OIL STORAGE TANKS: CONSTRUCTION AND TESTING ISSUES
ARISING FROM THE ASHLAND OIL SPILL

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SUMMARY

A 4-million-gallon oil storage tank owned by the Ashland oil company collapsed on Jan. 2, 1988. The 40-year-old tank had been moved, rebuilt, and put into service by August 1987. It burst while it was being filled, spilling about 1 million gallons of diesel fuel oil into a tributary of the Ohio River. The river-borne oil contaminated drinking water and interrupted commercial navigation.

The National Bureau of Standards (NBS) reports that brittle fracture caused the collapse. Any combination of factors including old steel wall materials, failure of welded joints, foundation settlement, and cold weather may have contributed to the fracture. Ashland reportedly admits that many defective older welds were not repaired before the tank was filled. Some structural engineering experts note that toughness of the steel may be a key factor. Toughness, the ability to resist brittle fracture, is affected by welding and cold weather. Steel produced since the mid-1970s is made tougher because it contains less carbon and more silicon and phosphorus than older steel. These experts report that on two or three occasions other large tanks rebuilt with older steel have failed suddenly in cold weather conditions. Experts note that as many as 15% to 20% of all existing storage tanks have been rebuilt with older materials and, thus, may also be at greater risk of collapse.

Tank testing procedures are also at issue in the Ashland incident. Ashland management admits that the tank was not tested for strength by filling it to its full height with water. However, Ashland argues that it complied with industry standards by performing a pressurized test for leakage. The Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) provide the only Federal regulations for oil tank construction and testing, and both of these agencies defer to procedures established by the American Petroleum Institute's (API's) Standard #650. Many State and local fire marshals have adopted the National Fire Protection Association's Standard #30 for Flammable and Combustible Liquids which, in turn, also adopts API Standard #650 for oil storage tanks. The API provides guidelines for materials toughness, welding, and other construction details. It also sets guidelines for inspecting and testing toughness, welds, and tank strength. Where a tank has passed API tests, it is marked with an API monogram. NBS reports that the Ashland tank did not have the API monogram. The EPA also requires that tanks be "fail-safe engineered." NBS says that this means that oil tanks should be built so that they could fail "only in a safe way," where slow leaks would provide warning of structural problems well before a collapse could occur.

Current legislation would empower the EPA to set performance standards for tank construction and require a study of existing above ground tanks. Two issues which the Congress may consider are: (1) Is the Ashland tank collapse a freak occurrence or are there other large oil storage tanks in use that may be at significant risk of collapsing? (2) Should the Federal Government have a greater role in regulating oil storage tank construction, testing, and inspection?
ISSUE DEFINITION

The major issue is whether enforcement of Federal standards for construction and testing of above ground oil storage tanks is adequate. This issue has surfaced as a result of the January 1988 Ashland oil spill near Pittsburgh, Pennsylvania. Existing regulations for these tanks are specified by the Environmental Protection Agency (EPA) under authority of the Clean Water Act (P.L. 92-500) and by the Occupational Health and Safety Administration (OSHA) under the Occupational Health and Safety Act (P.L. 91-596). Both agencies largely defer to oil industry engineering practices set out by the American Petroleum Institute (API). Collapses of this and other tanks rebuilt with steel materials manufactured before the mid-1970s suggests that additional tanks may also be at risk of catastrophic failure. Are industry tank testing procedures adequate? Are more explicit Federal performance standards and enforcement regulations needed?

BACKGROUND AND ANALYSIS

Ashland Oil Tank Collapse

A 4-million-gallon oil storage tank owned by Ashland Oil Company collapsed on Jan. 2, 1988. The tank was part of Ashland's pipeline terminal at Floreffe, Pennsylvania. The 40-year-old tank had been moved from Cleveland, OH, by the Skinner Tank Company of Yale, Oklahoma, rebuilt, and put into service in August 1987. It burst while it was being filled for the first time at its new location in Pennsylvania. About 2.8 million gallons of diesel fuel oil were held by a containment dike surrounding the tank. Another 1 million gallons of fuel oil escaped into the Monongahela River, which is a major tributary of the Ohio River. The movement of the oil down these rivers contaminated drinking water sources and interrupted commercial navigation. Cleanup costs are estimated to go as high as $15 million.

