with high-quality impermeable concrete. To avoid early age cracks, special measures such as mix design considering hydration heat reduction and a pouring organization suitable for continuous pouring were taken.

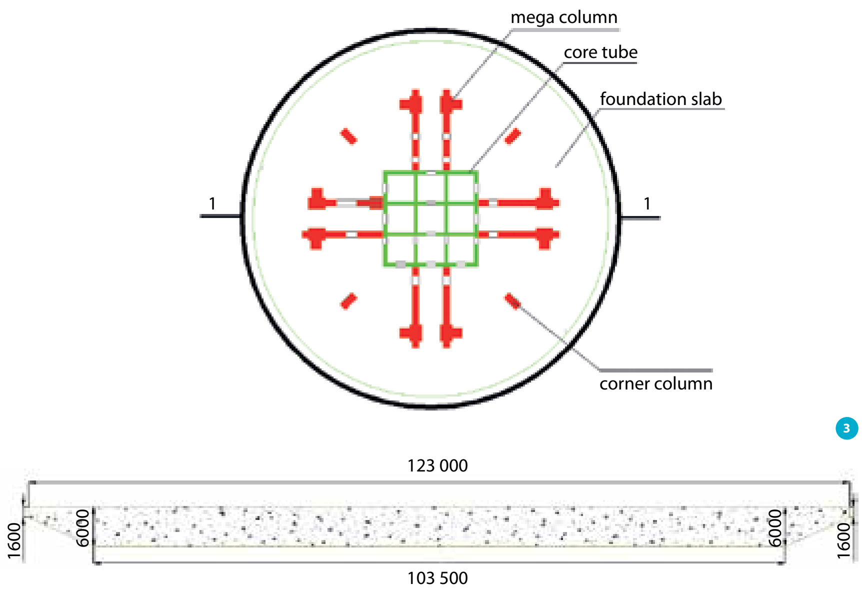
Outline of the Shanghai Tower

Location

Located in the central area of Lujiazui financial district in Shanghai city, Shanghai Tower is designed for offices, a hotel, a commercial and shopping mall, a conference hall and an exhibition hall, as well as leisure tourism and sightseeing platform. It consists of a tower building and a surrounding podium building. With the footprint of the complex covering an area of more than 30 000 m^2, the total useful area of the complex is about 570 000 m^2. The tower building has 121 floors above the ground, and below ground is 5 storey basement.

Foundation raft of main building

The foundation raft slab of the main building has a disk-like circular shape with a diameter of 123.0 m (fig. 3a). Along the radial direction from the center to the perimeter, the thickness of the slab changes from 6.0 m at the center to 1.60 m at the edge (fig. 3b). Special measures with respect to mix design and the organization of pouring were taken. The key challenge was to ensure continuous pouring with the limited thermal issues.



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Mix Proportions

The main issue during the mix design is to minimize the hydration heat of concrete. Therefore, raw materials which assure that the low-heat concrete is obtained, are used. Locally produced cement with hydration heat of 220 kJ/kg and 289 kJ/kg at 3 and 7 days, respectively, is chosen. Beside Ordinary Portland cement, fly ash and slag, as supplementary cementitious materials, are used as a binder. This leads to a decreases of the hydration heat by 22.3% at 3 days and 13.5% at 7 days compared to the cement without addition of supplementary cementitious materials. A polycarboxylic acid

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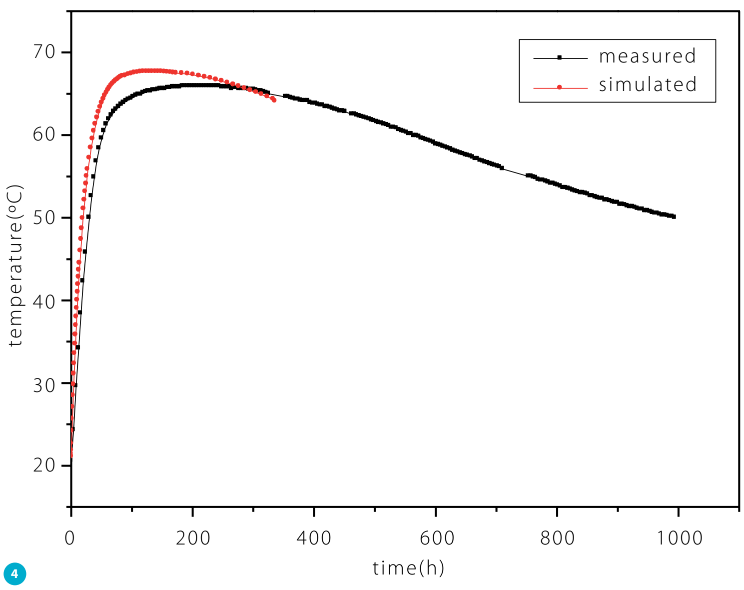
4 Temperature comparisons (measured and simulated in the core of the element)
5 Strength developing curve
6 The concrete pouring plan, pouring area and pump arrangement: (a) from top and (b) from side



