Willow Island cooling tower collapse: a lesson from nature

This month’s structural failure review from Sean Brady highlights the perils of sticking rigidly to a concrete construction schedule regardless of weather conditions.

Driving southwest along Riverview Drive, leaving the town of Belmont behind, the highway follows the curve of the Ohio River, separating the state of Ohio from West Virginia. About 2km out of town, just off the left-hand side of the highway, stands a memorial, its sides cut in a distorted hourglass shape mimicking the two power station cooling towers that stand across the highway in the distance. The memorial bears a black plaque with gold lettering. It lists 51 names, fatalities in what is still considered one of the worst construction disasters in US history (Figure 1).

Cooling towers

In the late 1970s, two cooling towers – known as the Willow Island cooling towers – were constructed as part of the Pleasants Power Station, the first being completed in 1977. The towers are formidable reinforced-concrete structures standing 131m high, with base diameters of 109m. Their diameter and thickness vary with height, and their hyperbolic profile allows for natural drafting. The design and construction of the towers was undertaken by the Hamon Cooling Tower Division of Research-Cottrell, Inc, which used its patented lift-form system, consisting of a formwork and scaffolding system that climbed the tower during construction in what was known as a series of ‘lifts’. Research-Cottrell had successfully used this system in the construction of 36 other towers prior to commencing the Willow Island project.

The lift-form system primarily consisted of four levels of scaffolding attached to jacking frames, which were in turn supported on jumpform beams attached to the tower shell (Figure 2). The jumpform beams, attached on both the inside and outside of the shell, were connected to one another by anchor bolts, which transferred the system and applied loading directly into the tower shell. Each jumpform beam consisted of an upper and lower section, with the lower beam essentially leapfrogging above the upper beam as the system ascended the tower.

In order to jump the system, the formwork from the previous day’s lift was removed; the lower jumpform beams were detached from the tower shell, moved upward, and reattached above the upper jumpform beam. The jacking frame was then jacked upwards. Once in place, the formwork for that day’s pour or ‘lift’ would be installed, with the four levels of scaffolding providing access for these activities. Below Lift 10, construction materials were lifted into position by six cathead gantry cranes, supported on the ground below (Figures 3 and 4). The scaffolding at this location suddenly tilted inwards, tearing concrete from the tower.

Failure

The incident was investigated by the National Bureau of Standards (NBS) on behalf of the Occupational Safety and Health Administration (OSHA). The investigation focused on three aspects of the collapse: the crane system, the scaffolding lift-form system, and the tower shell itself.

The crane system was quickly ruled out: it exhibited no damage and tests would confirm that its components met the relevant requirements. Similarly, the lift-form system itself was found to play no role in the failure. The investigation now turned to the tower shell structure itself.

system, along with the hoisting loads and newly placed steel and concrete, was supported by concrete poured in the previous days' lifts.

Investigation

The investigation now turned to the tower shell structure itself.
In order to estimate the strength of the Lift 28 concrete at the time of the failure, the NBS investigators conducted tests using similar concrete subjected to similar temperatures for a period of 20 hours – the estimated time that had elapsed between the placement of the Lift 28 concrete and collapse. The results were disturbing. The concrete had a cube strength of approximately 1.5MPa – shockingly low. The cold temperature conditions on site were to blame – the temperature resulted in the concrete simply not having enough time to develop the necessary strength to support the lift-form system and applied loading.

However, upon the release of the NBS report, Lev Zetlin Associates (LZA), which had been engaged by the contractor in the aftermath of the failure, disagreed with the official findings. They determined that a number of critical anchor bolts had been removed from the structure prior to the collapse. These bolts were located in the jumpform beams – and therefore played a role in transferring the load from the scaffolding to the tower shell concrete of Lift 27. LZA argued that if the bolts had not been removed, then failure would have been unlikely.

In response to this report, two of the original NBS investigators would undertake further investigation, which was released in 1980. They would ultimately conclude that the failure would have occurred regardless of the bolts being removed. They determined that failure was likely to occur if the concrete strength was below 6.9MPa. As we know, the strength at the time of failure was estimated at 1.5MPa, a long way from 6.9MPa.

This failure highlights the dangers of governing a concrete construction schedule based on time considerations alone, and it is not an isolated incident in the history of failure. Both the collapse of the Commonwealth Avenue building in Boston in 1971, which killed four, along with the dramatic collapse of an apartment building at Baileys Crossroads in Virginia in 1973, which killed 14, were also contributed to concrete being given insufficient time to develop necessary strength. As with Willow Island, the construction schedules were governed by time and did not consider the environmental conditions that the concrete had to contend with.

Aftermath
The OSHA was criticised for lax inspections – it didn’t have enough safety inspectors on the ground to enforce regulations in West Virginia. It did, however, adopt new guidelines to protect future workers, including requiring detailed safety manuals be produced for construction projects. It also made changes to the US Construction Safety Act, such as moving more responsibility for formwork decisions from the designer to the contractor, and requiring mandatory testing of concrete samples prior to formwork removal when the concrete was being relied upon to carry load.

Many years later, 12-year-old Anthony Lauer, while working on a school project, asked his teacher why there was no memorial for the 51 fatalities in the incident. His family had been devastated by the tragedy: his grandfather, Larry Gale Steele, along with Larry’s four sons – Emmett, Ernest, Miles and Ronald – were killed in the disaster. Young Lauer seized upon the idea for a memorial, and four years later he had collected over US$50 000 to build one – the very memorial that today stands across the highway from the completed towers.

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