TECHNIQUES & METHODOLOGIES FOR TANK BOTTOM PLATE REPLACEMENT OF FLOATING ROOF CRUDE OIL STORAGE TANKS – A CASE STUDY IN OIL INDIA LIMITED

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Abstract:
The crude oil produced by the exploration and production (E&P) companies are stored in tanks of various capacities at tank farms for onward dispatch to refineries. Such crude oil storage tanks may be of fixed roof or floating roof types, designed and constructed in accordance with API 650 standard. These crude oil storage tanks (steel- butt welded) are subjected to reversible stress induced by the inherent continuous loading and unloading of crude oil while in service which develops voids underneath of the tank. This void causes corrosion beneath the tank bottom plates while in service. Any development of leak to the tank bottom plate renders the tank out of service and becomes a serious safety hazard.

As the whole shell of the crude oil storage tank is welded to the tank bottom plate, development of leaks on the tank bottom plate leaves the maintenance personnel with only two options:

(a) To do away with the leaky tank and erect a new one.
(b) To replace / repair the tank bottom plate.

It is easily comprehensible that the option to erect a new replacement tank will never be cost effective. Moreover if NDT to the tank concerned suggests that the shell portion of the tank is free of corrosion, then the repair / replacement of the tank bottom plate will be the best optimal solution.

This paper tries to discuss and share the techniques, methodologies and subsequent learnings in a unique “first” tank bottom plate replacement operation carried out in a 5000 KL capacity floating roof crude oil storage tank at the Central Tank Farm at Moran Oil Field of Oil India Limited. The job involved separation of the shell from the tank bottom plate, lifting the shell of the tank for replacement of the tank bottom plate and final reassembling and testing. A comprehensive study of the crude oil storage tank bottom plate replacement methodology, which industries might adopt as a maintenance technique is the basic endeavor of this paper. Apart from the techniques involved in the process, the authors also try to focus on the cost effectiveness of the technique.

Key Words: Crude Oil Storage Tanks, Tank Bottom Plate, API standards, Reversible Stress, Corrosion.

1.0 Introduction:
Incorporated in February 18, 1959 and nationalized in 1981, Oil India Limited (OIL) is now a “Navaratna” PSU engaged in exploration and production of Crude Oil and Natural Gas in North Eastern Region of India, Rajasthan, Ganga Valley, Mahanadi, Mahanadi Offshore, Krishna Godavari Deepwater, etc as well as in various overseas projects in Venezuela, Libya, Gabon, Iran, Nigeria, Timor East and Sudan. Oil India Limited is also engaged in transportation of crude oil and production of LPG. OIL also provides exploration and production related services and holds 26% equity in Numaligarh Refinery Limited, Assam.

The Crude oil collected from various fields of OIL is stored in storage tanks for onward transportation of Refineries. Such storage tanks may be of two types: Fixed Roof tanks & Floating Roof tanks. OIL has a Central tank farm at Moran, Assam where floating roof type tanks used for storage of crude oil. These tanks have been commissioned in he year 1969 and in continuous service since then. The 5000 KL capacity Tank No 10 in this tank farm developed leaks through the bottom plates during July, 2004 and hence the whole tank was out of service.
An NDT (*Ultrasonic Thickness Analysis with Handheld device*) analysis of the tank was carried out and the results shown, that the thickness of the Bottom plate in the annular zone, 1400 mm radially from inside shell is 3 mm – 5 mm and the rest portion is 8 mm- 10 mm range (Fig -1).

Moreover the following observations were made during the Tank NDT:

a) Hole in three places are visible in bottom plate towards the shell of the tank.
b) Plate thickness observed through the holes is in the range of 2 mm to 3mm.
c) Cavities in the sand pad / crushed stone (tank foundation inside tank concrete ring wall) to the tune of 150 mm depth exists in the hole areas.
d) On the annular ring near the tank shell there is deformity (sharp bend - Fig -2) in the bottom plate and is 1200 mm (approx.) wide from the shell inside. The bend exists throughout the tank periphery.
e) The shell plates of the tank were considerably free from corrosions.
f) As the whole shell of the crude oil storage tank is welded to the tank bottom plate, development of leaks on the tank bottom plate leaves the maintenance personnel with only two options:

   (a) To do away with the leaky tank and erect a new one.
   (b) To replace / repair the tank bottom plate.

