Ferrybridge cooling towers collapse

Pontefract, England (1965)

Design that inadequately accounted for wind forces led to the collapse of three giant water cooling towers, spurring important research into wind dynamics.

Background

On November 1, 1965, at the Ferrybridge power station near Pontefract, England, three of the largest natural draft cooling towers in the world collapsed during a gale force wind. The cooling towers at Ferrybridge, operated by Britain's Central Electricity Generating Board, were structurally complete but not in operation. The wind stretched the reinforced concrete membranes of the towers beyond their structural capacity, causing the concrete to vibrate at a high-pitch and ripple into waves. The upper rim and the side sections ultimately buckled into the center of the towers.

Cooling towers play a critical role in power generation by providing low-temperature water for use as a coolant within the power plant. The eight towers at the Ferrybridge power station were "natural draft" towers, which cool water by spraying it through cooler air into large concrete tubes. The hourglass shape of natural draft towers and the warming of the air by the water draws the air up through the concrete tube without the aid of fans, like smoke up a chimney. Differences in water and air temperature and heat losses during evaporation cool the water. The cooled water then pools at the base of the tower and is recirculated to the power generating station.

The cooling towers at Ferrybridge rose 375 feet above the collection pools, spanned 290 feet in diameter at their bases, and weighed 8,000 tons. They were "thin shell" towers, with concrete structural membranes only five inches thick. In contrast, the shell of an egg as large as a Ferrybridge tower would be 25 inches thick. The eight towers at Ferrybridge were grouped into two rows of four, staggered into a checkerboard pattern. They were spaced closer together than towers in previous designs to take advantage of a "pillar of support," a localized area of superior foundation material.

Britain's Central Electricity Generating Board, an acknowledged leader in thin shell concrete cooling towers, did not venture into innovative design or construction with the Ferrybridge towers. Although these cooling towers were the largest to date, the increased size represented only a minor extrapolation from similar towers constructed two year before. The Board had contracted the design and construction of Ferrybridge towers to Film Cooling Towers (Concrete) Ltd., at an estimated cost of $700,000 to $840,000 each. Film Cooling Towers (Concrete) Ltd. had subcontracted the design to the consulting firm of Messrs. C. S. Allott and Son. The series of design and construction contracts left some ambiguity as to which parties were ultimately responsible for the design of the towers.

Details of the Collapse

A strong wind blew against the cooling towers at the Ferrybridge power station on November 1, 1965, creating a windward and a leeward row of towers. This wind was later estimated to have traveled at 76 to 84 miles per hour at 33 feet above the ground, and at 93 to 104 miles per hour at the upper rim of the towers. As the wind pushed past the towers in the windward row, it was funnelled through the spacing between them onto the windward faces of the second row of towers.

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This pressure caused the leeward towers to lean away from the windward towers, stretching their windward sides in the way that leaning from the waist stretches the muscles on one side. At the same time, the updraft through the towers created a force that tended to lift the towers off their foundations. This lifting action reduced the effective weight of the towers and increased the stretching of the concrete shells. The resulting vibration of the enormous concrete towers produced a high pitched whine that was reported by observers to resemble "someone rubbing a finger round the rim of a wineglass."

The wind eventually stretched the windward sides of three of the second row cooling towers beyond the strength of the steel reinforcing in the concrete shells. The towers lost their structural integrity and could no longer hold their shape. Initially, the upper rims of the three cooling towers buckled into the tower centers. The windward sides collapsed into the tower centers in turn, dragging in the adjacent side sections of the structures.

Three leeward towers collapsed in this fashion. Although the failures were sudden, they were not simultaneous. The first tower failure occurred at 10:30 A.M., the second about ten minutes later, and the third at about 11:30 A.M. A spectacular photograph was taken from the windward side of one of the towers during its collapse, showing the overstretched windward side of the tower dragging and twisting the adjoining sections inward.

Impact

The Central Electricity Generating Board formed a committee with expertise in concrete, wind dynamics, and civil engineering structures to investigate the causes of the failure. When records and inspection of the collapsed structures revealed no significant deficiencies in construction and materials, the committee reviewed the design of the towers. It was noted that the engineers had enlarged the height and diameter of the towers, in relation to the prototype design, without any corresponding thickening of the concrete shells. However, wind tests by Britain's National Physical Laboratory had indicated that five-inch thick shells could withstand winds up to 200 miles per hour. Therefore, the committee directed their investigation to the engineer's methodology in calculating wind pressure requirements.

The designers of the cooling towers had relied on data about specific wind speeds at predetermined heights above the ground in determining the structural requirements. The wind speeds were assumed to be static (uniform in speed throughout their duration). The design engineers then used equations to adjust this static wind data for tower height, the impact of temporal fluctuations in the wind (dynamic effects), and other conditions. These calculations formed the basis for designing the steel reinforcing in the concrete shells and in other structural features of the cooling towers. This approach to designing the thin shell towers was standard engineering practice at the time.

The committee found that the collapse of the cooling towers was related to various shortcomings in this process of calculating wind pressures: (1) the designers ignored the impacts of clustering the towers or locating them near other large power station structures; (2) the designers incorrectly interpreted a report by the National Physical Laboratory; and (3) the designer's equations to calculate the wind pressure at the tops of the towers generated a figure 24 percent less than what the equations specified in the British Standard Code of Practice would have produced. The cumulative effect of these and other deficiencies was the use of far less steel reinforcing in the walls of the towers than required. This led to the structural collapse of the towers at wind speeds that the committee estimated would occur every five years, far less than the design life of the towers.

The disaster at Ferrybridge had significant repercussions on the power station itself and on the structural engineering community as a whole. At the Ferrybridge power station, the five towers that did not collapse were inspected; crack lines revealed that they had also been damaged by the gale force wind on November 1. The engineers determined that these towers did not have to be demolished, but could be altered to make them structurally sound. A second layer of concrete was added to the outside of each of these towers, doubling the thickness of the shells, to provide the additional strength required. The three towers that collapsed were rebuilt using a similar "double-skin" design. Nonetheless, regulations were instituted to prevent anyone from approaching the cooling towers during gale-force winds, and these regulations have remained in effect over 25 years.

The most significant impact of the design failure at Ferrybridge, however, involved theoretical advances in the field of structural dynamics. The investigating committee recommended that the entire approach to designing cooling towers be reassessed, as current engineering practices did not adequately address the dynamic impacts of wind. The engineering community responded with extensive analytic and experimental research. The analytic approaches applied fundamental engineering concepts and the relatively new finite element method of structural analysis to predict the effects of dynamic wind pressures on cooling towers. Experimental researchers built models resembling the towers at Ferrybridge, installed them in wind tunnels, and tested the structural response. The research confirmed the investigations conducted by the committee, and led the way to many advances in cooling tower design.

The results of the research initiated by the collapse of the cooling towers at Ferrybridge ultimately were incorporated into international structural design methods and building codes. In this way, the structural failure at Ferrybridge led to an expanded understanding of wind dynamics and helped to prevent future engineering disasters—vividly illustrating the role that failure can play in the evolution and advancement of technology.

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Where to Learn More

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