The tank stood 48 feet high, had a diameter of 120 feet, and was topped with a flat roof. The Ashland company reports that the foundation for the tank was built with all new materials, but some of the supports and girders of the original tank were re-used in its construction. Ashland says that the tank bottom was built of one inch thick old steel and the walls were built of one-half inch thick old steel. The tank walls consisted of six rings of steel plate, each of which stood 8 feet high. The rings were staggered so that the newly welded joints did not line up.

The rupture of the tank is described as a catastrophic failure because of the speed and intensity of the collapse. The National Bureau of Standards (NBS) says that the tank appears to have split open the full height of the tank's side and then tore open along the bottom. The ensuing outpouring of fuel oil was similar to "air escaping from a balloon." The force of expulsion was so great that the tank was propelled backwards about 100 feet and the escaping oil formed a 30-foot-high wave which dented a nearby tank and then splashed over the top of the
surrounding containment dike which stood about 10 feet high. Ashland reports that the dike was built of earth and concrete and was designed to hold 110% of the tank's maximum capacity.

Possible Causes of the Collapse

NBS reports that a brittle fracture caused the spill. However, it is uncertain about the cause of fracture which, it says, could possibly have resulted from any combination of factors including foundation settlement, old steel wall materials, failure of welded joints, and cold weather. A preliminary investigation by NBS found no obvious evidence of foundation problems and it reports that the fracture coincides with a short length of the welded joints. (Personal communication with Dr. Richard Wright, Jan. 11, 1988.) API says that brittle fracture occurs only when two conditions exist: a steel material is operated below its design temperature and a notch or micro-crack is present in the material. Such notches are most likely to occur in the form of welding defects. In most tank failures to date, a welding defect has initiated the failure. Some brittle failures have occurred during hydrostatic strength testing of tanks. Both API and the Naval Research Laboratory conduct research and development on fracture toughness and fracture-safe design. (API, Guide for Inspection of Refinery Equipment, Chapter II, Conditions Causing Deterioration or Failures, Section 205.01, Brittle Fracture, Washington, 1973.)

Ashland reportedly admits that normal company practices for weld inspections were not followed. A November 1986 memo from Progress Services, a Pittsburgh-area x-ray firm, reported to Ashland that its x-ray inspections had found defects in 22 of 39 older welds that were made before the tank was moved to Floreffe. (Associated Press, Bad Welds Detected A Year Before Tank Collapsed, Jan. 28, 1988.) The Pittsburgh Post-Gazette reports that some experts in steel failures agree that toughness of the steel, which is affected by welded joints and cold weather, appears to be a key factor in the collapse. One of these experts, Dr. Regis Pelloux of the Massachusetts Institute of Technology, emphasized that today's steel is at least twice as tough as that used 40 years ago when the Ashland tank was first built. Further, he stressed that the toughness of steel declines in cold temperatures. (Pittsburgh Post-Gazette, Weld, Brittle Steel Suspected in Spill, Jan. 8, 1988.)

A search for the root cause of the collapse continues. Ashland reports that it has hired researchers of the Battelle Memorial Institute in Columbus, OH, to do an independent investigation into possible causes of the collapse. (Personal communication with Mr. Will Haddland, Ashland Oil Company, Jan. 6, 1988.) NBS will also study the causes of the Ashland tank collapse. It expects that the study will take about 6 months to complete. Empowered by the Clean Water Act (P.L. 92-500), Environmental Protection Agency regulations require that the EPA's On-Scene Coordinator (OSC) prepare a complete report within 60 days after a major oil discharge, such as the one that occurred at the Ashland facility. The regulations require that the report include a discussion of the cause of the discharge. (40 CFR 300.40, July 1, 1986, edition, Section on OSC reports, p. 757.)
Other Major Oil Tank Failures

