Paper No.
10043

13th Middle East Corrosion Conference & Exhibition

Evaluation of the Tank Bottom Corrosion and CP Effectiveness at a Saudi Aramco Crude Oil Tank Farm

Xianming (Andy) Yu
Saudi Arabian Oil Company
P. O. Box 4151
Ras Tanura, Saudi Arabia 31311
Fax: +966 3 6733143
Email: xianming.yu@aramco.com

ABSTRACT

This paper summarized the investigations on the severe underside corrosion on the bottom of a crude oil storage tank at a Saudi Aramco Crude Oil Tank Farm. The gaps between the bottom plates and soil were found to be the main cause of the corrosion failure because they blocked the CP current. The potential settlement of the tank foundation, the high density of the repair patches on the bottom and the tank filling/refilling cycle all could contribute to the buckling of the tank bottom, resulting in the formation of the gaps. Injection of vapor phase corrosion inhibitor into the gaps or removing the buckled plates and replacing the oily sand layer with sweet sand was recommended to mitigate the corrosion.

1. INTRODUCTION

Tank T-08 at a Saudi Aramco Crude Oil Tank Farm (COTF) was built in 1981 for storing crude oil. The tank with a nominal diameter of 360 ft (109.7 m) was constructed on oily sand pads. Impressed current cathodic protection (CP) systems were utilized to protect the underside surfaces of the 16 oil tanks and associated buried pipelines at the tank farm. The CP system included a combination of the remote deep anode beds and distributed anode beds. The anodes were LIDA® type, mixed metal oxide (MMO) anodes. The bottom underside surface of T-08 was primarily protected with four (4) remote deep anode beds surrounding the tank (Figure 1).

The last Test and Inspection (T&I) of T-08 was conducted between 1998 and 1999 and during which a 100% Magnetic Flux Leakage Test (MFLT) was carried out on the tank bottom to inspect for underside corrosion. The MFLT results indicated 83 inboard and sketch plates (nominal thickness: 6.35 mm) had corrosion features with 60% and above metal loss including eight (8) holes and 71 plates had corrosion features with 40-60% metal loss (Figure 2). A total of 338 locations on the sketch/inboard plates on the bottom of T-08 were repaired by replacement or patch-on methods as per API 653. However, no investigations were performed on the bottom corrosion.

T-08 was taken out of service in October 2008 for another T&I. The first MFLT was done by a vendor in November 2008 and only ten (10) corrosion features with 40-55% metal loss were reported on the 479 bottom plates of the tank. However, several new pinholes were found on the bottom during the grit blasting process after performing mechanical repairs.

The 2nd MFLT was performed by another vendor in July 2009. 19 sketch and inboard plates with 60% and above metal loss were reported including 39 holes. 89 sketch/inboard plates had corrosion features with 40-60% metal loss (Figure 3). Also, two deep corrosion pits with 84% metal loss were identified on the annular plates (nominal thickness: 16 mm).

Due to the severity of the bottom corrosion of T-08 and the concerns/impacts on the underground oil leaks at COTF, this evaluation was requested to find out the root causes of the severe corrosion.

2. FIELD INVESTIGATIONS

During the site visit, the following investigations were performed:

1. Visual inspection of the topside corrosion on the tank bottom.
2. Underside corrosion inspection by cutting four (4) corrosion coupons: 3 from the severely corroded area and 1 from the location with minimal corrosion for comparison purposes based on the result of the second MFLT (Figure 3). After cutting, all of the 4 cut-out samples were carefully examined for corrosion by visual inspection. The gaps between the bottom plates and soil were inspected and measured. Also, the CP potentials were taken from the 4 cut locations inside the tank including "as-found" readings and wet readings after adding water (Tables 1 and 2, Figures 4-13).

Table 1 – Four Corrosion Coupons

Coupon #	Location (Plate ID)	Distance to Tank Shell (ft)	Information from 2nd MFLT
1	14/2	14	1 hole and 2 low UT readings
2	9/2 & 10/4	22	8 holes
3	10/8	44	3 holes
4	20/15	44 (to tank sump)	No corrosion was reported

Table 2 – Measurements and Observations from the Locations of the Coupons

Coupon #	Gap Thickness (in)	"As found" plate-to-soil ON Potential (CSE_mV)	"Wet" plate-to-soil ON Potential (CSE_mV)	Soil Conditions
1	2.0	-1557	-1557	Hard soil layer with a big gap
2	2.0	-724	-1626	Very hard oily sand layer with a big gap
3	1.0	-583	-705	Very hard oily sand layer with a gap
4	0	-1582	-1582	Good contact with plate

3. A CP survey was conducted for T-08 including taking tank bottom-to-soil ON potentials from the periphery of the tank (Table 3) and checking the status of the relevant rectifiers and anodes. The results were all satisfactory. The records of the annual CP survey also indicated that the CP system for T-08 had worked normally since last T&I from 1999 to 2008.

