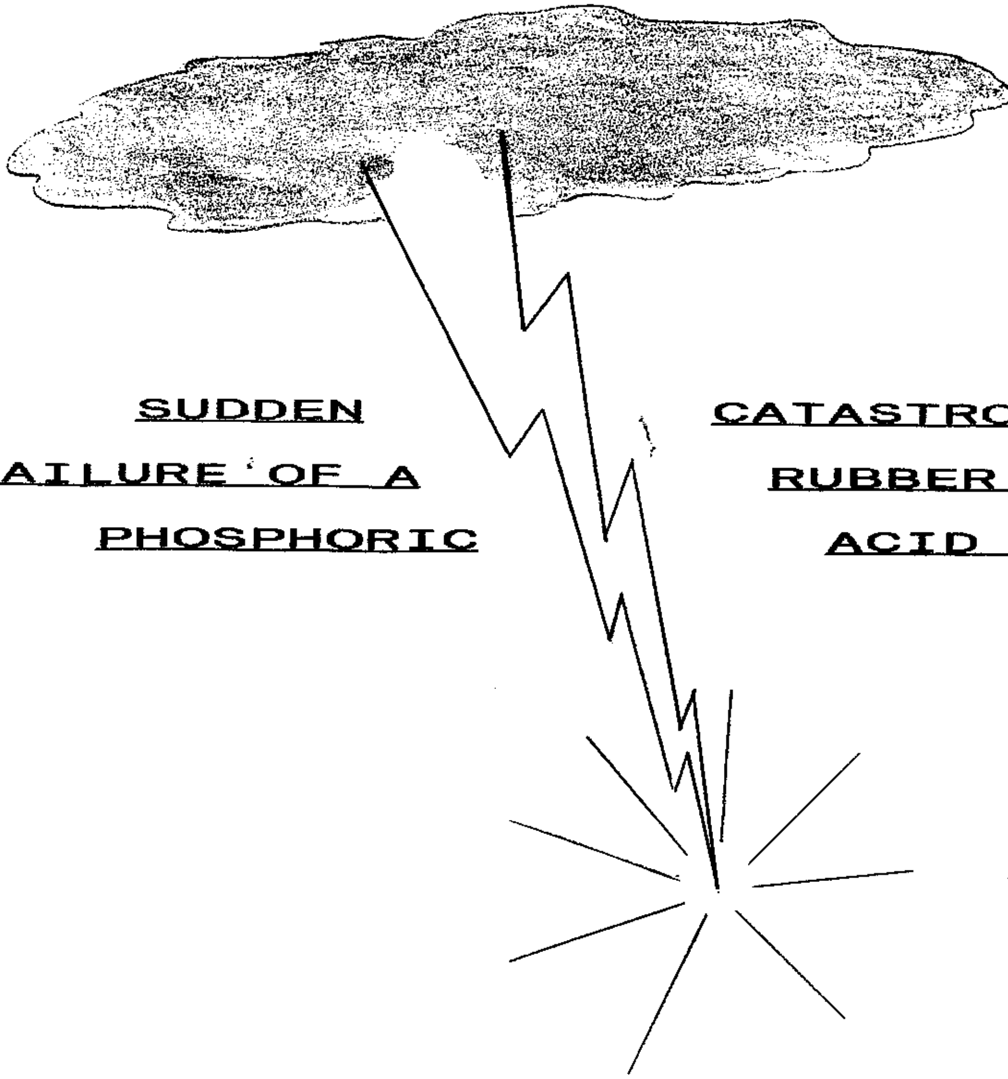

SUDDEN CATASTROPHIC FAILURE OF A RUBBER LINED PHOSPHORIC ACID TANK

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      1. Require metal repairs to be in accordance with API-653
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      1. Require filling tanks with water if they are to be empty for extended periods of time
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RUBBER LINED PHOSPHORIC ACID TANK

TANK BACKGROUND AND OPERATIONAL HISTORY

The No. 2 Aging Tank was one of several rubber lined, carbon steel, phosphoric acid vessels specified by Wellman-Power Gas for CFI's B-Phosphoric Acid plant expansion and built in 1974 by Chicago Bridge & Iron. The tank was 35' in diameter and 36' high, designed to the American Petroleum Institute (API) Standard 650, "Welded Steel Tanks for Oil Storage". It was specifically designed to contain up to 259,000 gallons of 54% phosphoric acid with a specific gravity of 1.75, at a maximum operating temperature of 150°F. The tank was furnished with a stainless steel agitator, an agitator support structure mounted from the upper shell, four internal baffles and a domed roof. The tank was internally lined with a 1/4" thick atmospherically steam cured flexible ebonite lining.