The Pittsburgh Press has quoted one expert in tank failures, Mr. Lain LeMay, President of Metallurgical Consulting Services in Saskatoon, Saskatchewan, Canada, as saying that most modern tank failures have occurred in units that have been cut apart and moved. (Pittsburgh Press, Experts Believe Rebuilt Tanks are Prone to Collapse, Jan. 10, 1988.) For example, he pointed out that a 3-million-gallon tank collapsed in Moose Jaw, Saskatchewan, Canada, in 1969. The tank, owned by Gulf Oil Company, had been taken apart at another site and rebuilt in Moose Jaw from old steel that did not meet current API standards for toughness. An additional case is cited by another expert on tank failures, Mr. Allen Selz, Vice President of O'Donnell & Associates, a Pittsburgh, Pennsylvania, firm which performs analyses of storage tank failures. A rebuilt tank owned by Mid-Valley Pipeline Company was located in Lima, Ohio. It collapsed in 1983, due to breaks in the steel plates that supported the tank walls. Mr. Selz says that old steel that has been reassembled has contributed to other tank failures. (Pittsburgh Press, op. cit.)

Mr. Selz argues that more attention should be focused on tanks made of used steel. Mr. LeMay suggests that as much as 15% to 20% of all existing storage tanks in North America have been rebuilt from old materials and, thus, may be susceptible to collapse in cold weather. He says that there is no firm data on either the number of rebuilt tanks in existence or on the number of collapse incidents. However, a tank made of old steel may not need to be taken out of service. It can, he says, be insulated to keep the temperature of the metal high enough so that it won't break. Both experts say that steelmakers did not know how to make steel strong without making it brittle under cold weather conditions until the mid-1970s. Modern steel is tougher, more capable of resisting brittle fracture, because it contains less carbon and more phosphorus and silicon than older steel. Toughness includes the characteristics of strength and ductility. The latter term means that the metal can be bent or deformed without breaking. It is also heat-treated after rolling to increase toughness. (Pittsburgh Press, op. cit.)

Tests of the Ashland Tank

According to the Pittsburgh Post-Gazette, Mr. Martin Jacobs, the Allegheny County Fire Marshall, said that the Ashland tank was subject to State codes covering storage of flammable and combustible liquids which, in turn, adopts American Petroleum Institute (API) standards. Many States, including Pennsylvania, have adopted the National Fire Protection Association's (NFPA's) Standard #30, Flammable and Combustible Liquids Code. NFPA #30, in turn, adopts API Standard #650, Welded Steel Tanks for Oil Storage. The Marshall said that the stress testing methods used on the Ashland tank failed to meet industry and governmental standards. Ashland's Chief Executive Officer, John Hall, admitted that the project engineer did not use the full hydro test set out in API standards. This test would have required that Ashland's diesel storage tank be filled to the 48-foot-high top with water to test its strength. However, Mr. Hall argued that the company met industry requirements by using a vacuum test. In this test, the tank was filled with water to a 5-foot height. Then
diesel fuel was sprayed on the walls and the tank was pressurized to determine its integrity, the capability to resist leakage. Mr. Hall also asserted that the company met other industry standards for x-ray tests of welded joints, the quality of construction material, and diking capability. Also, Ashland did not have a construction permit for the tank, but Mr. Hall argues that the permit may not have been needed. (Pittsburgh Post-Gazette, Ashland's Tank Testing Didn't Meet Standards, Jan. 7, 1988: 1-4.)

Mr. LeMay and Mr. Selz agree that the standard engineering tests performed on new tanks before they go into service are not sufficient for old rebuilt tanks. Testing procedures are focused more on structural integrity than on the strength of materials. They note that API standards for oil storage tank materials and construction, which clearly state what types of steel can and cannot be used in cold temperatures, have been updated seven times over the past 30 years. (Pittsburgh Press, op. cit.) Further, they assert that new tanks are built with bulges in the bottom, so that they will sit level when the foundation settles.

Regulations for Tank Construction, Testing, and Inspection

State and local governments have primary responsibility for the regulation of above ground oil storage tanks. Due to the potential fire hazard of oil storage, these regulations are usually set by State and local fire marshals. Many States and localities choose to follow the National Fire Protection Association's (NFPA's) Standard #30, Flammable and Combustible Liquids Code (National Fire Protection Association, Quincy, Massachusetts). This code specifies that atmospheric pressure tanks, such as the Ashland tank, shall be built in accordance with API Standard #650. (NFPA 30, Flammable and Combustible Liquids Code, 1987 Edition, Chapter 2, Tank Storage, p. 30-9.)