Table 3 – Tank Bottom-to-Soil ON Potentials from the Periphery of T-08

North	East	South	West
-1446 mV	**-1514 mV**	**-1633 mV**	**-1636 mV**

4. Soil analysis: Two fresh soil samples were collected from the locations of coupon #2 and #4. The samples were sent to a chemical lab for analysis and the results are shown in Table 4.

Table 4 – Results of Soil Analysis

Soil Sample ID	Moisture Content (wt%)	Chloride Content (ppm)	Underside Corrosion on the Coupons
#2	**1.28**	**<100**	**Severe pitting (8 holes)**
#4	**0.60**	**500**	**Minor general corrosion**

3. MAJOR FINDINGS AND CONCLUSIONS

1. Visual inspection revealed that the topside corrosion on the bottom of T-08 was insignificant. The topside surface of the tank bottom was well protected by coal tar epoxy coating and 16 sacrificial anodes within and around the tank water sump.

2. The major corrosion on the tank bottom was from underside attack (pitting and corrosion lakes). Most severe corrosion was identified in the northwest quadrant of the tank bottom by MFLT (Figure 3). There were 1, 8 and 3 holes on the cut-out samples #1, #2 and #3, respectively. The holes were made by hammering on the locations with very low UT readings (< 2 mm) during the MFLT. No oil leaks were found at the cut-out locations.

3. The underside surface of the tank bottom was supposed to be protected by the existing CP systems. However, some big air gaps between the tank bottom and soil (1-2 inch thick) were identified underneath the tank bottom at the locations with severe underside corrosion (see Figures 5, 9 and 11). The gaps blocked the CP current resulting in corrosion. CP needs good contact between the soil (electrolyte) and the bottom plates, which allows the current flow through the soil back to the protected metal surfaces. Poor or no contact means inadequate or no CP. The gaps in the central areas should be closed when the tank is loaded. However, some gaps far away from the tank center are believed to be present even when the tank is full of crude oil.

4. Major underside attacks were concentrated on the areas where the bottom plates severely buckled. The buckling of the tank bottom could come from the tank filling/unloading/re-filling cycle. It may also result from the uneven distribution and high density of the repair patches on the bottom plates in certain areas (Figure 6). The buckling of the bottom plates led to the formation of the gaps.

5. During the T&I, the ring wall concrete and rebar were both found severely damaged and corroded at many locations, especially on the internal layer and this may allow more moisture/water to penetrate into the gaps and accelerate bottom underside corrosion. Furthermore, this indicated there might be some local settlement in the northwest quadrant of the tank bottom. If so, the tank settlement could also result in the buckling of the bottom plates.

6. The CP potentials measured around the tank bottom met the company requirements (between -1000 mV and -3000 mV, Table 3). The rectifiers close to T-08 and the relevant junction boxes all worked well. This means that the CP system for the tank bottom seemed acceptable. However, the distribution of the CP current on the underside surface of the tank bottom was not uniform. In some places, the oily-sand layer had hardened, creating an electrical insulation which resulted in localized inadequate cathodic protection (Table 2).

7. Sample #4 was removed from a near-central location with no reported corrosion by MFLT. The bottom plate was well contacted with the soil (no air gaps). The CP readings were satisfactory. Only minor general corrosion was identified on the underside of the cut-out sample (see Figure 12).

8. The soil under the tank bottom was not consistent. As shown in Table 4, there was a big difference between the two oily sand samples. Sample #2 contained more water but less chloride. There was 500 ppm of chloride in Sample #4, which was quite high and corrosive (usually < 50 ppm in sweet sand). However, only minor general corrosion was identified on the underside of coupon #4. This indicated that the CP worked very well at this location. Although the soil #2 contained less chloride, severe pitting had occurred on coupon #2 because the air gap blocked the CP current.

4. RECOMMENDATIONS

1 Remove the severely buckled sections of the bottom plates and replace the oily-sand layer with sweet sand to ensure good contact between the new bottom plates and the soil.

2 Replace the bottom plates where the metal loss exceeds 60% and above of the plate thickness to reduce the number of patch-on repairs. Also, replace the 8” thick oily sand layer with sweet sand at the same time.