The tank originally went into service in early 1975, but beginning in the 1980's, the tank was periodically drained of acid and refilled with condensate or sometimes left empty for extended periods of time. During its lifetime, some minor repairs to the rubber lining, baffles and carbon steel shell were required. Most of these repairs were near the baffle attachments or at rubber lining seams that became disbonded. The original rubber lining was still in service in October 1991 after almost 17 years.

The traditional industry and CFI practice for inspection and repair of most rubber lined tanks was to drain the tank and cleanout only enough of the hard build-up to be able to make repairs when a leak developed. These tanks were not routinely opened, thoroughly cleaned, inspected and repaired on a set schedule. The primary reason for this was that in the cleaning process extensive damage was inevitably done to the rubber lining. Because of these factors, repairs would frequently be made in less than ideal clean and dry interior conditions. Stainless steel "sandwich patches", chemically cured or precured rubber patches and generous amounts of epoxy cement were often all that was used to effect a repair. Occasionally "temporary" shell repairs have been done by simply lowering the liquid level to below the leak and patching from the outside.

THE FAILURE AND RESULTANT DAMAGE

On the night of Sunday, October 13, 1991 at 8:45 PM, the shell of the No. 2 Aging Tank suddenly split apart along a vertical line, allowing the entire liquid contents to violently rush out. At the time of the failure, the tank contained about

THE FAILURE AND RESULTANT DAMAGE (continued)

19 feet (140,000 gallons) of 54% phosphoric acid. The sudden outpouring of the acid created a tidal wave that severely damaged a nearby 15,000 gallon defoamer tank and pushed it off its foundation. The tidal wave also ruined bearings and shorted-out several electric motors in its path.

The release of the energy in the stored acid threw open the shell, damaging the No. 3 Aging Tank to the north and the Wet Rock Blend Tank to the south. The No. 3 Aging Tank was very severely damaged and partially pushed off its foundation by the impact. The Wet Rock Blend Tank received only relatively minor damage as a result of the impact. The force of the acid rushing out in one direction pushed the No. 2 Aging Tank off its foundation in the opposite direction. The movement of the two aging tanks destroyed adjacent piping and pipe racks. Displacement of these pipe racks resulted in upper shell damage to a 306,000 gallon condensate tank and to a 300,000 gallon 54% phosphoric acid storage tank nearby.

As the shell of the No. 2 Aging Tank flew open, support for the domed roof and agitator structure was lost; they both collapsed. The agitator gearbox and motor were pushed off the support structure, but remained attached to the upper end of the slightly bent agitator shaft. While the No. 2 Aging Tank was moving, all the steel grillage support beams (12" Wide Flange) under the floor were crushed and twisted. Most of the concrete foundation piers were fractured or severely spalled on the east end. Fortunately there were no personnel injuries or significant environmental impact as a result of this accident. All required regulatory notifications were promptly made and the Hillsborough County Environmental Protection Commission commented that the clean-up effort and our reaction to this incident was a "textbook response".

FAILURE INVESTIGATION

I received a phone call at home that Sunday night at 9:45 PM from the weekend coverage plant manager. He told me that the No. 2, 54% Phosphoric Acid Aging Tank had collapsed and briefly listed some of the more obvious consequential damage. When I expressed some doubt about this story, he assured me that it was really true, so I drove out to the plant at that time.

The clean-up operation was already well underway by the time I arrived on the scene around 10:30 PM. Remaining evidence of the phosphoric acid tidal wave was everywhere around the failed tank. There were no eye witnesses to the rupture, but an operator nearby said that he heard a sudden loud bang (like rail cars bumping together) followed by a roar (like a giant water fall) lasting three to four seconds. About the time the noise stopped, he saw a wall of acid heading in his direction and was fortunate to be on top of the filtrate tank. He was able to watch the acid rush

FAILURE INVESTIGATION (continued)

against the sides and around the concrete filtrate tank, but doing no harm there. Because of the extensive damage to the No. 2 Aging Tank, several people at the plant that night were convinced that terrorists or saboteurs had exploded a bomb inside the tank.