American Petroleum Institute (API) Standards

API provides oil industry guidelines for materials, welding and other construction details of large steel tanks for oil storage. (American Petroleum Institute, Welded Steel Tanks for Oil Storage, API Standard 650, Revision 1, Washington, February 1984.) It also lays out guidelines for testing the tank shell, foundation, steel plate toughness and welded joints.

Procedures for testing the strength and leakage of atmospheric storage tanks are described in API Standard #650. They specify that the tank shall be filled with water to the maximum design level and inspected frequently during the filling operation. Further, Standard #650 states that if sufficient water to fill the tank is not available, the tank shell can be tested by "...painting all [welded] joints on the inside with a highly penetrating oil... applying a vacuum to either side of the joints... and carefully examining the outside of the joints for leakage. (API Standard #650, Section 5.3.6, Testing Tank Shell, p. 5-3.) However, API's "Guide for Inspection of Atmospheric and Low-Pressure Storage Tanks" specifies more strongly that, "Atmospheric storage tanks... are normally tested only by filling the tanks with water." If water is not available,
it says that the vacuum test may be applied. But the Guide emphasizes that, "This type of test is of very little use as a strength test and is used only in inspection for leaks." Further, the Guide notes that when major repairs or rebuilding have been done, the need for a strength test should be considered. (API, Guide for Inspection of Refinery Equipment, Chapter XIII -- Atmospheric and Low-Pressure Storage Tanks, Section 13.4.5, Testing of Tanks, Washington, April 1981: 35.)

The toughness of the steel plate materials comprising the tank walls is another area in which API recommends guidelines for industry to follow. Standard #650 says that the purchaser of steel plates can require impact tests of their brittleness. In this test, also known as the Charpy test or notch test, samples of the steel are struck with a pendulum hammer made from the same steel. The samples are then examined for brittle fractures. (Section 2.2.8, Impact Testing of Plates, p. 2-3.) The Guide says that consideration should be given to the notch toughness of the tank shell material, at the air and water temperature existing at the time of the hydro strength test. (Guide to the Inspection of Atmospheric and Low-Pressure Storage Tanks, op. cit.) This test is used to show the temperature at which an otherwise ductile steel material becomes brittle and, thus, susceptible to fracture.

API Standard #650 recommends design metal temperatures for all regions of the United States. The design metal temperature is a climatic characteristic which determines the grade of steel alloy that must be used in order to resist brittle fracture under cold weather conditions. The lower the design metal temperature, the tougher the grade of steel that should be used. The design metal temperature is derived by adding 15 degrees Fahrenheit (F) to the lowest 1-day mean ambient temperature. A map of the lowest mean ambient temperatures for the continental United States appears in Appendix 1. It shows that the lowest ambient temperature for Pittsburgh is 10 degrees F below zero. Thus, the design metal temperature for that area is 5 degrees F above zero. The map shows that, for the United States, the tougher grades of steel should be used in the Upper Midwest, Great Lakes, and New England regions.

Standard #650's toughness specifications say that steel plates less than 1.5 inches thick, except controlled rolled plates, may be used at the design metal temperature or higher, without impact testing. Appendix 2 shows how minimum permissible design metal temperatures vary with thickness and type of steel alloy. At one-half-inch thickness, the thickness of Ashland's tank walls, Standard #650 shows that the design metal temperature for different grades of steel plate alloy varies from 40 degrees F below zero to 20 degrees F above zero. (Section 2.2.9, Toughness Requirements, p. 2-4.) However, NBS does not yet know what grade of steel alloy was used in the Ashland tank. (Personal communication with Dr. John Gross, NBS, Jan. 20, 1988.)

