U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Safety Culture Communicator

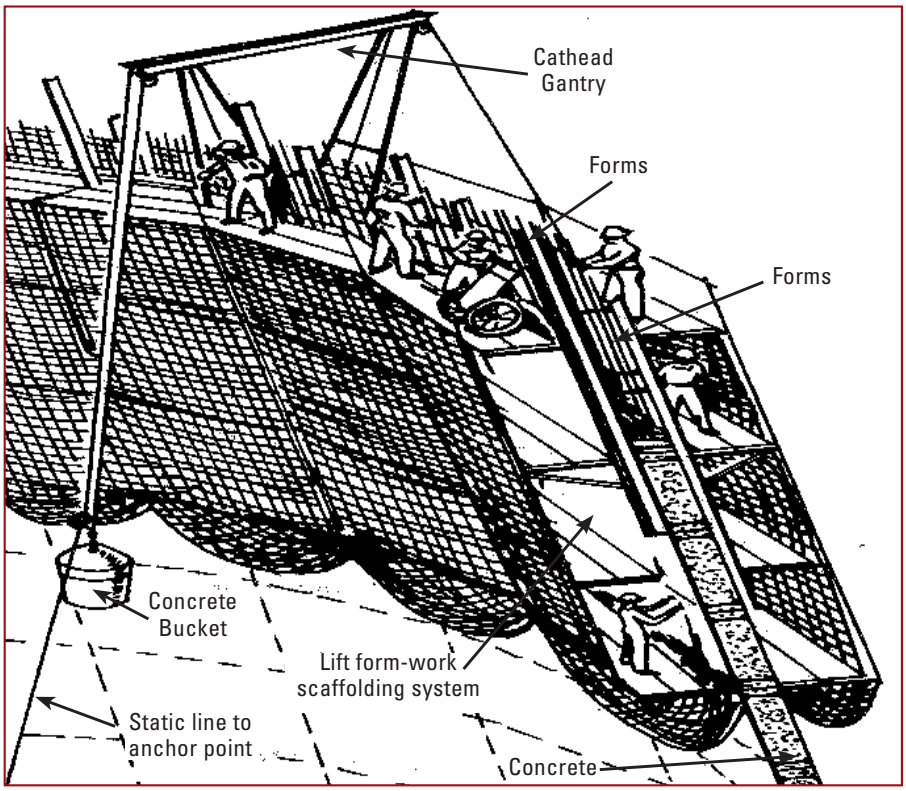
Case Study 3 **September 2011**

Partial Collapse of the Willow Island Cooling Tower

PURPOSE

This case study is intended to provide a useful tool for the U.S. Nuclear Regulatory Commission (NRC) staff as it interacts with their stakeholders. It will also enable the regulated community to identify with, and learn from, the findings made by the West Virginia Governor's Commission on Willow Island and the Occupational Safety and Health Administration (OSHA). The safety culture traits that the NRC has incorporated into its recent Safety Culture Policy Statement can be applied to these findings.

This case study describes the safety culture shortcomings that led directly to the partial collapse of a natural draft, hyperbolic, reinforced concrete cooling tower at Willow Island, WV, on April 27, 1978. The cooling tower was one of two towers being constructed by Research-Cottrell, Inc., for the Pleasants Power Station, a coal-fired electric power station owned by Allegheny Energy Supply Company. The resulting deaths of 51 construction workers represent one of the most costly accidents, in human terms, of any in the U.S. construction industry's history.



Perspective of Scaffolding System (NBS Rpt, 1979)

WHAT HAPPENED?

A post accident report by the Center for Building Technology, National Engineering Laboratory, National Bureau of Standards,[1] describes the accident as follows:

> The shell [of the cooling tower] was constructed through the use of a patented lift form technique.[2] Except for the lower and upper portions of the tower, the construction procedure at Willow Island utilized a scheme to place a 5-ft (1.5-m) lift per day. At the time of failure, 28 lifts had been completed with the most recent one having been placed the previous day. The form work which supported the less than one day old concrete of lift 28 had been raised into place for lift 29. According to eyewitness accounts by workers, lift 28 began to collapse when the third bucket of concrete was being hoisted up to the working platform… According to eyewitnesses, the entire section of lift 28 collapsed into the tower [falling approximately 170 feet] within a few minutes.

Following the accident, the State of West Virginia commissioned a study of the accident.[3] OSHA commissioned a report prepared by the National Bureau of Standards as described in footnote 1 and in a second report.[4]

PROBABLE CAUSE

- The concrete that supported the lift form-work scaffolding system was of insufficient compressive strength to support the loads to which it was being subjected. The concrete had been placed only 18 hours before being required to support the lift form-work scaffolding system and had a predicted compressive strength of 220 pounds per square inch (psi) as noted in NBSIR 80-2010.[4] As further noted, the concrete would have started to fail at a compressive strength of 1,000 psi. In addition, the required concrete strength to support the lift form-work system should have included a factor of safety of 2 and consideration of the dynamic effects of the hoisting loads.
- The anchor point for the static line that was used by the hoisting system for lifting concrete was moved from a point on the ground near the cooling tower wall to a point on the ground at approximately the center of the cooling tower. The anchor point is routinely moved because of the changing geometry of the ongoing construction.[5] NBSIR 80-2010 concludes, "If the base anchor point of the static line had been kept at its previous location (before the last move to near the center of the tower), the effects of the construction loads would have been reduced to such an extent that failure of lift 28 of the tower would probably not have occurred."