3 Apply appropriate coating on the underside of the newly replaced plates to improve the corrosion protection.

4 Conduct a settlement survey for T-08 to confirm the possible cause which led to severe buckling of the bottom plates.

5 Inject vapor phase corrosion inhibitor (VpCI) into the gaps between the bottom plates and the soil. This is a cost effective method. VpCIs are special corrosion inhibitors (organic amines or carboxylates) which can be transported in a closed system to the site of corrosion by volatilization and diffusion from the source. VpCIs are adsorbed onto the metal surface with a thin film to mitigate corrosion.

5. ACKNOWLEDGMENT

The author would like to thank Terminal Inspection Unit of Saudi Aramco Terminal Department for their assistance and support during the field investigations and evaluations.

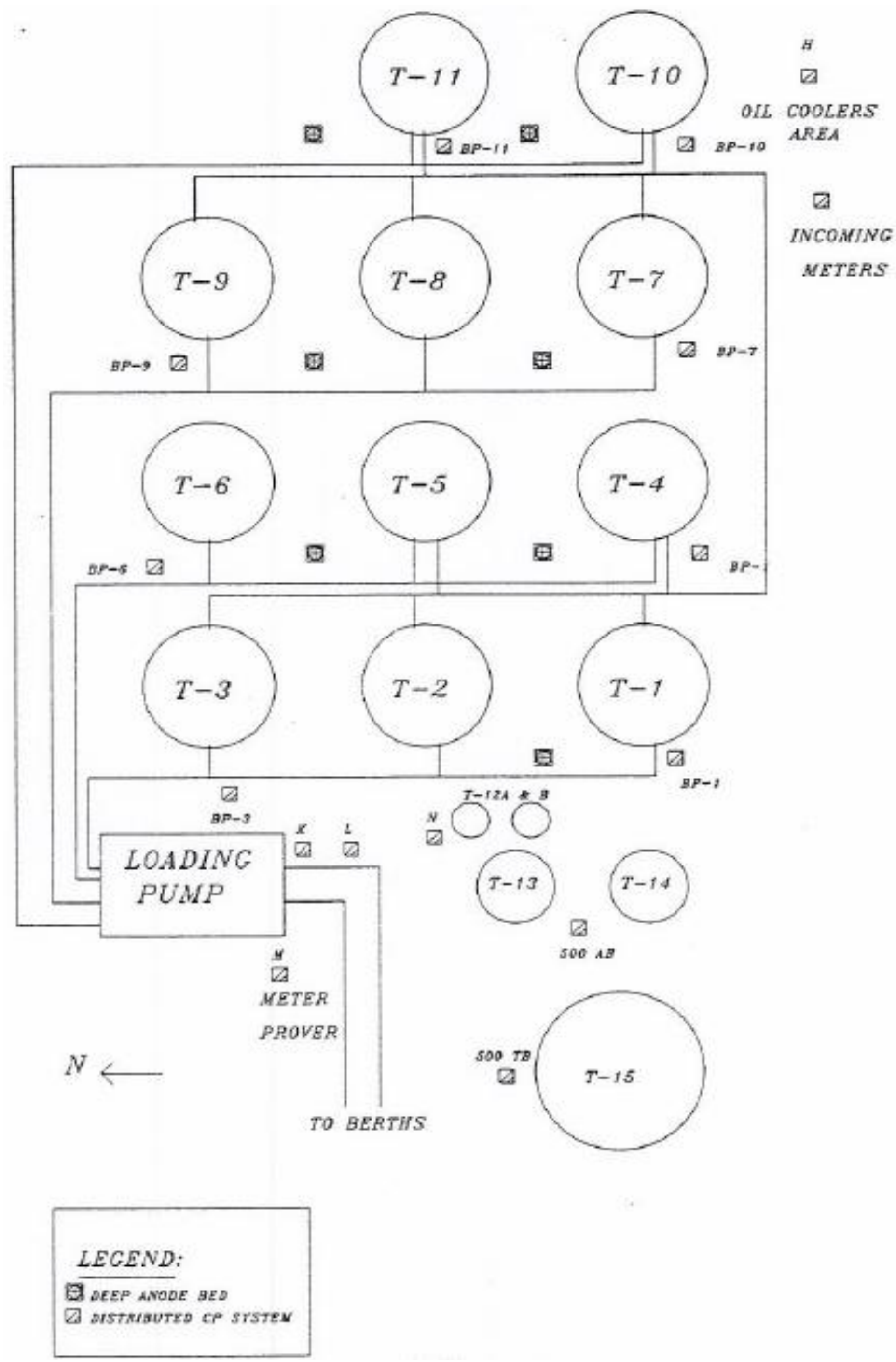

Figure 1 – Locations of the CP systems at the COTF

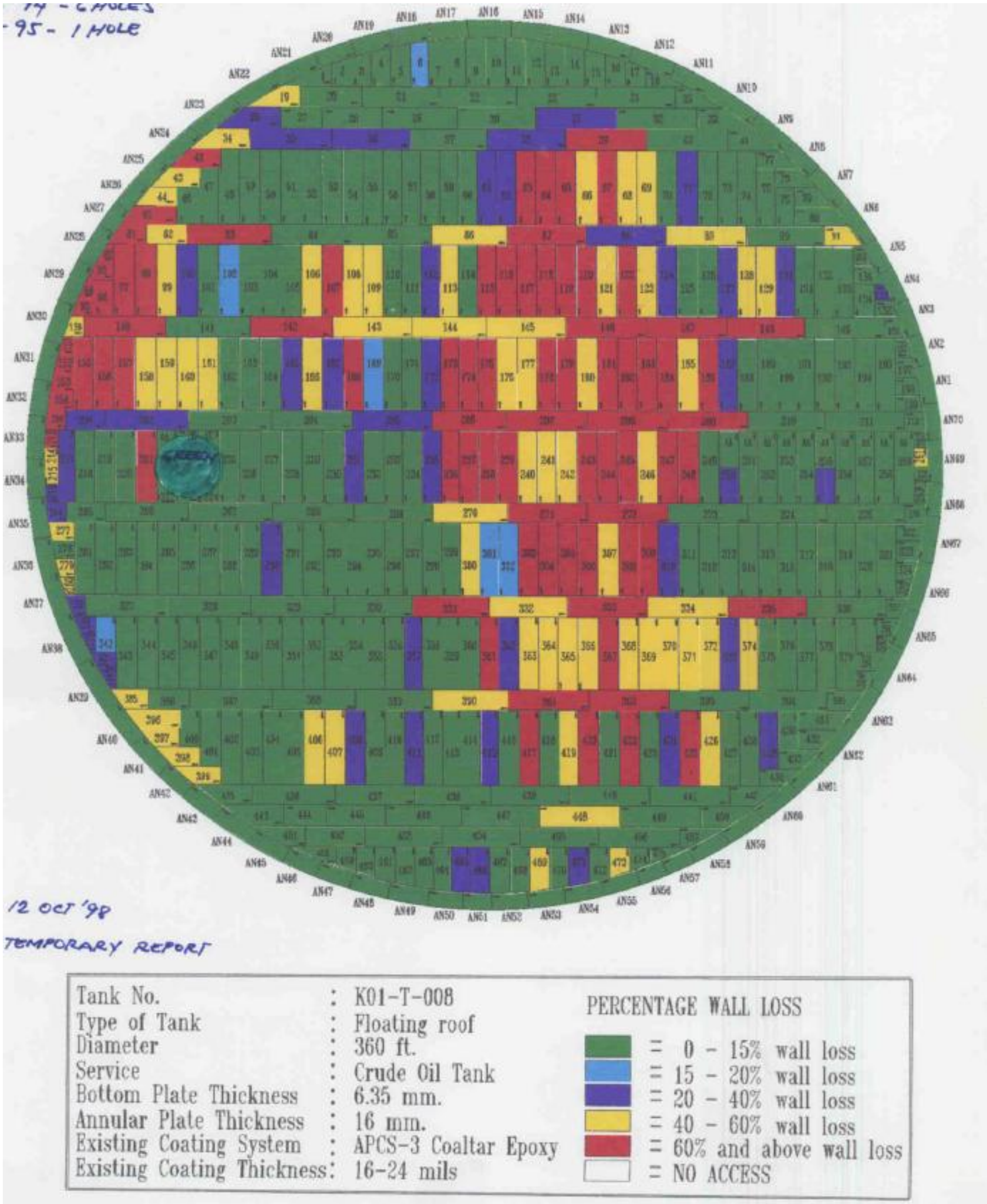