API Standard #650 notes that the welded metal and adjacent heat-affected zone, the area on either side of the weld where toughness may be reduced by the flow of heat from the welding process, could be expected to be more susceptible to cracking than unwelded areas of the tank's steel plates. (Ibid, Section 3-4.) Thus, it concludes that the former areas should be subjected to hardness tests. However, API states
that the methods of hardness testing and the standards of acceptance shall be "a matter of agreement between the purchaser and the manufacturer." (Section 3.3.4, Weld Hardness, p. 3-4.) However, radiographic (x-ray) inspection is required for several types of tank welds. (Section 6.1, Radiographic Method, p. 6-1.) For welds between shell plates, the purchaser may require radiographs if the inspector's visual examination indicates unsatisfactory work. (Ibid, Section 5.3.1.4 and 5.3.2.1.) Except as modified by API #650, the radiographic examination method is directed to follow standards for "Nondestructive Examination" set by the American Society of Mechanical Engineers. (ASME Boiler and Pressure Vessel Code, Section V, Article 2.)

API #650 specifies that the adequacy of the foundation is the responsibility of the purchaser. (Section 3.3.1, Foundation, p. 3-4.) It recommends that information on soil conditions should be obtained by deep borings, load and soil tests, and by review of experience with similar structures in the vicinity. Special engineering consideration is to be given to sites adjacent to water courses or where tanks may be exposed to flood waters. API #650 also makes recommendations for soil compaction, use of fill material, and construction of an elevated grade for the tank bottom, which is at least 1 foot above the surrounding ground surface. (Appendix B, Recommended Practice for Construction of Foundations for API Vertical Cylindrical Oil Storage Tanks, p. B-l.)

API #650 stipulates that tanks made according to the standard shall be identified by a nameplate attached to the tank shell. (Ibid, p. 8-1.) An NBS on-site investigator reports that he did not see an API nameplate on the Ashland tank. (Personal communication with Dr. Richard Wright, NBS, Jan. 11, 1988.)

Environmental Protection Agency (EPA) Regulations

Empowered by the Clean Water Act (P.L. 92-500, 33 U.S.C. 1321) the EPA established requirements for owners of above ground oil storage tanks to prepare Spill Prevention Control and Countermeasure (SPCC) Plans. (U.S. EPA, Guidelines for the Preparation and Implementation of a Spill Prevention Control and Countermeasure Plan, 40 CFR Chapter 1, Section 112.7, July 1, 1987 edition.) These regulations include several provisions related to the construction, testing, and inspection of the tanks. One provision specifies that above ground tanks should be subject to periodic integrity testing, taking into account tank design, and using techniques such as hydrostatic testing, visual inspection or a system of nondestructive shell thickness testing. Also, inspection records should be kept where appropriate, and tank supports and foundations should be included in these inspections. Another provision specifies that new and old tank installations should, as far as practical, be fail-safe engineered or updated into a fail-safe engineered installation to avoid spills. EPA says that the term "fail-safe engineered" means "engineered according to standard industry practices." (Personal communication with Jack Kooyoomjian, EPA, Jan. 12, 1988.) This, in turn, may then defer to the practices contained in API #650 as the standard for "fail-safe engineered." However, NBS says that the term has a more specific meaning, namely that the tank material should be engineered with sufficient toughness and ductility that if it were to fail, it would "fail in a safe
way." That is, there would be a period of noticeable leakage well before a catastrophic collapse would occur. This leakage would serve as a warning, allowing time for the tank to be drained and repaired before a complete rupture could occur. (Dr. Wright, NBS, Jan. 29, 1988.)

EPA requires that an SPCC Plan be prepared within 6 months after a facility begins to operate. It also requires that a Registered Professional Engineer review the Plan and certify that it was prepared in accordance with "good engineering practices." (Ibid, Section 112.4.)

Occupational Safety and Health Administration (OSHA) Regulations

Empowered by the Occupational Health and Safety Act (P.L. 91-596), OSHA established requirements (29 CFR Chapter XVII, Section 1910.106) for owners of atmospheric oil storage tanks to build them "in accordance with acceptable good standards of design," which includes API Standard #650. OSHA regulations also specify that all tanks "shall be strength tested before they are placed in service in accordance with the applicable paragraphs of the code under which they were built." Further, OSHA regulations say that the API monogram "shall be evidence of compliance with this strength test." However, tanks not marked in this way are allowed to be strength tested "in accordance with good engineering principles." Additionally, OSHA specifies that "all leaks or deformations shall be corrected in an acceptable manner before the tank is placed in service." P.L. 91-596, Section 659, specifies that after an inspection or investigation, the Secretary of Labor may issue a citation and propose a penalty assessment -- both of which the tank owner may contest.

