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TANK 20
ENGINEERING REVIEW AND SUITABILITY FOR SERVICE EVALUATION
API 653 OUT-OF-SERVICE TANK INSPECTION BY OTHERS

FISC PEARL HARBOR
RED HILL COMPLEX, HAWAII

Final Report January 2009

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EEI Project 08-4895

RED HILL TANK 20
FISC PEARL HARBOR, HAWAII

SUITABILITY FOR SERVICE EVALUATION
(API 653 TANK INSPECTION BY OTHERS)

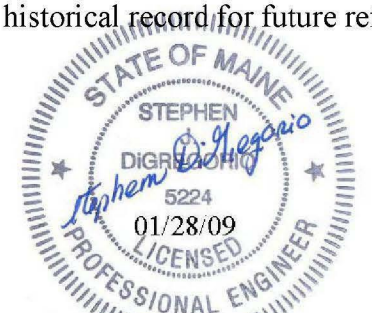
ABSTRACT

The API 653 out-of-service inspection of Tank 20 at FISC Pearl Harbor, Red Hill was performed by Engineering & Inspections Hawaii, Inc. (E&I) during September and October 2008 under contract to Shaw. Non-destructive examination of Tank 20 was performed by TesTex. A follow-up inspection of voids behind the liner plates in the lower dome was performed by E&I in January 2009. Enterprise Engineering, Inc. (EEI) has reviewed the documentation on Tank 20 prepared by E&I and TesTex and has prepared this engineering evaluation of Tank 20. The engineering evaluation was performed in accordance with the applicable sections of API Standard 653 Third Edition December 2001, Addendum 3 February 2008 and is solely based on the items presented in E&I's inspection report and follow-up correspondence and discussions. Information not presented by E&I, but possibly relevant to the integrity of the tank, has not been considered in this evaluation. This report only provides a review of relevant inspection findings by others, plus an evaluation of tank suitability for service completed by EEI, and should be read in conjunction with the formal report prepared by E&I. The E&I recommendations for repair prior to returning the tank to service are discussed herein as necessary from an engineering and repair requirements perspective.

Based on information presented in E&I's report and information provided by TesTex, our evaluation determined there are conditions that affect the hydraulic and structural integrity of Tank 20. Mandatory repairs are required prior to placing the tank back in-service.

EEI recommends the next API 653 out-of-service internal inspection be scheduled for no later than October 2028 (i.e. 20 years from the date of the inspection). The next out-of-service internal inspection should be performed sooner than October 2028 if a change in condition or a change in service occurs. EEI also recommends the condition of the interior coating be inspected and assessed at every fuel quality inspection.

In accordance with API Standard 653, this report satisfies the requirement for an out-of-service integrity evaluation and as such, must be kept permanently available for the life of the tank as a historical record for future reference.



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I hereby acknowledge that being familiar with the provisions of API Standard 653, the engineering evaluation was performed in accordance with the provisions of API Standard 653 and good engineering practices, and with the exercise of usual and customary care.

This tank inspection determined that mandatory repairs are required. Based on the extent of the out-of-service inspection, Tank 20 is considered suitable for service after mandatory repairs are completed.

TABLE OF CONTENTS

APPENDICES

RED HILL TANK 20
FISC PEARL HARBOR, HAWAII

ENGINEERING REVIEW AND SUITABILITY FOR SERVICE EVALUATION

SUMMARY

Enterprise Engineering, Inc. (EEI) performed an engineering review and suitability for service evaluation of Tank 20 based on the API 653 out-of-service inspection report prepared by Engineering & Inspections Hawaii, Inc (E&I) and follow-up correspondence and discussions. The engineering evaluation was performed in accordance with the applicable sections of API Standard 653 Third Edition December 2001, Addendum 3 February 2008. API 653 has only limited application to this highly custom designed concrete tank with a steel liner.

This report provides an engineering review of the E&I inspection report with additional suitability for service assessment comments as appropriate. Information not presented by E&I, but possibly relevant to the integrity of the tank, has not been considered in this evaluation.

REPAIR ITEMS

Repair Categories

The recommendations for repair were categorized by E&I based on paragraph 4.6.2.6 in the NFESC Statement of Work. The categorization is a practical time line basis, not necessarily considering whether a repair recommendation is considered a mandatory repair to meet the strict provisions of API 653, or a compelling recommendation based on life extension and preservation or military criteria.

