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5. Andheri Water Tower (India)

Owner:	*Greater Bombay Municipal Corporation*
Architect:	*Shashi Prabhu & Associates, Bombay*
Engineer & Contractor:	*Gammon India Limited, Bombay*
Construction:	*1986*

Introduction

The tower is constructed to cater the water supply needs of an integrated sports complex at Andheri, a suburb of Bombay, India, with a total capacity of 218500 litres at a height of 41 m above ground level. The original profile of the tower as conceived by the architect, consisted of two square-shaped tanks at different elevations near the top, supported on a square shaft. Construction of this type of tower meant adopting traditional methods using extensive scaffolding and formwork for the full height which worked out uneconomical and time consuming. To overcome these problems, a method was developed indigenously which involved construction of the shaft first, later casting the upper tank around the shaft at ground level and then lifting along the shaft, and finally connecting the tank to the shaft by an in-situ joint. Subsequently, the same construction procedure is to repeat for the second lower tank. In order to adopt this method, the original profile of the tower was changed to conical-shaped tanks supported on a circular shaft which was ideal for the construction of the shaft by slip-form technique and the lifting of the tanks by cables. The owner and the architect accepted these changes without reservation in view of a novel method being adopted for the construction, incidentally for the first time in India.

Structure

The tower which is in reinforced concrete, consists of two separate tanks in the form of an inverted frustrum of a cone, supported on a circular shaft of 3.25 m inside diameter × 250/300 mm thick × 47.65 m overall height above ground level (Fig. 1). The upper tank which serves in emergency situations, is of size 9.64 m top diameter × 1.65 m height, and has a capacity of 23500 litres located at + 46.6 m level, whilst the lower tank, located at + 41.05 m level, is of size 14.89 m top diameter × 3.75 m height with a larger capacity of 195000 litres to cater for domestic and flushing purposes. The shaft has on the outer surface 12 nos. uniformly spaced 550 mm wide × 50 mm deep vertical recess, and these recesses are extended to the underside of the tanks, for aesthetic reason. The inside of the shaft houses a mild steel staircase for access upto the top, besides various service pipes to the tanks.

Design

The design of the tower required consideration of various loads that occur during construction and in the service condition. In addition to water load, the structure is designed for external forces due to wind and earthquake. The tower is designed for a basic wind pressure of 1.5 kN/m^2 upto 30 m height and there above increasing to a maximum value of 1.7 kN/m^2 at the top, as per the Indian Code of Practice IS: 875-1964. Along-wind moments on the tower are calculated by using a drag coefficient of 0.8 for the shaft and a higher value of 1.4 for the portion of the tanks in view of the flared profile.

The calculated maximum deflection at the top is 75 mm which is less than the normal permitted value of H/500. As the shaft is a slender structure with a high aspect-ratio of nearly 14, it required investigations into aerodynamic effects, particularly during construction stage when only the shaft is constructed. The natural frequency of the shaft alone is 1.05 Hz in the fundamental mode and 6.66 Hz in the second mode of vibration. Considering a Strouhal number of 0.2, the critical wind speed is 20.15 m/s in the fundamental mode and 128 m/s in the second mode. As the design wind speed at one-third height from the top is 45 m/s, cross-wind response is expected to take place in the fundamental mode, and the calculated amplitude in this mode is 0.036 m. In the completed condition, investigation into cross-wind response was not considered necessary as the two tanks at upper elevations act as mass-tuned damper by which the tower is stable against such oscillation. The earthquake effect on the completed tower is calculated on the basis of seismic accelerations as applicable for zone III of the Indian Code of Practice IS: 1893-1975. A model analysis was carried out for the first five modes of oscillation, considering 5% damping and the zone factor equal to 0.2. The earthquake moments are based on root-mean-square of the value of the five modes for the combined effect. The conical tanks are designed mainly for the membrane forces due to self weight and hydro-static pressures acting on them, as uncracked sections by limiting tensile stresses in concrete to 1.7 N/mm^2 and reduced stresses in steel, as generally adopted for water retaining structures. The design also considered effects due to high concentration of stresses that occur during the lifting operation of the tanks, local to the point of lifting at the bottom of the tanks and in the projecting ring of the shaft at the top where jacks were operated, which resulted in closely-spaced large diameter reinforcement in the regions.

Some of the other interesting features of the design are connection between the precast tanks and the shaft, temporary stiffening of the shaft section at the top with a framework of steel beams during the lifting operation, which required special care in both detailing and construction. M20 grade concrete is used throughout, except for the shaft section upto + 7 m level where M30 grade concrete is used for design consideration. Reinforcement steel used are high-yield deformed bars for the shaft and mild steel bars for the tanks.