Federal Legislation Related to Oil Storage Tanks

Prior to the Ashland oil spill event, two bills were introduced in the 100th Congress relating to oil storage tanks, the Storage Tank Safety Act (S.899, Daschle) and the Pipeline Safety Act of 1987 (S.888, Durenberger). Both bills would add parallel regulations for above ground storage tanks to the existing regulations for underground storage tanks set by the Solid Waste Disposal Act (P.L. 89-272 as amended by P.L. 98-616). These bills direct the EPA to: (1) provide identifying information about all tanks specifying their age, size, type, location, and use; (2) set release prevention regulations which may distinguish among tanks according to age, location, maintenance history, and recommended industry practices; (3) set Federal performance standards for new tanks which includes provisions related to their design, construction and installation; and (4) perform a study of existing above ground storage tanks, including an assessment of age, climate and method of materials manufacture. The study would also include an assessment of the effectiveness of existing tank testing methods.

The bills also direct each State to make an inventory of all above ground petroleum storage tanks. Further, they allow States to establish release prevention programs and standards of performance for new tanks, but only if the State regulations and standards are no less stringent than Federal standards.
Conclusion and Issues for Congressional Consideration

Some expert opinion appears to suggest that several factors, including old steel and cold weather, may have contributed to the collapse of the Ashland oil tank. A preliminary review of similar oil tank failures seems to suggest that rebuilt storage tanks containing steel plates which were manufactured before the mid-1970s may pose special concerns for testing and inspection regulations. No matter which factors are ultimately determined to have caused the collapse, it seems that testing and inspection requirements could have detected some areas for concern beforehand. For the most part, existing Federal and State regulation of oil storage tanks currently adopt industry standards and testing procedures for tank strength, tank integrity, steel toughness, welded joints, and foundations. Current legislation, S. 888 and S. 899, would empower EPA to set Federal performance standards for design, construction, and installation of oil storage tanks. However, neither of these bills specifically identifies the testing and inspection of tank strength, materials toughness, welded joints, or foundation construction as key areas of concern for EPA to focus upon. Further, they place no special emphasis on rebuilt storage tanks which use steel that was manufactured before the mid-1970s. However, S. 899 does call for a study of the effectiveness of existing tank testing methods.

The collapses of the Ashland tank and others appear to raise several important questions. Were industry construction standards and thus Federal and State standards adhered to? If not, does this suggest that more explicit Federal enforcement standards and regulations are needed? If industry standards were followed, does that collapse suggest that stronger Federal testing and inspection requirements are needed? Are industry tank testing procedures adequate?

The following issues are suggested by the above discussion for congressional consideration:

(1) Are there other large oil storage tanks in use that are currently at risk of collapsing?
(2) Is there a need for a Federal data source on oil storage tanks?
(3) Should the Federal Government have a greater role in regulating oil storage tank construction, testing, and inspection?

LEGISLATION

S. 888 (Durenberger)
S. 899 (Daschle)

S. 2020 (Heinz)
Regulates above-ground storage tanks with capacity to store at least 1 million gallons of petroleum. Introduced Feb. 1, 1988; referred to Committee on Environment and Public Works.

CONGRESSIONAL HEARINGS, REPORTS, AND DOCUMENTS


CHRONOLOGY
01/02/88 --- Ashland oil storage tank in Floreffe, PA, collapsed.
Appendix I. Lowest One-Day Mean Temperatures


Isothermal Lines of Lowest One-Day Mean Temperatures

Compiled from U.S. Weather Bureau and Meteorological Service of Dominion of Canada. November 1952

CRS 11
Appendix 2. Minimum Permissible Design Metal Temperature for Plates Used in Tank Shells Without Impact Testing (in Degrees Fahrenheit)