Since there was no major corrosion to the tank shell observed during the NDT, it was decided to replace the annular ring with new plates after removal of the damaged one and filling up the voids of the sand / crushed stone foundation by suitable means.
2.0 Causative Analysis:
The NDT investigation (Ultra Sonic Thickness measurement) of the Tank No 10 in Moran Tank Farm of OIL revealed that the extent of corrosion is severe near the tank’s critical zone \( \text{[the portion of the tank bottom or the annular plate within 3 inch (= 76 mm) of the inside edge of the tank shell measured radially inwards]} \). It could be established that the reason of the tank bottom plate failure (sever corrosion) was due to the formation of voids on the sand pad / crushed stone foundation inside the tank ring wall near the tank’s critical zone and subsequent oxidation of the bottom plate. The rate of corrosion was calculated to be 8.44 mils/ year in the minimum thickness zone. Also a gradual reduction in the thickness from centre to wards the circumference was observed. The annular ring (critical zone) of the tank was also observed to have developed a sharp bend from the shell inside. The plausible causes of the above could be summarized as follows:

a) Inherent dynamic loading and unloading of the tank resulting in reversible stresses on the tank bottom plate.

b) Since the concrete ring wall of the tank extends up to about 6 inch (150 mm) inside the tank shell, the bottom (annular) plate is subjected to severe reversible stress near the tank’s critical zone.

c) The reversible stress induced by the inherent loading and unloading of crude oil inside the tank directly acts on the bottom plate of the tank. The bottom plate in turn rests on a sand /crushed stone foundation inside the tank ring wall. Since the foundation of the tank (sand / crushed stone) is not elastic, the elastic movement of the bottom plate induced by the reversible stress causes formation of voids on the sand / crushed stone foundation. As the bottom (annular) plate of the tank is subjected to severe stresses near the critical zone as explained in point (b) above, formation of voids in this region is much more profound. Such voids developed beneath the bottom (annular) plates in turn causes oxidation of the underside of the bottom plates which results in corrosion.

d) Since the development of the voids on the critical zone of the tank is much more profound, the support / foundation of the bottom (annular) plate on the tank’s critical zone gets affected once the voids are developed. And as a result of the reversible stresses continuing
to act on the bottom plate on a depleted foundation the bottom plate tends to develop deformity (bends) near the critical zone of the tank throughout the tank periphery.

3.0 Literature Survey:
For formulating the techniques & methodologies for replacement of the bottom (annular) plate, a detailed study and analysis of the relevant codes and standards were carried out and from application point of view the same were categorized as below,

3.1.0 Design Codes:
(a) IS: 803, Indian Standard for design, fabrication and erection of mild steel cylindrical welded storage tanks or API 650 welded steel tanks for oil storage. (Items not covered under IS : 803 as per API 650)
(b) API 653, Tank inspection, repair, alteration and reconstruction, OISD Std. 129 for inspection of storage tanks and IS: 10987 India Standard for code of practice for design, fabrication, testing and installation of underground / above ground horizontal cylindrical storage tanks for petroleum products.
(c) ASME boiler and pressure vessel code Section VIII, Div 1 / Section IX / IS 2825.

3.1.1 Material Codes:
(a) Plate material: IS 2062 Gr A
(b) Structural, stairway, platform, toe: IS2062 Gr A
(c) Supports: 2062 Gr A
(d) Nozzle Flanges: ASTM A 105
(e) Nozzle necks: API 5L Gr A Sch 40 / IS 1978/SA 53
(f) Fasteners for structural and holding down bolts: IS 1363
(g) Fasteners for nozzles, manholes: IS 1376 / ASTM A 193 B7 , ASTM A 193 2H
(h) Handrails: IS 1239
(i) Steel Wire Ropes for Haulage Purposes : IS 1856 : 2005

