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Analysis of the failure of the ultrasonic scanning of bottom plate of storage tanks to detect localized corrosion

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ABSTRACT

Metallic corrosion from contact with soil is mostly due to complex environment with moisture content of the soil. Corrosion of metals in soil can vary from relatively rapid material loss to negligible effects, depending on soil environment. In the Middle East countries, the weather is mostly hot, and the temperature will cross 45 degrees during the mid-summer i.e. in August. The amount of rainfall is also very less with less than 120mm. during the peak summer, the humidity sometimes are also very high contributing to the moisture ingress. Most of the above ground storage tanks in this region are situated along the coastal areas where the moisture is humid and contains salts. Although most of the storage tanks are based on processed sand bed like bituminous sand and Asphalt fireboard, the sealing at the tank annular plate outer edges sometimes breaks and thus paves the way for ingress of moisture. Over the time this moisture is collected at the bottom between the bottom plate and the soil and starts localized corrosion.

Here in this paper we have described a situation after all NDT and Inspection tasks as per API 653 guidelines have been completed, repairs have been attended satisfactorily and the tank released for Hydrotest, a very small leakage of water from the bottom plates was observed during the Hydrotest. Seepage of water have been noticed and after that the tank was emptied to verify and surprisingly two leakage spots have been identified adjacent to the shell to bottom plate welds. To find the cause of such failure, a portion of the bottom annular plate (1 meter x 500mm) from the affected

portion including the shell to bottom weld has been cut and analyzed. The results of investigation and further possible ways to avoid such incident has been discussed in detail.

Keywords: Soil side corrosion, Ultrasonic testing, Magnetic Flux Leakage, Critical Zone.

INTRODUCTION

Corrosion of the soil side of bottom plates of above ground storage tanks is a common damage mechanism occurs in most of the above ground storage tanks. Depending on the environmental conditions in different regions of the world, the rate of corrosion, type corrosion varies. Most of the storage tank manufacturers and Owners design the bottom plate's pad in such a way that it can prevent corrosion. Bituminous sand, and other non-corrosive materials are used as a pad and cushion for the bottom plates. Cathodic protection is one of the most useful and widely used process to prevent such corrosion for a long period. In spite of such efforts, rapid corrosion of bottom plates has been observed in several locations. In the Middle East countries, the atmospheric condition is harsh and saline environment sometimes accelerate the corrosion in an unprecedented speed and sometimes leakage and loss of containment occurs before the predicted inspection schedule. [4] In several cases, the corrosion was found to be highly localized in nature and located near the edge of the shell to bottom plate fillet weld inside the tank. Here we will discuss one such unique case, where the scheduled tank shut down offered various NDT methods including Magnetic Flux leakage, ultrasonic scanning. All the NDT have been performed in accordance with approved procedures complying with the API 653 inspection code requirements. Some of the bottom plate conditions were found to be beyond acceptable limits and hence recommended for repair. After all the repair, have been performed and all repaired locations have been tested and cleared by NDT, the tank was subjected to full Hydrostatic test in accordance with API 653 requirements. Unfortunately, the tank failed during hydrostatic test and leakage was observed in at least two locations while inspecting from outside the tank periphery during the hydrostatic test. The objective of this paper is to focus on the issues of missing the critical flaws not due to the improper application or incompetency of the operator, but due to the need for use of advanced methods or change of method or technique and ways to avoid such failures.

CORROSION MECHANISM:

Corrosion of storage tank bottoms is a much-discussed phenomenon. Based on the soil types, the corrosion of underside of tanks corrode at different rates. Generally, in the middles east countries, the tank manufacturers construct storage tanks on tank pads consisting of thick layers of bituminous (oily) sand. The formula for the mixture and the thickness of the oily sand varies throughout the region. Sand contains varying levels of chlorides and moisture. It is observed that many corrosion issues are likely related to the inability of cathodic protection (CP) current to flow through the oily sand and effectively distribute throughout the tank floor plate surface. The oily sand presents a high resistance barrier to flow of CP current to the tank floor. Numerous air gaps between the oily sand surface and the tank floor surfaces also negate CP effectiveness. The pH value has a significant effect on water corrosivity through hydrogen ion reaction. As water ingress between the bottom plate and the foundation it is possible that differential oxygen concentration may have been regenerated thus promoting the underside corrosion of the failed ASTs. The low concentration of dissolved oxygen (3.2 mg/l) in the water sample also suggests the possibility of anaerobic corrosion. Chloride concentration promotes localized corrosion. The high concentration of chloride ion maybe due to seawater evaporation. The physico-chemical characteristics of the water sample that ingress between the bottom tank plate and its foundation may be the primary reason of such localized form of corrosion. [3]