CFI's initial investigation revealed that the vertical rupture line crossed each of the girth (circumferential) welds, but was not associated with any shell welds. The vertical failure line coincided with the edge (toe) of a vertical two inch wide skived lap in the rubber lining. There were also cracks along the same edge of almost every other rubber lining lap (Photo 16). These laps and adjacent cracks ran continuously from floor to roof. Removing the rubber lining on top of some of these other cracks revealed a narrow trough of corrosion in the steel directly under the cracks. At the failure line the thinning averaged about 1/2" wide, with the shell corroded to less than 1/16" in places. The tank shell was horizontally sheared off just above the floor for over 180° of its circumference.

CFI also sought assistance from other independent sources in analyzing this failure. The Radian division of The Hartford Steam Boiler Inspection & Insurance Co. and Chicago Bridge & Iron (CB&I) were asked to investigate the accident. In addition Martin Rubber Co. was asked to specifically analyze the failed rubber lining material. Each investigating firm was furnished with samples from the failed tank for their analysis.

CFI, Radian and CB&I came to the same basic conclusions:

1. The tank shell split apart vertically at a crack along the edge of a vertical lap in the rubber lining that extended the full height of the tank.

2. The tank shell was severely thinned by corrosion along a narrow vertical line under this crack in the lining.

3. This corrosion proceeded until the remaining shell thickness, at one location could not contain the weight (circumferential hoop stress) of the acid.

4. The rupture initiated in a zone about 14'-16' above the tank floor and quickly propagated vertically up and down the full height of the tank from this location.

5. When the rupture reached the tank floor it changed its course and tore the shell off the floor for over 90° in each direction.

6. The torn edge of the failure and subsequent material tests confirmed that this was a ductile failure.

FAILURE INVESTIGATION (continued)

Martin Rubber Co. analyzed the interior rubber lining and concluded that it was a flexible ebonite, probably manufactured by Automotive Rubber Co. (ARCO No. 864). They theorized that induced stress at the edge of the laps, caused by use of a narrow stitching tool to force down the toe of the skived edge, led to the cracking. They also found the adhesion to the steel to be excellent and stated "Aside from the cracks along most of the joints, the lining appears to be in good functional condition".

ACTIONS TO MINIMIZE THE RISK OF THIS TYPE OF FAILURE

Our rubber lining specifications were modified to eliminate flexible ebonite and other hard, single layer, natural rubber lining materials. Cracks have been found in three layer linings too, but fewer in number and less severe. Vertical laps in rubber linings are now required by CFI specifications to be horizontally staggered half the roll width (usually 42" or 48"). Also, vertical laps in rubber linings are now required by CFI specifications to be limited to a maximum of 12 feet high.

Our specifications for rubber lined steel tanks were changed to require a greater shell corrosion allowance in addition to the calculated API-650 thickness. The total of these two is then rounded off to the next larger standard mill plate thickness, usually in 1/16" increments. This will eliminate getting a tank built with shell plates specifically rolled to the exact required thickness; for example 0.234" would be rounded off to 0.250" (1/4") plate.

CFI specifications for the inspection and repair of rubber lined storage tanks have been changed to require that all metal repairs be made in accordance with the API-653 Standard, "Tank Inspection, Repair, Alteration and Reconstruction". This includes radiography of welds and the use of certified welders. Actually, the Florida Department of Environmental Regulation by law (Florida Administrative Code, Chapters 17-762 and 17-767), now requires that aboveground and mineral acid storage tanks be maintained in accordance with the API-653 Standard. Periodic complete inspection of the internal rubber lining is now required by CFI specifications five years after a new lining is installed, three years after that and every two years thereafter; unless there is evidence indicating the need for more frequent inspection. Circumstances that indicate a need for more frequent inspection would include a change in service conditions or the recurrence of leaks. During these inspections all build-up will be removed and the lining laps sandblasted, visually examined and spark tested.

ACTIONS TO MINIMIZE THE RISK (continued)

Because of inherent damage done to the rubber lining when the tanks are completely cleaned, an alternative to these total cleanings was developed. Specifically, external reinforcing bands can be installed and maintained that are designed to completely resist the hoop stress of a full tank. Therefore, even if the shell were to split vertically, a significant leak would occur, but the reinforcing bands would restrain the shell from opening up and releasing a tidal wave of liquid.

Plant operating procedures have been revised so that empty rubber lined tanks will be filled with water if they are to be out of service for a prolonged period of time. This will help prevent premature drying and cracking of the lining. We no longer routinely alternately store condensate and phosphoric acid in the same rubber lined tanks.

It is CFI's hope that distribution of this information and the cooperative spirit within the fertilizer industry will go a long way toward elimination of this type of catastrophic tank failure in the future.