3.1.2 Wind Speeds: IS : 875 (Part 3) - 1987
3.1.3 Welding Electrodes: Low hydrogen, high cellulose / rutile type welding electrode conforming to AWS SFA 5.1 classifications.
3.1.4 Welding procedure qualification and qualification of welders shall be carried out as per ASME Section IX or IS 817.
3.1.5 Calibration of the tank after repairs shall be done as per IS 2008 & IS 2009.
3.1.6 Inspection: ASNT / ISNT Level II Certified qualified personnel.
3.1.7 Statutory Standards:
The relevant statutory Oil Industry Safety Directorate (OISD) standards / guidelines are as appended below,

a) OISD-STD-105: Work Permit System
b) OISD-GDN-206: Guidelines on Safety Management System in Petroleum Industry
c) OISD-GDN-207: Contractor Safety
d) OISD-RP-108: Recommended Practices on Oil Storage and handling
e) OISD-GDN-115: Guidelines on Fire Fighting Equipment and Appliances in Petroleum Industry
f) OISD-STD-116: Fire Protection facilities for Petroleum Refineries and Oil/Gas Processing Plants
g) OISD-STD-117: Fire Protection Facilities for Petroleum Depots, Terminals, Pipeline Installations and Lube Oil Installations
h) OISD-STD-129: Inspection of storage tanks
i) OISD-RP-146: Preservation of idle electrical equipment
k) OISD-STD-155 (Part II): Personal Protective Equipment, Part II Respiratory Equipment
l) OISD-STD-164: Fire Proofing in Oil & Gas Industry
m) OISD-STD-170: Inspection, Maintenance, Repairs and Rehabilitation of foundations and structures
n) OISD-STD-189: Standard On Fire Fighting Equipment For Drilling Rigs, Work Over Rigs And Production Installations
4.0 Design of Methodology and Sequence of operation for Tank Bottom Plate replacement:

4.1.0 Identification of Sequence of operation:
For achieving the final result of replacement of the bottom plate of the tank no 10 at Moran CTF of OIL, the following sequence of operations were finalized after detailed analysis:

a) Formulation Safe Operating / working guide lines
b) Cleaning of the entrapped oil from the tank / tank foundation
c) Removal of Peripheral plates / Shell and Lifting of the whole shell
d) Rectification of the sand pad
e) Fabrication and erection of the annular plates
f) Tank testing and Calibration

The above steps are deliberated below in details:

4.1.1 Formulation Safe Operating / working guide lines: Since the tank concerned was inside an operating tank farm surrounded by other tanks, special safety measures had to be formulated and adopted. Broadly the safety philosophy was guided by relevant Oil Industry Safety Directorate (OISD) Standards. The details of the Safe Operating Procedure (SOP)/ working guide lines are as appended below,

a) All mandatory work permits to be obtained before commencing work.
b) To ensure that the dead volume of the oil / sludge in the tank is less than equal to 0.95 mtrs. (As above this level the volume can be transferred to other tanks, thus minimizing loss.)
c) Use of necessary PPE is mandatory.
d) To have a personnel management programme in place at the work site consisting of duty registers, job progress diaries etc.
e) To isolate the inlet and out let lines of the tank, so that no static charge can flow and to blind all open ends and provide necessary signages.
f) The electrical connection to the agitator must be isolated.
g) Gas testing of the entire surrounding of the tank.
h) To have “A” class fire protection as stand by.
i) Erection of a 10 M high barricade walls (CGI Sheets) around the tank to prevent any flammable vapor from the operating tank nearby.
j) Digging of a pit atleast 30 mts away from the tank for pumping / dumping of the semi fluid / solid sludge from the tank.
k) Both ends of the steam coils are to be isolated and blinded.
l) The man holes are to be opened by use of non sparking tools and adequate precautions to be taken against the sudden gush of sludge through the man holes.
m) The weather and tube seal are to be dismantled for easy escape of vapor and also to allow light inside the tank.
n) Air purging of the tank to be done to bring down the flammable vapor level (LEL < 20%).
o) Wooden scrappers are to be used for scrapping of the reminder sludge after pumping.
p) No person to be allowed to enter the tank unless the tank is first “gas tested" and found the level within allowable limits.
q) When it is necessary to enter the tank if it is not “gas free” or the oxygen level is less than 19%, persons are required to be provided with breathing apparatus (the person must be well trained in use of the breathing apparatus).
r) While working inside the tank, persons must be provided with safety belts and life lines. The free ends of the life lines should be held by a person outside the tank, who must be well versed with the distress signals, which the person working inside the tank might transmit.
s) The personnel working inside the tank must be replaced, at an interval of 30 minutes.
t) During time of work, qualified paramedics team may be at work site as stand by.
u) Adequate number of DGMS approved FLP self contained hand lamps should be provided for use inside the tanks.
v) Adequate number of approved type man coolers to be provided inside the tank.
w) Once all the sludge is removed from the tank, the tank should be thoroughly flushed, so that no trace of crude oil is present and whole tank is “gas free”.