INSPECTION STEPS & LEAKAGE OF BOTTOM PLATES:

As a routine internal inspection process (out of service), the NDT methods recommended by API 653 [2] and Owner project specification has been followed strictly as per the approved procedures. The following steps have been adopted:

1. 100% visual inspection of entire bottom plates including annular plates and shell to bottom welds.
2. 100% Magnetic Flux leakage (MFL) examination of entire bottom plates excluding the 300 mm band from shell to bottom welds because MFL equipment cannot scan this zone.
3. 100% manual UT scanning of the above 300 mm band (not accessible by MFL).
4. Leak testing (Vacuum box) of all bottom plate lap welds.
5. Wet fluorescent magnetic particle testing of shell to bottom welds.

After all the above tests have been completed and the defective locations indicated by all or any of the testing methods have been rectified, the tank was subjected to Hydrostatic test and the leakage of tank bottom plates noticed during the Hydrotest. The tank was subsequently emptied and internal inspection was carried out all around the inside peripheral zone adjacent to shell to bottom weld (critical zone). The peripheral zone was found to be fine except in two adjacent locations near the edge of the shell to bottom weld, where some rust spots were observed. Further mechanical chipping in that area, revealed some shallow corrosion pits but no evidence of through hole could be noticed. Visual inspection and further ultrasonic scanning (B scan) have been performed to determine the nature of leakage but did not succeed to find the through hole.

SUBSEQUENT ACTIONS AND ADVANCED NDT RESULTS: [1]

Since the cause of leakage was yet to be determined and leakage path through corrosion could not be established Ultrasonic testing, the Owner have decided to cut out two such affected portions of the bottom plate and send for investigation. Accordingly, two portions of bottom plates (annular plates) have been cut each of approximately 500mm length and one such plate send to us for further analysis. Localized corrosion pits were observed at the two ends of the cut plate and those areas have been marked with ‘SPOT-1’ and ‘SPOT-2’ to correlate the results of advanced NDT methods (radiography-digitized films and Ultrasonic Phased Arrays) to be applied to the plate to investigate the failure by leakage and determine the corrosion path. Refer to figure-1 and 2.

Shell to bottom weld; Shell removed.

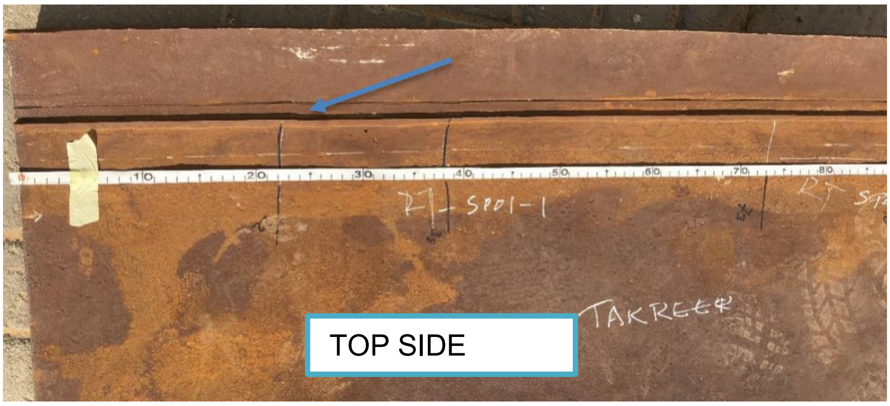

Figure-1: Bottom plate Top side. The general surface condition is mostly satisfactory with the exception a few localized corrosion pits at two locations.