ATTACHMENTS
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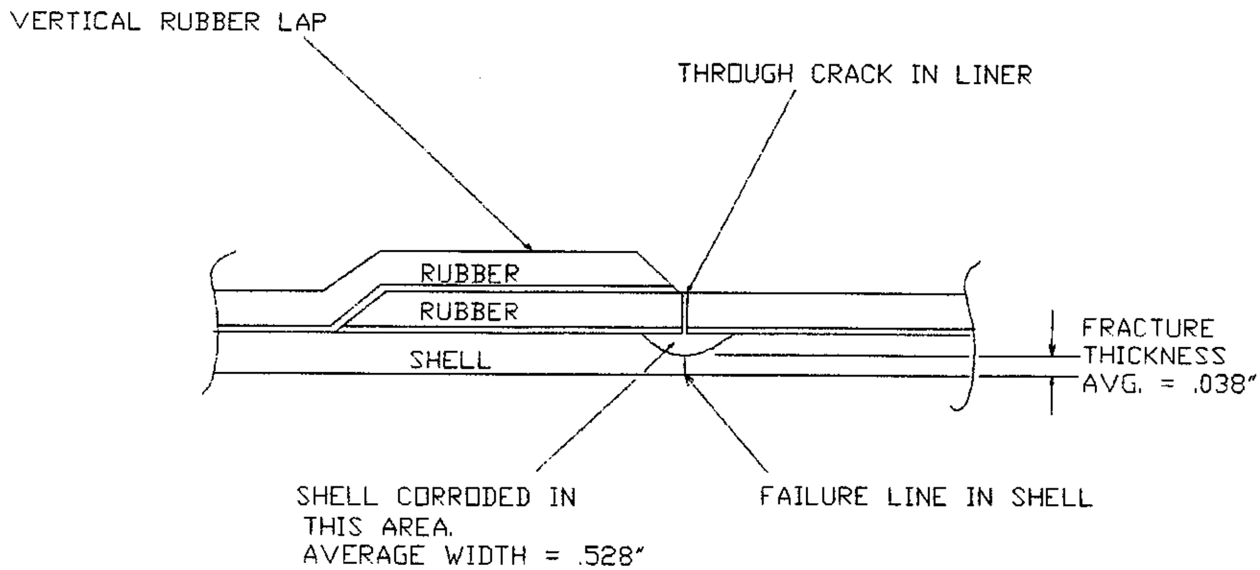

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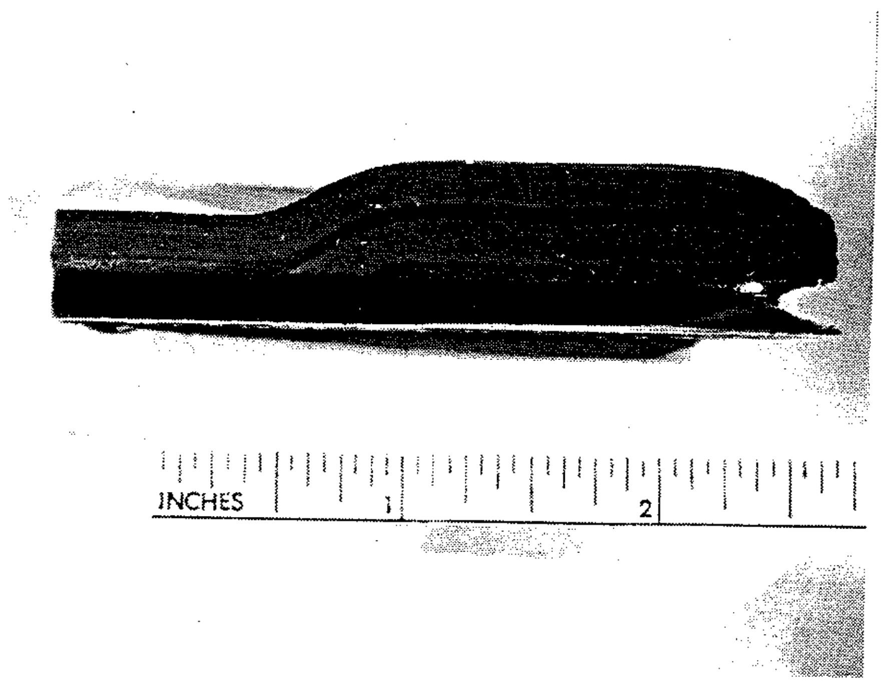

Figure 10. Cross-section through the lapped joint in the rubber liner on the north edge of the rupture.