Repairs - Standard of Care

All repairs shall strictly meet the requirements of API 650 and API 653 regarding material, welding procedures and qualification of welders, non destructive examination (NDE) of welding, and testing requirements.

Mandatory Repairs

Mandatory repairs are repairs that are required prior to placing the tank in service as either compelling under API 653, for hydraulic and structural integrity, or from a practical consideration as the only opportunity to complete the work is prior to filling the tank. The following repairs are listed in the E&I report as mandatory.

1. Tank Access Structure: Perform visual and magnetic particle inspection of the tower and access walkway where additional structural members or repairs have been made as outlined in the Hawaii Engineering Group, Inc. report.

   EEI Comments:

   - No exception taken to E&I's recommendation.
   - As the internal tower and access walkway was inspected by Hawaii Engineering Group, EEI is excluding review and comment of their findings and recommendations from our review of Tank 20 inspection.

2. Internal Coating: Evaluate the Internal Coating by a certified NACE inspector.

   EEI Comments:

   - Based on discussions with Shaw, NFESC will have a coating inspector inspect the interior coating. An inspection by a NACE coating inspector provided by Shaw is not necessary.
   - Based on discussions with Shaw, the government has decided to re-coat the lower dome.

3. Voids behind Steel Liner in the Lower Dome: Perform an engineering evaluation of large voids behind the liner in the lower dome.

   EEI Comments:

   - E&I's report identified numerous voids behind the steel liner of the lower dome. E&I's report noted the following conditions:
     a. Hammer testing found some degree of voids in 22 plates of the lower dome.
     b. The smallest void areas are 6 to 8 square inches.
     c. Plates 23 and 24 have larger void areas that deflect when hammer tested.
   - Hammer testing is a valid method to check for voids. A hollow ringing sound indicates that a void or gap is present behind the plate. It is not possible, however, to determine from hammer testing alone the depth of the void.
   - E&I did not report any noticeable bulges at the void areas. The voids detected by hammer testing are most likely small gaps between the steel liner plate and the grout behind it. This is not an uncommon condition and can be caused by shrinkage of the grout when it cured.
   - In general small voids less than 12 inches in diameter with no noticeable bulge are not a concern and do not need to be repaired. If a void is behind a welded joint, it is recommended that the weld be inspected for cracks.
   - Large voids with noticeable flexing can cause adjacent welds to crack. These voids should be filled with non-shrink grout to prevent further flexing of the plate.

E&I Follow-up Inspection of Voids in Lower Dome:

E&I performed a follow-up inspection and mapping of voids larger than 12 inches diameter in the lower dome in January 2009. E&I reported that 90% of the voids larger than 12" diameter were within the vicinity of removed leak detection piping and that visual inspection found grout within 1/4" of the liner plate (i.e. the voids were not larger than 1/4" deep). E&I recommended no further action should be necessary.

EEI Comments:

- No exception taken to E&I's findings.
- E&I's mapping of voids in the lower dome shows three large voids in course 1 that are behind welds. The voids are located between plates 7 and 8, the lower portion of plate 20, and between plates 40 and 41. As flexing of the liner plate may cause the welds to crack, EEI recommends the three voids be filled with grout. See EEI added Mandatory Repairs.

4. Steel Liner Repairs: E&I's report recommends repair of flaws in the steel liner plates and welds based on findings provided by TesTex.

   EEI Comments:

   - No exception taken to the list of liner repairs identified in E&I's report.
   - Repair the flaws listed in E&I's report. See the discussion that follows for EEI recommendations on repair requirements. Note: Flaw #415 and Flaw #463 listed in E&I's report are located in the upper dome, not the barrel.
   - Before performing any repairs of the steel liner, EEI recommends a Marine Chemist evaluate conditions at the area of repair for hot work and prepare hot work requirements. Past history on Red Hill has found some areas safe for hot work and some areas not safe unless special purging requirements are followed. EEI recommends the Marine Chemist prepare a series of procedures for conditions found.