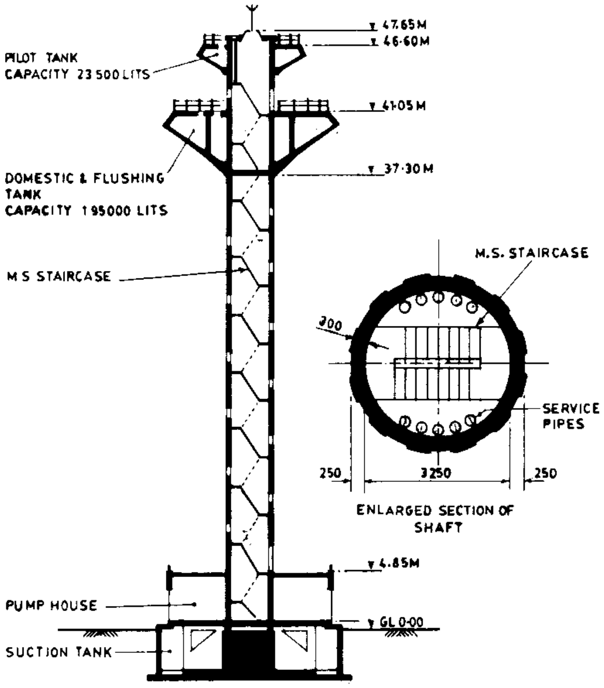

Fig. 1 General arrangement

Construction

The shaft was constructed by slip-form technique using 6 nos. 6 t capacity jacks, and it was completed in 12 days by round the clock operation. Each tank was cast at ground level, encircling the shaft, in one continuous operation without any construction joint. The dead weight of the tanks lifted are 70 t for the upper tank and 240 t for the lower one. The lifting of each tank was carried out separately by hydraulic jacks of 100 t capacity each, located on the top of the shaft, and 3 nos. such jacks were employed for the upper tank and 6 nos. for the lower tank. All the jacks were connected to a common manifold and were operated by a pump. The tanks were suspended by means of 13 mm diameter high tensile stranded steel cables, a pair on both side of each jack, and the cables were anchored to a steel ring beam placed at the base of the tank. The lifting of each tank was carried out in successive increments of 125 mm, and each lifting operation comprised the alternate blocking and releasing of anchorages mounted above and below the jacks. The average speed of lifting achieved was 750 mm per hour. After lifting of each tank to its final position, the connection between the tank and the shaft was carried out by an in-situ joint using a richer mix concrete with a high slump, placed at the bottom of the tanks and openings in the shaft provided for this purpose.

(N. Prabhakar)

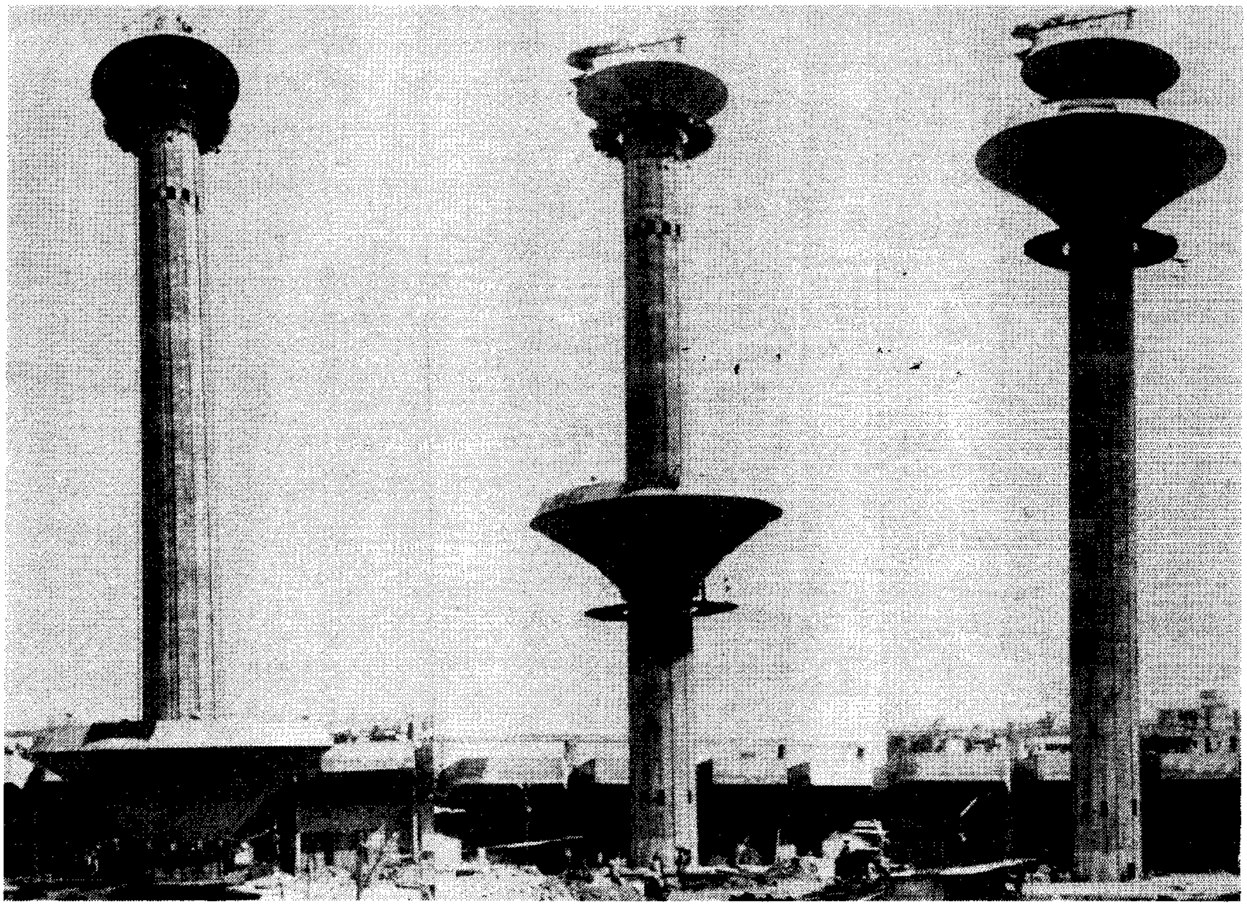

Fig. 2 View during different stages of lifting of the lower tank