The darker tie gum bonding the rubber to the steel is readily visible, as is the undercutting of the rubber at the rupture and the thinning of the shell. White deposits are visible at the crevice between the rubber and the corroded steel shell.

Table 1

Fracture Measurements

Elevation Above Tank Floor (ft)	Width of Corrosion (inches)	Fracture Thickness (inches)	Estimated Corr Depth (inches)
Ductile Plate Thickness Reduction Zone			
12.0	0.165	0.095	0
12.5	0.159	0.186	0
13.0	0.162	0.187	0
13.5	0.192	0.141	0
14.0	0.170	0.106	0
14.5	0.183	0.092	0
15.0	0.195	0.083	0
Corrosion Thinning Zone			
15.5	0.349	0.040	0.142
16.0	0.336	0.058	0.124
16.5	0.496	0.033	0.149
17.0	0.598	0.037	0.145
17.5	0.421	0.035	0.147
18.0	0.533	0.037	0.145
18.5	0.565	0.029	0.153
19.0	0.555	0.031	0.151
19.5	0.476	0.037	0.145
20.0	0.637	0.035	0.147
20.5	0.599	0.033	0.149
21.0	0.573	0.035	0.156
21.5	0.642	0.042	0.149
22.0	0.485	0.031	0.160
22.5	0.572	0.046	0.145
23.0	0.502	0.045	0.146
23.5	0.639	0.048	0.143
Statistics Within Corrosion Thinning Zone			
Mean	0.528	0.038	0.147
Max	0.642	0.058	0.160
Min	0.336	0.029	0.124
Trend with height	Increasing Width	None	None