Figure 2 – MFLT Report during the T&I of 1998-1999

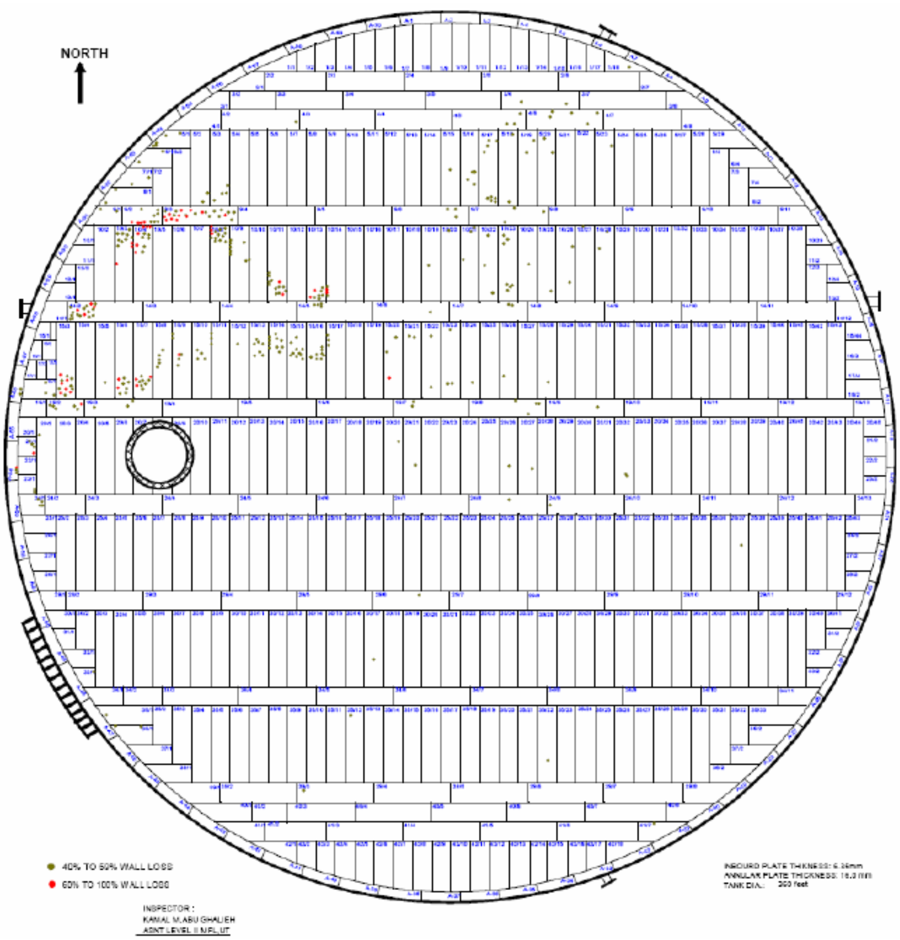

Figure 3 – MFLT Report in July 2009

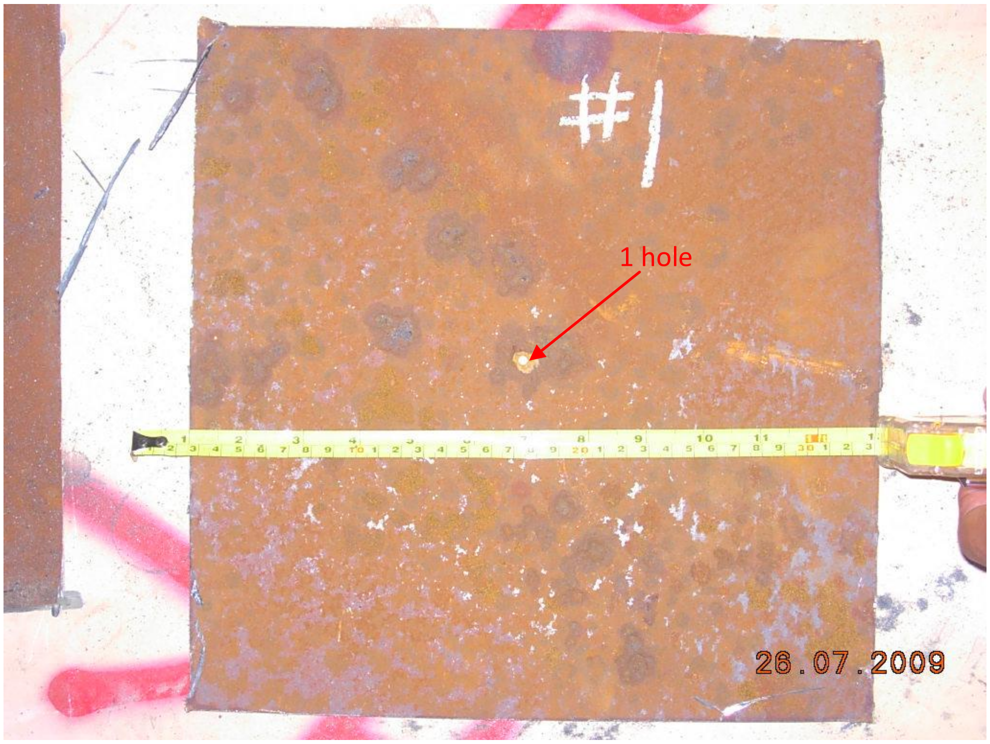

Figure 4 – Underside of Sample #1 after Cutting

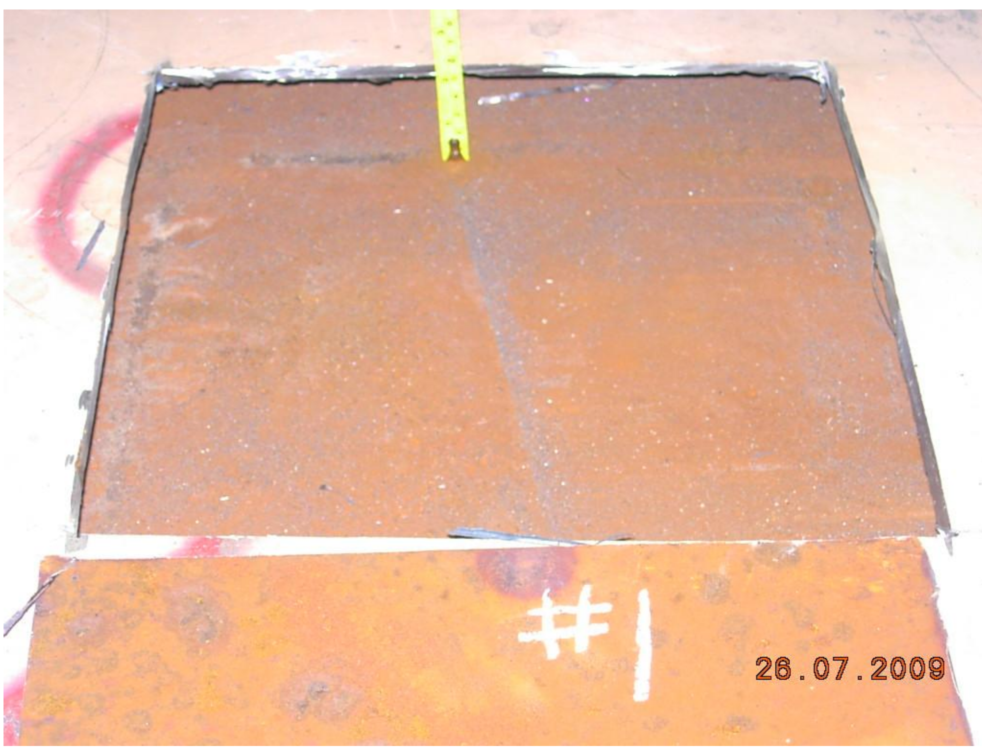

Figure 5 – 2” Thick Air Gap between Bottom Plate and Soil at the Location of Sample #1