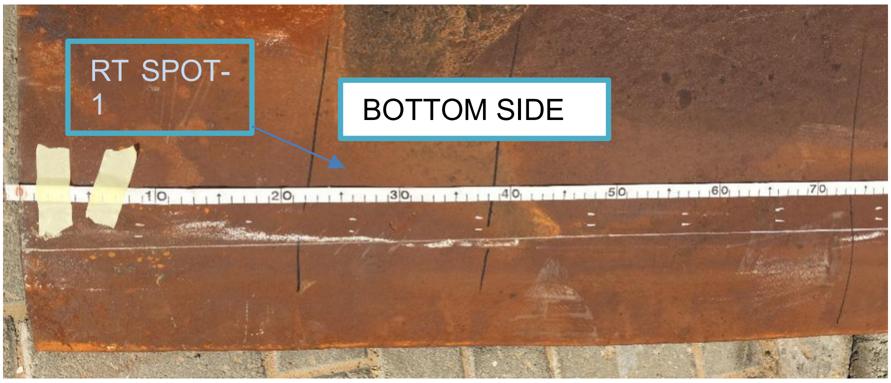

Figure-2: Bottom plate bottom side. The general surface condition is mostly satisfactory with the exception a few localized corrosion pits at two locations.

Figure-3 and 4 below are a correlation between top and bottom plate corrosion indications for Spot-1. Similarly figures 5 and 6 are the same correlations between top and bottom portions of spot-2. Although the pits on the top and bottom sides are almost located nearby but there is no through hole and hence the connection between the top and bottom indications could not be determined by visual examination. The selected spots were then subjected to Radiography. Figures 7 and 8 are Radiographs of Spot-1 and spot-2 in digitized formats. Form figures 7 and 8, it is understood that there ate extensions of visible pits inside the plate in oblique directions (not vertically through thickness direction) and it is clear that there are links between top and bottom pits in some complicated paths passing through the plate. It is not clear that the plates were having previously existing inclusions or air gaps which may accelerate the corrosion progression and thereby leakage of containment. No previous evidence of such flaws could be collected.

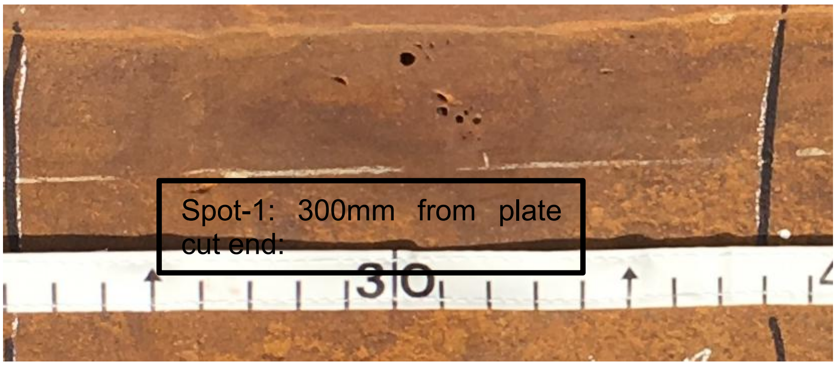

Figure-3 (SPOT-1): Visual photograph show highly localized pin-hole type corrosion pits @ 300mm from end spread over a length of 30mm. photograph from face A (Bottom plate top side).

Figure-4 (SPOT-1): Visual photograph show localized corrosion pits having sharp edges @ 300mm from end spread over a length of 25mm. photograph from face B (Bottom plate bottom side).

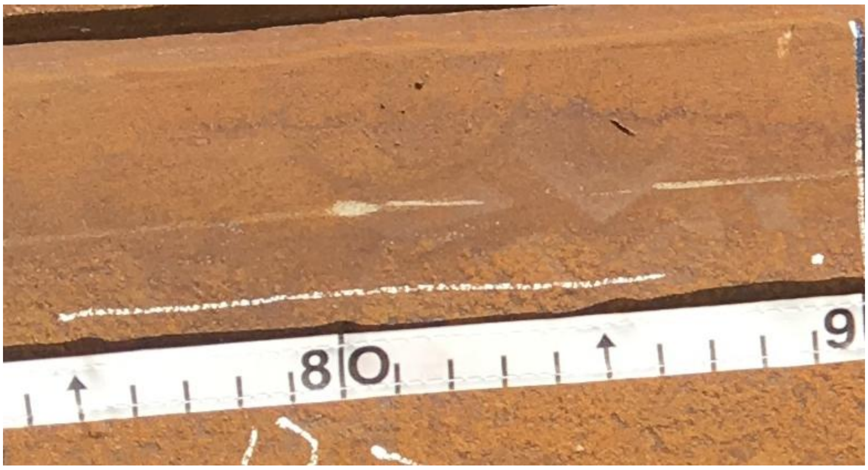

Figure-5 (SPOT-2): Visual photograph show scattered highly localized pin-hole type corrosion pits @ 800mm from end spread over a length of 50mm. photograph from face A (Bottom plate top side). A sharp edged corrosion (dent mark) also noticed nearby.