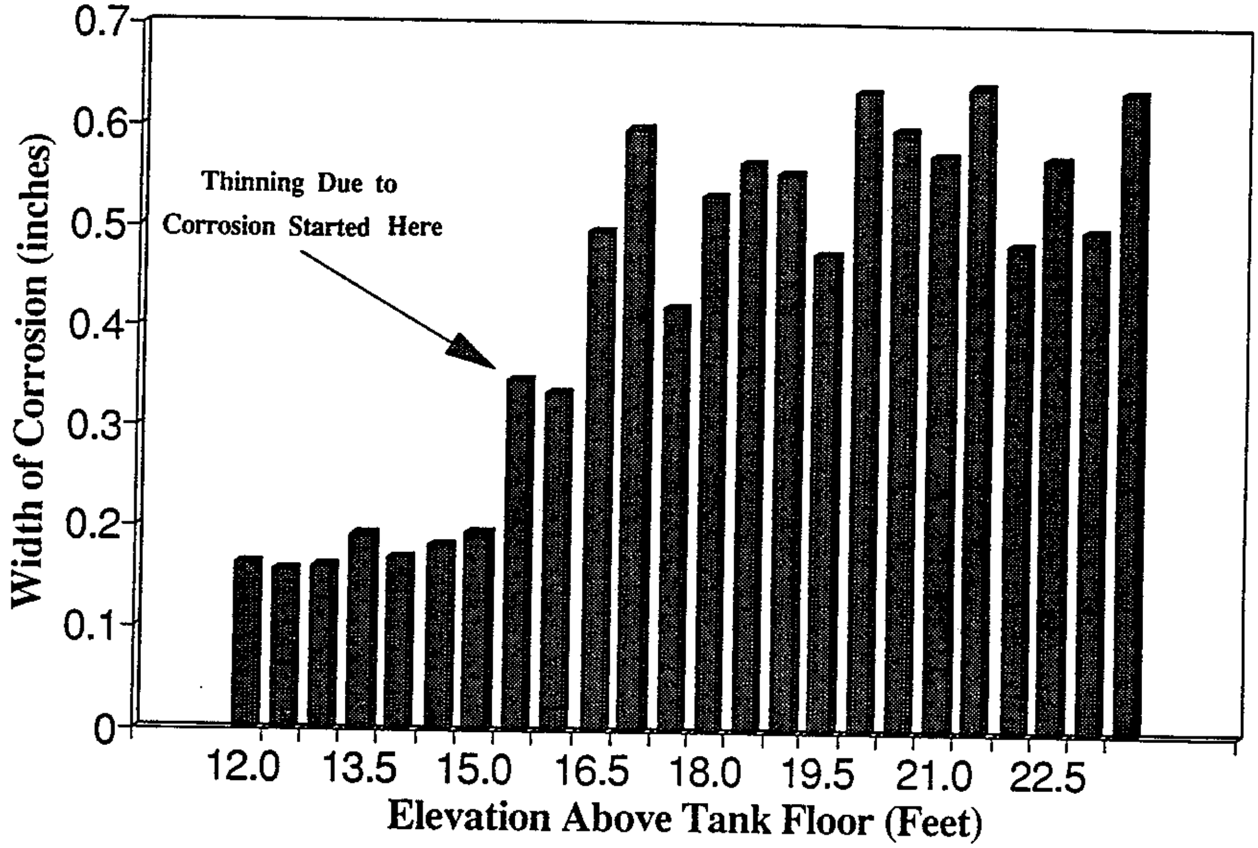

Figure 12. Width of debonding of the rubber liner along the south edge of the rupture as a function of elevation above the tank floor.

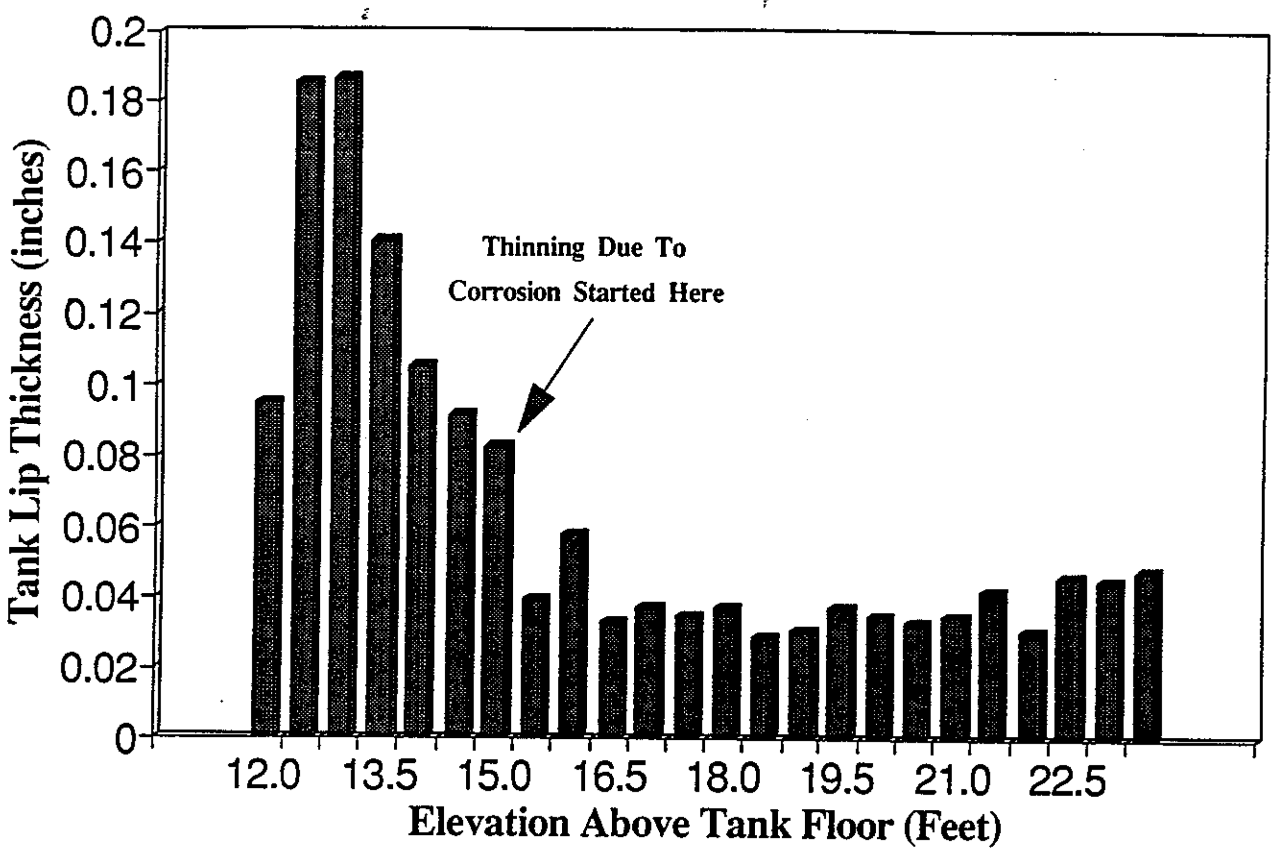

Figure 11. **Thickness of the lip along the south edges of the rupture as function of elevation above the tank floor.**