1. H.S. Lew, et al., "Investigation of the Construction Failure of Reinforced Concrete Cooling Tower at Willow Island, West Virginia," NBSIR-1578, Center for Building Technology, National Engineering Laboratory, National Bureau of Standards, November 1979.
2. The lift form-work scaffolding system was a complex structure containing the concrete forms, scaffolding, and a hoisting system for lifting concrete up to the pour site. The lift form-work scaffolding system structure contained a hydraulic jacking frame so that the entire structure could be lifted up in preparation for placing a new circular ring section of the cooling tower. Once the form-work scaffolding was lifted up, it was secured into the most recently placed concrete.
3. "Governor's Commission on Willow Island—Report to the Governor and Legislature," 1980.
4. H.S. Lew and S.G. Fattal, "Analysis of Construction Conditions Affecting the Structural Response of the Cooling Tower at Willow Island, West Virginia," NBSIR 80-2010, July 1980.
5. Norbert J. Delatte, Jr., "Beyond Failure—Forensic Case Studies for Civil Engineers," ASCE Press, 2009.

NRC Positive Safety Culture Traits	Evidence of Weak Safety Culture Traits
Leadership Safety Values and Actions in which leaders demonstrate a commitment to safety in their decisions and behaviors. **Work Process** in which the process of planning and controlling work activities is implemented so that safety is maintained.	It appears that no one was responsible for process safety at Willow Island. The Governor's Commission on Willow Island Report found that "…there were no inspectors or supervisors of any kind on the job whose responsibility it was to check the work to make the determination either to proceed with the work or give the concrete more time to gain strength."
Problem Identification and Resolution in which issues potentially impacting safety are promptly identified, fully evaluated, and promptly addressed and corrected commensurate with their significance.	Given that the lift form-work scaffolding system was anchored in the previously poured concrete and had no other means of support, the strength of the supporting concrete was crucial. However, the contractor never established, or questioned, the strength of the supporting concrete. As noted in the Governor's Commission on Willow Island report, "Although Pittsburgh Testing Laboratories personnel tested the concrete, it was not necessarily done before the framework was removed, and nothing in their contract would seem to indicate they would have any authority to shut the job down if they found problems." OSHA issued Research-Cottrell "…a citation alleging a willful violation [an intentional and knowing violation] for failure to make field tests on field-cured concrete specimens to insure that the concrete had attained sufficient strength to safely support the load prior to removal of the forms."[6]
Continuous Learning in which opportunities to learn about ways to ensure safety are sought out and implemented.	There appeared to be no formal training program for workers. The Governor's Commission on Willow Island report found that "Because of the word-of-mouth training that is a natural part of the work environment and because there were no written specifications available for reference, workers could inadvertently make gradual modifications that might compromise the design and cause conditions beyond the limitations of the materials."

6. Statement of Dr. Eula Bingham, Assistant Secretary of Labor, Transcript of the House of Representatives Subcommittee on Compensation, Health and Safety, Committee on Education and Labor, June 30, 1978.

WHAT CAN ORGANIZATIONS LEARN FROM THIS ACCIDENT?

This accident reinforces the need for, and the importance of, promoting a positive safety culture by routinely evaluating safety culture activities and initiatives and making enhancements and adjustments to ensure that an organization remains proactive and appropriately focused in this important area.

Key lessons from this case study are the following:

- **Critical safety-related process variables should be identified and controlled.** In the case of the Willow Island accident, the strength of the supporting concrete and the anchor point for the static line that was used by the hoisting system for lifting concrete were critical safety-related process variables; no limitations on these critical safety-related process variables had been established.
- A **decisionmaking process for critical safety-related process variables, based on written procedures, should be established.** In the case of the Willow Island accident, movement of the lift form-work scaffolding system should have been based on demonstration, via a concrete testing program, that the concrete had achieved minimum safety strength. Likewise, movement of the anchor point for the static line that was used by the hoisting system for lifting concrete should have been subjected to a careful decisionmaking process.
- **The root causes of past incidents should be thoroughly investigated to establish the facts of any safety issue to have an overall understanding of the event and to take necessary actions to prevent recurrence.** The lessons learned from the root cause analysis should be used to establish corrective actions that apply to a broader set of similar circumstances in other work scenarios. As a result of this incident, major industry-wide improvements have been made in the construction of cooling towers and other similar specialty structures.

Sources of Information:

1. H.S. Lew, et al., "Investigation of the Construction Failure of Reinforced Concrete Cooling Tower at Willow Island, West Virginia," NBSIR-1578, Center for Building Technology, National Engineering Laboratory, National Bureau of Standards, November 1979.
2. H.S. Lew and S.G. Fattal, "Analysis of Construction Conditions Affecting the Structural Response of the Cooling Tower at Willow Island, West Virginia," NBSIR 80-2010, July 1980.
3. "Governor's Commission on Willow Island—Report to the Governor and Legislature," 1980.
4. Transcript of the House of Representatives Subcommittee on Compensation, Health and Safety, Committee on Education and Labor, June 30, 1978.

This Safety Culture Case Study was developed by David H. Jaffe on rotational assignment to the NRC's Office of Enforcement. If you have any questions, please contact David Solorio, Branch Chief, at 301-415-0149 or by e-mail at Dave.Solorio@nrc.gov.

Note that the NRC has not conducted a formal analysis of the events discussed herein for, or in conjunction with, the West Virginia Governor's Commission on Willow Island, OSHA, or any other organization. The NRC compiled the factual information presented and discussed from publicly available sources, as identified.