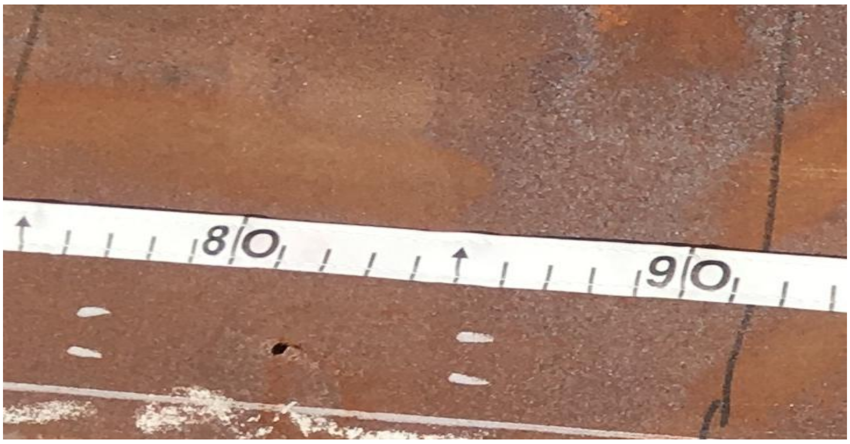

Figure-6 (SPOT-2): Visual photograph show a highly localized pin-hole type corrosion pit @ 810mm from end. Photograph from face B (Bottom plate bottom side).

Figure-7 (SPOT-1): Digitized radiograph of Spot-1 show extended corrosion inside the plate thickness @ 300mm from end.

Figure-8 (SPOT-2): Digitized radiograph of Spot-2 show extended corrosion inside the plate thickness @ 800mm from end.

Ultrasonic Phased Array angle bean examination have been performed at those locations and some snap shots and results are given in figures 9 to 10 below for spot-1 and in figure 11 and 12 for spot-2. Phased Array results also showed indications under the surface and extended to some extent but links between the flaws are not quite evidence in Phased Array results.

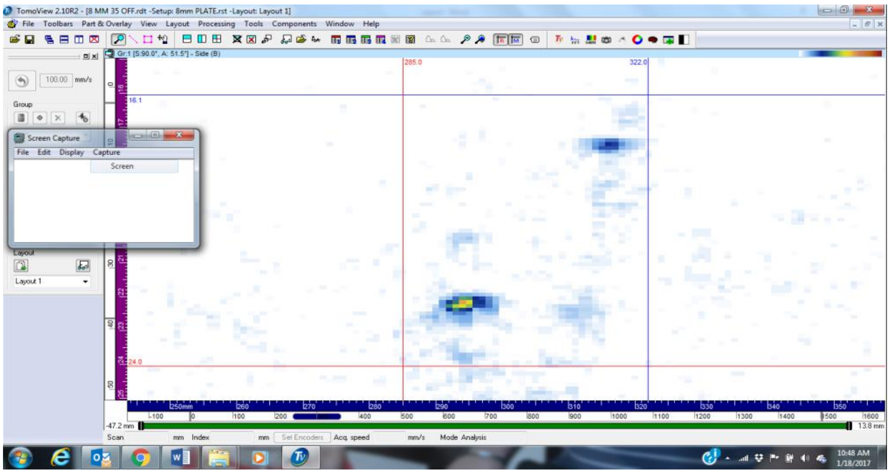

Figure-9 (SPOT-1): B scan (Side sectional view) of UT Phased Array shows rounded type indications.