4.1.2 Cleaning of the entrapped oil from the tank / tank foundation:
   a) Drilling of 13 numbers (80 MM NB) of holes in the annular portion.
   b) Checking of the oil leakages in the tank foundation from outside. Breaking of the ring wall of the tank outside the holes if required.
   c) Through the drilled 80 MM NB holes, steam to be injected to disperse the entrapped gas and also to bring down the concentration of the crude oil.
   d) The steam flushing need to be continued for long time, intermittently in each hole. Multiple hoses shall be required.

4.1.3 Removal of Peripheral plates / Shell and Lifting of the whole shell
   a) Peripheral portion of the tank bottom need to be cut off, because the thickness has gone down beyond acceptable limit (i.e. 6 MM).
   b) Before gas cutting, water from the fire ring shall be injected through the holes made earlier after steam flushing.
   c) After steam and water flushing DCP fire extinguisher to be injected inside the tank sand / crushed stone pad to provide a film for arresting flame propagation.
   d) Welding of jack brackets (total 13 nos) as per onto the shell of the tank. (Shell weight = 65 Ton, Mechanical Jacks of 5 Ton Capacity to be used)
   e) Annular portion shall be cut from the bottom portion by gas cutting, radial width 1400 approx. from inside the shell. Cutting to be done in segments.
   f) Gas cutting of the shell to bottom weld joint.
   g) Meteorological Data to be collected to ensure that no high velocity wind / storm is ensuing to prevent toppling of the tank due to wind pressure. (details discussed under para 6 below)
   h) Lifting of the shell by mechanical jacking. The jacks to be placed outside the ring wall on the ground through the jack brackets welded on to the shell.
   i) After jacking of the shell, the tank from the shell to be tied with other structures available in the tank farm through wire ropes from all sides 45 deg. apart.
   j) Peripheral portion of the bottom plate can now be removed by cutting the radial segments.

4.1.4 Rectification of the sand pad
   a) After removal of the annular ring / bottom plate, the exposed portion of the sand pad to be cleaned from all foreign materials and sand soaked with crude oil.
   b) The cavities formed to be filled with sand / crushed stone and bitumen carpeting. Finished level shall be maintained same as the existing one.

4.1.5 Fabrication and erection of the annular plates
   a) New steel plates as per IS 2062 Gr B thickness 12 mm shall be used for annular plates.
   b) Soil face of the annular plate shall be sand blasted and painted.
   c) The new annular plates are to be put into position through the lifted shell.
   d) Annular joints are now to be welded with low hydrogen electrodes.
   e) 50% of the annular joints shall be taken 30 mm long spot radiography.
   f) Bottom plates shall now be released and locked temporarily with annular plate by wedge.
   g) Shell can be released / lowered after completion of the all annular joint welding, subject to acceptance of radiography reports and vacuum box tests.
   h) Shell to bottom fit up to be done.
   i) Inside shell to bottom to be welded (10mm fillet) with low hydrogen electrodes.
   j) Oil chalk test to be carried out for leak identification.
   k) Out side shell bottom welding after acceptance of the said test.
   l) Annular to existing bottom plate fit up and welding.
   m) Vacuum box test for annular plate to shell plate weld joint.
   n) Broken foundation / ring wall to be repaired.
   o) The tank is now ready for commissioning after calibration etc.
   p) Safety Equipment required or the work:
i. DCP cylinders: 25 nos (approx.)
ii. Fire hose with nozzles: 04 nos.
iii. Filled sand scoops: 10 nos.
iv. Fire screen in two sides of the tank and localized for outside welding.

4.1.6 Tank testing and Calibration: The testing and calibration of the tank after repairs are subdivided into the following steps: (Personnel in charge of the job must hold at least ASNT / ISNT Level II Certificate adequate and suitable training)

4.1.6.1 Bottom Test: Vacuum Box testing to be carried out for detection of leaks at the entire length of the bottom welds. The weld joints under the shell periphery shall be tested before erection and welding of first shell course.