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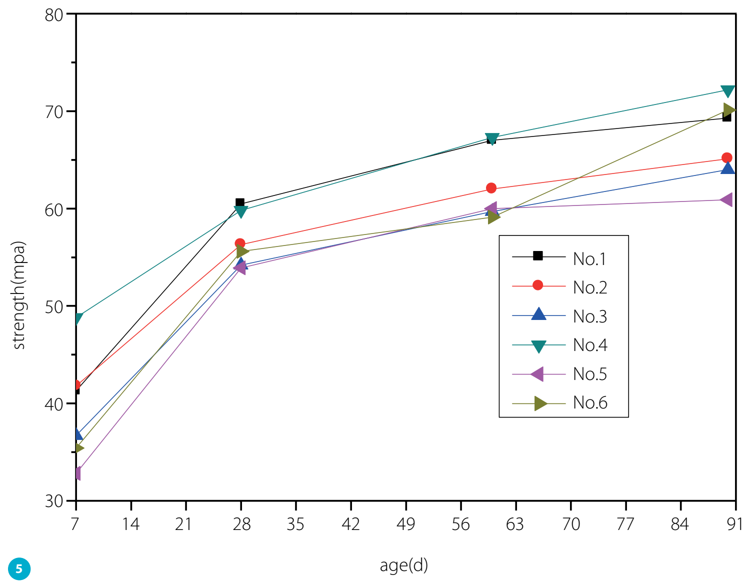

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Table 1 Mix design of concrete C50 (kg/m³)

W/B	water	cement	slag power	fly ash	sand	gravel	additional-agent
		P.O.42.5	S95	III	middle	5~25	poly carboxylic acid
0.36	160	240	120	80	760	1030	4.4

superplasticizer is added to decrease the water - cement ratio. The addition of superplasticizer resulted also in the reduction of the hydration heat by 37.3% and 24.6% at 3 and 7 days, respectively, in comparison to those without superplasticizer.

The final mix (see table 1) should also comply with the following requirements: the 28 days strength is not below 50 MPa and the slump is around 180 mm (based on pumping requirement). For the purpose of checking the thermal performance, a 6.0 m × 8.0 m × 3.0 m test block is poured prior to casting of the foundation with the same mix proportions. Temperature monitoring is carried out simultaneously. The temperatures reach the peak values within 48~72 h and the peak value does not overpass 65°C. The designed mix proved to be suitable for the construction and it was further used in the actual project.

Temperature monitoring is carried out on the spot during the project. Temperature development is also simulated, and temperature comparisons are shown in figure 4. The temperature-time curves resemble except for peak values. The difference between simulated and measured temperature is 2°C. Strength tests were performed on concrete used for real pouring. The average compressive strength of concrete, obtained from each plant for foundation pouring is shown in figure 5. The strength all passes 50 Mpa at 28th day, so the concrete meets performance requirements.

Pouring Organization

Concrete supply and transportation is the basic issue of the 60 000 m³ pouring. The main principle was to fulfill the pouring work within 60 h. Careful calculation on concrete supply and transportation is combined with extensive project experience. Six pre-mixing plants are chosen with the total supply capacity of 1250 m³/h. 355 mixing trucks with an average size of 8 m³ were in charge of the transportation.

Central flowering pouring

Pouring usually takes place from one side to another side in a traditional pouring method. For this huge mass concrete member the poring distance was too long. Therefore, a new concrete pouring method, called 'central flowering pouring', is used in this project. Unlike with the traditional pouring method, pouring of the concrete begins at the center and concrete flows to the surrounding area.