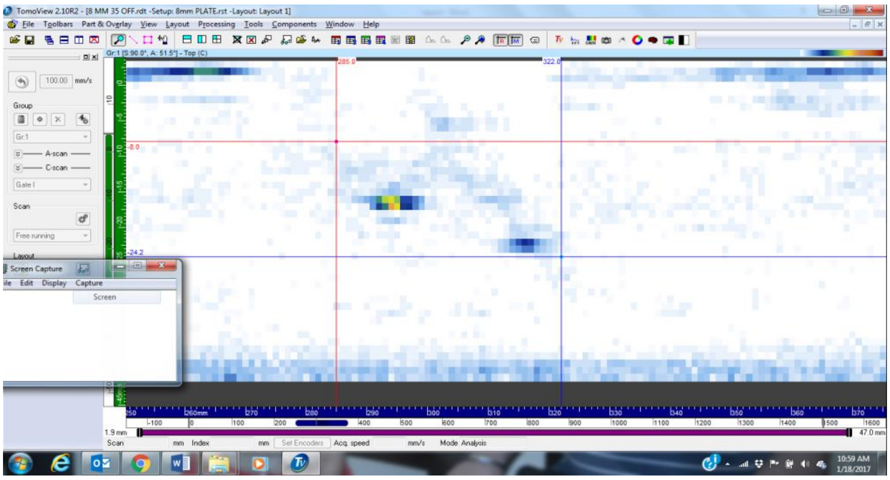

Figure-10 (SPOT-1): C scan (Top view) of UT Phased Array shows rounded type indications.

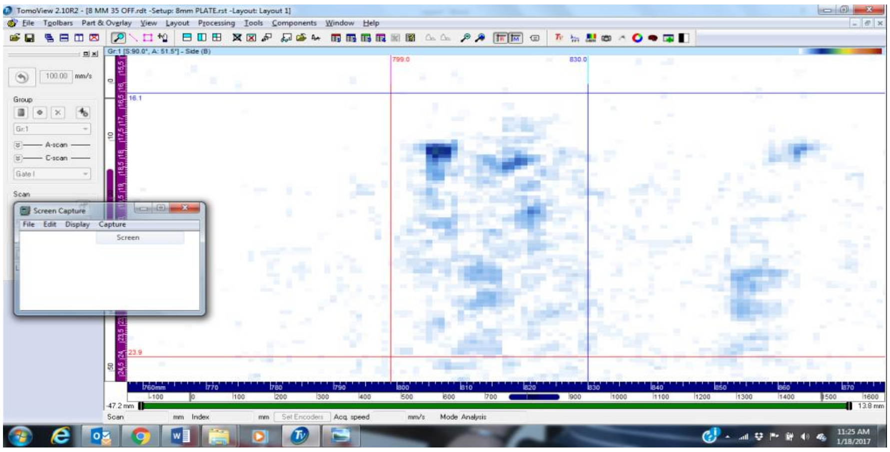

Figure-11 (SPOT-2): B scan (Side sectional view) of UT Phased Array shows rounded type scattered indications confined within 800 – 830mm from end. The sectional view shows indications starting from the top side (1mm from top surface) and several other indications extended to the bottom. No clear link between the flaws is evident.

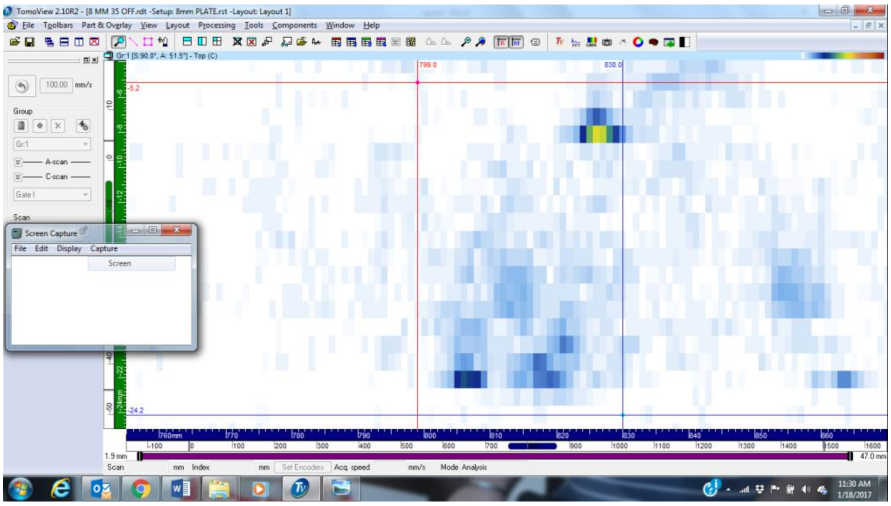

Figure-12 (SPOT-2): C scan (Top view) of UT Phased Array shows rounded type indications. The pattern of major indications and associated indications almost matches with the radiography view and shows there may be interconnections between the flaws. The indications are almost 5-6mm offset from the shell to bottom plate welds.

ANALYSIS OF NDT RESULTS:

1. Visual inspection only shows there are isolated and scattered pits at some locations on the top side of the plate stated above. Pits are also found at the bottom side almost at the same locations but interconnections are not verified.