4.1.6.2 Shell Test:

a) Shell to bottom joints to be inspected and tested with liquid penetrant after welding the inner fillet weld prior to welding the outside fillet weld.
b) All nozzle reinforcing plates shall be pneumatically tested at 1.05 Kg/ sq. cm with soap solution. This test shall be carried out before filing tank for hydrostatic testing.
c) Water for hydrostatic testing of the tank shall be filled with water to the maximum designed liquid level (curb angle). Till 5 M of the height from the bottom, the tank can be filled in 1 M stages and thereafter till the designed liquid level in 0.5 m stages. After each stage, the tank shall be kept under observation for stabilization of settlement as per API 653 before further filling.
   After filling the tank up to level, all openings in the roof shall be closed and all welded joints in the roof shall be checked with soap suds for detection of leaks.

4.1.6.3 Calibration: Calibration of the tank after necessary testing etc shall be carried out as per IS 2009. Approval of competent authority (Chief Controller of Explosives) to be obtained, before handing over the tank for operation.

5.0 Some Photographs of the OIL’s Site for Tank Bottom Plate Replacement:

Fig- 3: Tank with Jack Brackets and Cutting of Shell to Bottom Weld Cutting
6.0 Mathematical Considerations:

API Standard 650 has provisions for addressing storm related issues that affect storage tanks due to Shell Buckling or Tank Overturning. These guidelines were taken into consideration / validated before taking up the Tank No – 10 of OIL’s Moran Tank Farm for repairs.

6.1.2 Wind Overturning:

Wind overturning is primarily a problem for small diameter tanks that are empty but doesn’t happen often, but the factor was considered and validated in accordance to API 650. The tank under study (Tank No 10 of OIL's Moran Tank Farm) is situated in the State of Assam, India. The average wind speeds for the location varies from 3 Km/hr to 180 Km/hr.
6.1.2.1 API 650 Guidelines:
   a) Wind load on tanks: 1.4 kPa (on vertical plane surfaces for 160 km/hr API 650 for wind speeds). For wind loads other than this, the wind load to be adjusted as, \( (V/160)^2 \). Where \( V \) = wind velocity in km/hr as specified.
   b) For an unanchored tank, the overturning moment from wind pressure shall not exceed two-thirds of the dead load resisting moment, excluding any tank contents.
      \[ M \leq \frac{2}{3} (WD/2) \]
      ---- Equation: (i)
   Where,
   - \( M \) = Overturning moment from wind pressure, in N-m
   - \( W \) = Shell weight available to resist uplift, less any corrosion allowance.
   - \( D \) = Tank diameter
   c) Considering uplift load case for Wind load \( (W) \):
      \[ W_i, \text{ in kPa} = [4 \times \frac{M}{D}] - W \]
      ---- Equation: (ii)

6.1.2.2 Dimensions of the tank:
   a) Diameter = 24m
   b) Height = 11m
   c) Shell weight = 65 ton.
   d) Specific gravity of the liquid (crude) = 0.85
   e) Wind speed = 180 km/hr [IS : 875 (Part 3) – 1987]

From equation (ii), \( M = 3834300 \text{ Nm} \)
And from Equation: (i), \( 2/3 (WD/2) = 5101200 \text{ Nm} \)

So for our tank of study \( M \leq 2/3 (WD/2) \) guide line has been validated for wind speeds of 180 km / hr.

7.0 Conclusion:
The bottom (annular) plate replacement of a crude oil storage tank is a unique and challenging task from technical as well as safety aspects. The above real life case study tries to emphasis on the causative analysis of the tank bottom plate failure and subsequent repair/ replacement methodology and techniques. The special safety measures as well as the safe operating procedures (SOP) / guidelines formulated for the task is also deliberated in details in this paper. Though API (American Petroleum Institute) standards guide on the ways and means for Crude Oil Storage tank construction and repairs, the country specific statutory norms are naturally kept out side the purview of these standards. Hence this paper also tries to dwell at length the statutory norms that are to be followed while taking up Crude Oil Storage Tank Bottom Plate Replacement job in India. Another important comprehension obtained from the case study is of paramount importance, the “life enhancement” of the tank after repairs. From the available data, (corrosion rate: 8.44 mils/ year), it is easily comprehensible that the tank shall be suitable for service (wrt bottom plate thickness at the present rate of corrosion per year) for another 20 year at least.

Acknowledgment:
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References:
1) API : 650
2) API : 653
3) IS : 803
4) IS : 875 (Part 3) – 1987
5) IS :2062
6) IS :2008 / 2009
7) OISD Standards and guide lines