Mobile pumps have flexibility and high pouring capacity, but its pouring range is limited by its arm. Fixed pumps can overcome this disadvantage. Two kinds of mobile pumps were used i.e. a 56 m long arm concrete pump and a 48 m long arm one. As the maximum pouring distance is 61.5 m long (radius of circular mat), the mobile pumps cannot reach the central area. Therefore, fixed pumps are in charge of that area. Based on their maximum pouring length, the whole slab is divided into three parts in the radial direction. The three areas in horizontal direction are shown in figure 6a. All the area divisions can be explained by the pumps' maximum length. The pouring amounts of the three areas are 880 m^3, 10 150 m^3 and 48 950 m^3 respectively. Firstly, the fixed pump started to pump in the central area. Then, when the concrete from the central area reaches the pouring boundary of other pumps, they begin to pump. Figure 6b shows the concrete is supposed to flow along a slope of 1:12.

Layout of concrete pumps

Four 56 m long arm mobile pumps are installed on the previous soil digging platforms. Other pumps are arranged along the edge of the foundation pit (fig. 6a). Based on experience and the actual situation, six fixed pumps are used for the pouring work of area 1. The theoretical pouring capacity of the three types of pumps is 40 m^3/h (fixed pump), 80~100 m^3/h (56 m mobile pump) and 60~80 m^3/h (48 m mobile pump) respectively. The average pouring speed should not be lower than 1000 m^3/h. Therefore, eight 48 m-long arm pumps are chosen. The pouring speed is:

$$V_s = Q_1 \cdot N_1 + Q_2 \cdot N_2 + Q_3 \cdot N_3 = 40 \cdot 6 + 80 \cdot 4 + 60 \cdot 8 = 1040\ m^3/h$$

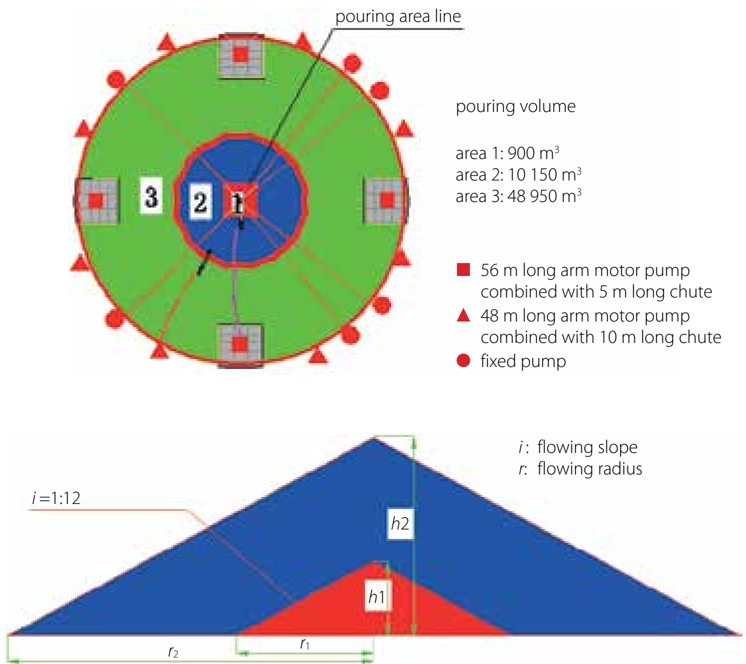
In other words, the 60 000 m^3 of concrete can be poured in 60 hours theoretically under such pump arrangement.

Pouring on the spot

All the 18 pumps are placed along the perimeter of the foundation pit. The whole pouring scene is shown in photo 1. During the actual pouring process, the fixed pumps showed some disadvantages such as inflexibility and low pouring speed. Therefore, another four 48 m long arm pumps were put into use instead of the fixed pumps. Because of the traffic jam on the spot, the pouring speed was lower than the theoretical value. Curing is carried out after concrete initial setting for each area. The main curing materials were film and sack. The coverage contained four layers: film, sack, film and sack from the bottom to the top. By this the temperature difference between the surface and the central area of the concrete was reduced.

Conclusions

The foundation raft of Shanghai Tower was poured continuously in 63 hours without construction joints and without post cooling measures. The continuous pouring for such huge volume concrete was never reported before. Mix proportion design and pouring organization are important parameter for this construction method. According to the data obtained by temperature monitoring, the used procedure resulted in the desired effect.



6

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