2. Radiography of two selected spots showed visually identified pits along with other internal flaws interconnected possibly but not evidenced by visual inspection.

3. Phased array testing of those areas also shows several internal indications similar to those shown in radiography which were not found by visual inspection.

4. Magnetic particle test did not reveal any such indications.

5. The type of corrosion is highly localized, not usually seen in the tank bottom plate.

6. No general corrosion of the bottom plates was observed.

7. The corrosion has been extended through the plate very selectively and possibly exposed to the other side.

8. It is not sure whether the corrosion have started from bottom or top side. No. of pits are more on the top (product) side than from the bottom side (soil side) which may be indicative of corrosion starting from product side.
9. There is possibility of some internal inclusion already present in the plate during manufacture, which may contribute to the preferred path of selective corrosion started from the surface. Inclusions of such small sizes are generally acceptable as per plate ultrasonic test specifications, but those apparent innocuous inclusions may contribute to the selective corrosion.

10. The above points are assumptions only, source of corrosion and initiation or propagation path cannot be verified unless a thorough corrosion and metallurgical study have been carried out.

NON-DESTRUCTIVE TESTING LIMITATIONS:

1. Generally as per recommendations of API 653, for annular plates, ultrasonic conventional scanning is supposed to be sufficient to detect soil side general corrosion.

2. For the present case, it is noticed that the above flaws could not be detected by conventions ultrasonic technique using normal beam probe. The reasons for such limitations are:
   2.1 The flaw type as evidenced by the radiography and visual photographs are very localized and of very small shapes which may hide from the ultrasonic beam and may get undetected.
   2.2 The internal extension of the flaws (corrosion paths) may have a very uneven profile rendering it very difficult to be detected. Since the plate thickness is small (10mm), using a transmitter receiver probe to avoid dead zone effect may have other effect of flaw being out side of the focal zone of the probe which may effectively reduce the indication amplitude to a negligible level.
   2.3 The profile of the flaw is so uneven that a realistic echo pattern cannot generated and hence the ultrasonic test has missed the flaw location.

3. With regard to magnetic particle testing, the reason for not detecting the flaws, is probably the shape and size of the flaws. Magnetic particle testing is very sensitive to linear type indications. It can detect very fine linear indications (of few microns cracks) but is comparatively insensitive to rounded indications. Moreover, it can detect only flaws either on the surface or very near to the surface. For the present case, the indications are rounded and most of them are visible by visual inspection, so use of magnetic particle inspection did not provide any extra value to the overall detection of flaws in this case.

CONCLUSIONS:

1. Several NDT methods are under considerations to detect soil side corrosion in the critical zones and specifically below the shell to annular plate weld, because this zone is typically get undetected by most of the NDT techniques and prone to soil side corrosion.

2. Out of the advanced NDT methods, short range ultrasonic, acoustic emission, phased array and eddy current testing have been tried but no method can still provide a fast and reliable method of detecting such flaws in the critical area.

3. Based on the criticality of the damage mechanism and the type of damage occurred in the present case, we understand that out of all the techniques, a B scan ultrasonic technique should be the most suitable technique to detect corrosion in the critical zone (excluding the shell to bottom weld underside area).
4. Although the earlier scan was a b scan only, but it was manual method with no recording facility. A recordable B scan will provide data which can be viewed later to find any scanning related discrepancy.

5. The reason for the above conclusion is that by observing the flaw type in radiography, we assume that although there was no signal indication, there might be a back wall drop in the ultrasonic signal which may be overlooked by the operator. Because back wall drop sometimes indicate presence of flaw, we need to be careful when scanning in the critical zone near the shell to bottom weld.

6. Sometimes the drop of back wall may be caused by uneven surfaces or unparallel front and back wall surface or a severe corrosion on the soil side. In such cases a rescanning is required with surface finished properly to enable proper coupling between the probe and surface and carefully observing the echo pattern of the back wall.

7. A vacuum box leak test with corner adapter is also recommend to supplement the above testing to ensure that corrosion leaks do not exist adjacent to the shell to bottom welds.

REFERENCES:

[1]: Intertek failure investigation report for tank bottom failure.
[2]: API 653: Tank inspection Code

[3]: Mitigation of Soil-Side Corrosion on Storage Tank Bottoms in the Absence or Deficient of CP System: NACE Paper MECCFEB16-7995
[4]:Underside Corrosion of above Ground Storage Tanks (ASTs): RIM-RUKEH, OKOKOYO, P. A.