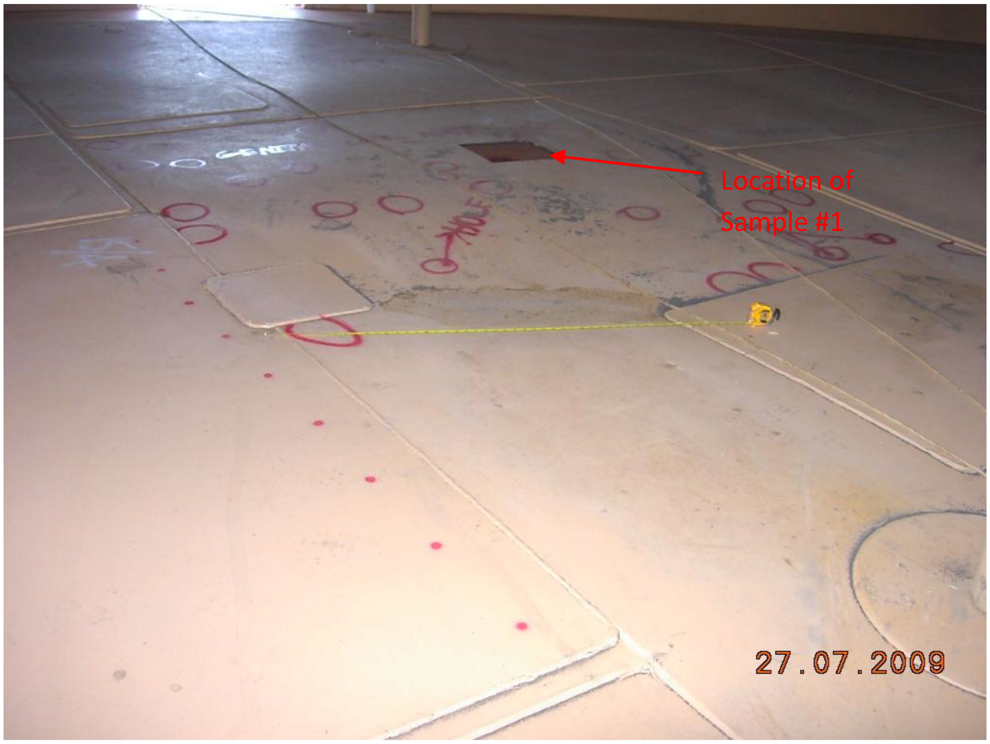

Figure 6 – Severe Buckling of Bottom Plates around Sample #1

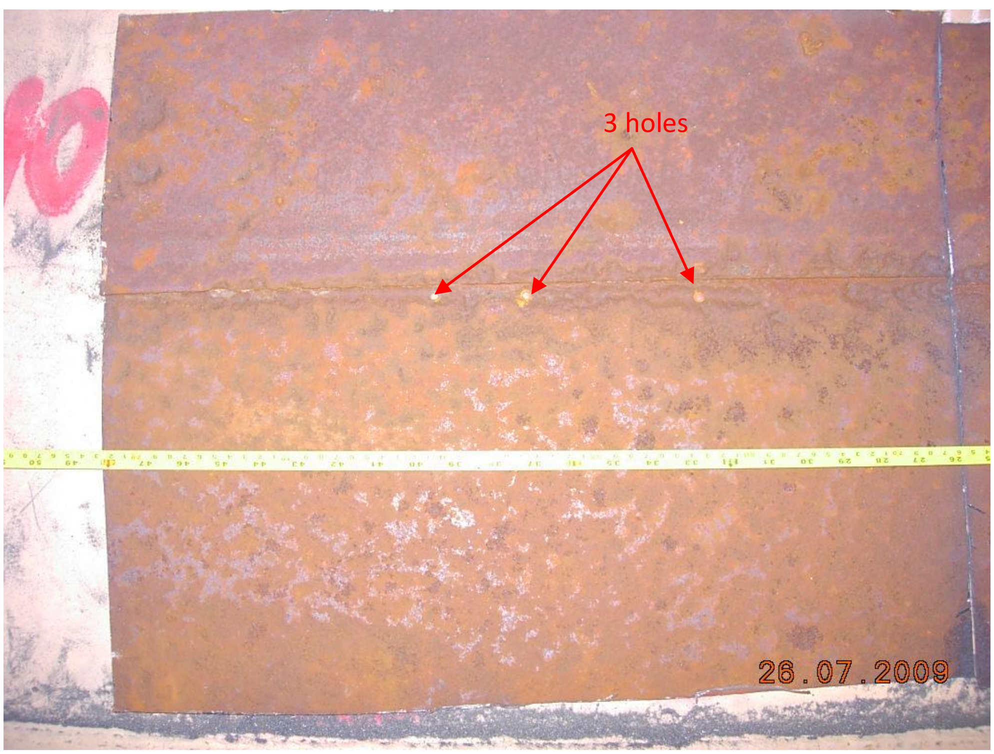

Figure 7 – Underside Corrosion of Sample #2 (1st Half) after Cutting

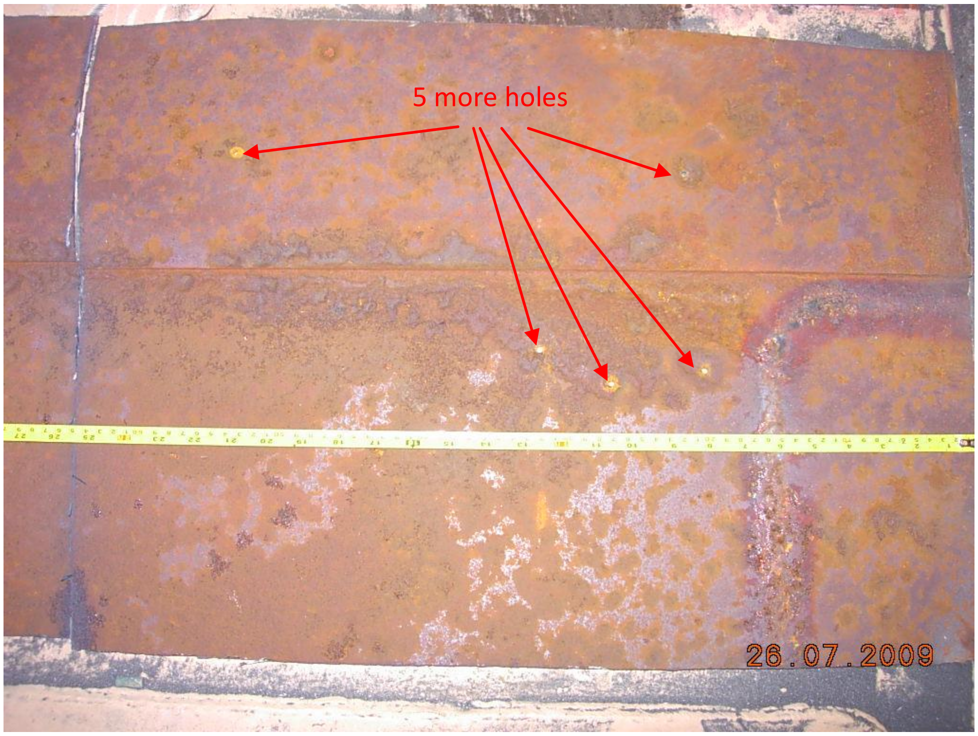

Figure 8 – Underside Corrosion of Sample #2 (2^{nd} Half) after Cutting

Figure 9 – 2" Thick Air Gap between Bottom Plate and Soil at the Location of Sample #2

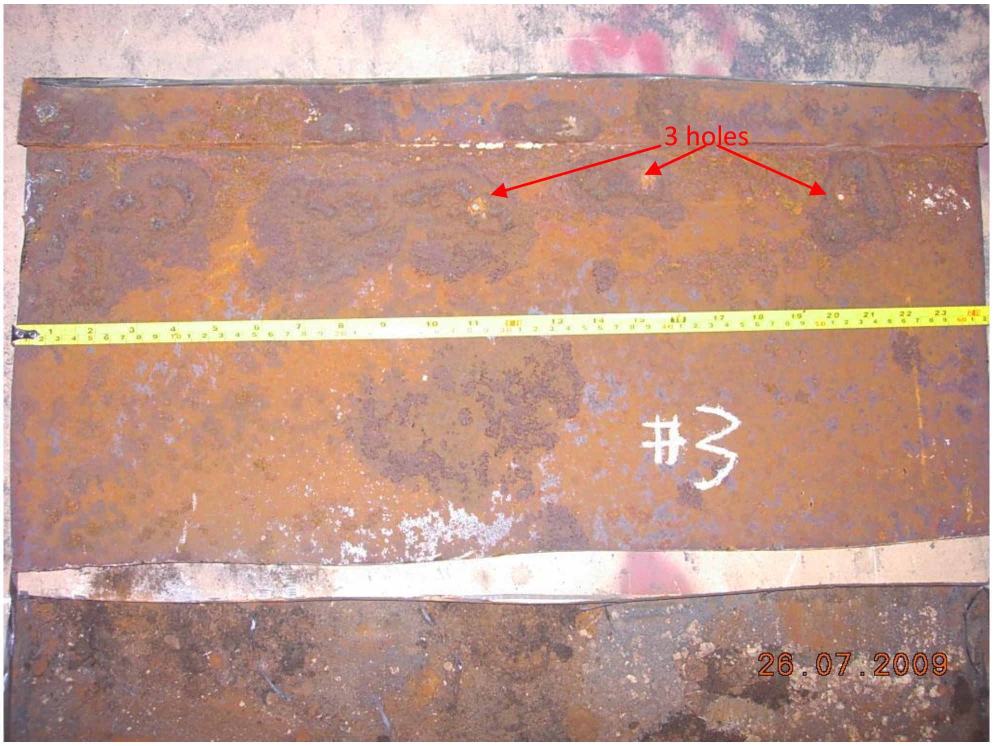

Figure 10 – Underside Corrosion of Sample #3 after Cutting

Figure 11 – 1" Thick Air Gap between Bottom Plate and Soil at the Location of Sample #3

Figure 12 – Underside Mild General Corrosion of Sample #4 after Cutting

Figure 13 – No Air Gaps between Bottom Plate and Soil at the Location of Sample #4