Steel Liner Repair Requirements

1. Cracks in Welds

   - Remove cracks by grinding.
   - Perform magnetic particle or ultrasonic inspection to verify that the crack has been removed.
   - Provide weld passes to restore the full thickness of the weld. Control heat input and rate of cooling to prevent new cracks from forming.
   - Perform magnetic particle or ultrasonic inspection of the completed repair. Inspect for cracks, lack of fusion, porosity, and slag inclusions. Repair all rejectable defects found.
   - NOTE: It may be necessary to weld a doubler plate over the repaired welds to reinforce the joint.

2. Lack of Fusion in Welds

   - Remove lack of fusion by grinding.
   - Perform magnetic particle or ultrasonic inspection to verify that the lack of fusion has been removed.
   - Provide weld passes to restore the full thickness of the weld.
   - Perform magnetic particle or ultrasonic inspection of the completed repair. Inspect for cracks, lack of fusion, porosity, and slag inclusions. Repair all rejectable defects found.

3. Arc Gouges and Mechanical Gouges

   - Blend grind arc gouges and mechanical gouges with the base metal.
   - Perform magnetic particle inspection of the area to verify that the gouge has been removed and that there are no cracks in the base metal.
   - Repair areas having a remaining metal thickness less than 0.200" by welding to restore the thickness of the liner plate.
   - Perform magnetic particle or ultrasonic inspection of the weld repair. Inspect for cracks, lack of fusion, porosity, and slag inclusions. Repair all rejectable defects found.

4. Backside Corrosion (Loss of Wall)

   - Repair by welding a 1/4" thick patch plate over the area.
   - Perform magnetic particle inspection and vacuum box testing of the patch plate weld. Inspect for cracks, lack, of fusion, porosity, and leak indications. Repair all rejectable defects found.

5. Through Wall Hole in Batten Plate (Flaw #347)

   - Repair by welding to fill the hole.
   - Perform magnetic particle inspection and vacuum box testing of the weld repair. Inspect for cracks, lack, of fusion, porosity, and leak indications. Repair all rejectable defects found.

EEI Added Mandatory Repairs

1. Repair Voids in Lower Dome

   - E&I' mapping of voids in the lower dome shows three large voids in course 1 that are behind a weld: The voids are located between plates 7 and 8, the lower portion of plate 20, and between plates 40 and 41. As flexing of the liner plate may cause the welds to crack, repair the three voids by injecting grout to fill the void. Take precautions to prevent excess filling with grout as this will create a bulge in the liner.

- After grouting the voids, perform magnetic particle or ultrasonic inspection of the entire length of the welds at the three voids. Repair any cracks found.

2. Repair Removed Leak Detection Pipe Penetrations

- The leak detection piping in Tank 20 was removed during the inspection per government direction due to concerns about leaks in the leak detection piping. A short pipe stub section, however, was left in place at each location. Remove the remaining portion of the leak detection piping stubs flush with the existing 5" diameter x 3/8" thick doubler plate. It is not necessary to remove the existing doubler plate.
- Remove existing coating on the doubler plate to 2" beyond the doubler plate.
- Repair any flaws in the weld attaching the doubler plate to the steel liner found during the inspection of Tank 20.
    a. Remove cracks, lack of fusion, porosity and slag inclusions by grinding.
    b. Perform magnetic particle or ultrasonic inspection to verify that the defects have been removed.
    c. Provide welds passes to restore the full thickness of the weld. Control heat input and rate of cooling to prevent new cracks from forming.
    d. Perform magnetic particle or ultrasonic inspection of the completed repair. Inspect for cracks, lack of fusion, porosity, and slag inclusions. Repair all rejectable defects found.
- Per discussions with TesTex the doubler plates were inspected, thus it is not necessary to re-inspect the doubler plates.
- Weld a 1/4" thick x 3" diameter patch plate over the opening in the existing doubler plate.
- Perform magnetic particle or ultrasonic inspection of the weld joining the patch plate to the existing doubler plate. Inspect for cracks, lack of fusion, porosity and slag inclusions.
    a. Remove cracks, lack of fusion, porosity and slag inclusions by grinding.
    b. Perform magnetic particle or ultrasonic inspection to verify that the defects have been removed.
    c. Provide welds passes to restore the full thickness of the weld. Control heat input and rate of cooling to prevent new cracks from forming.
    d. Perform magnetic particle or ultrasonic inspection of the completed repair. Inspect for cracks, lack of fusion, porosity, and slag inclusions. Repair all rejectable defects found.
- Perform vacuum box testing of the doubler plate weld and patch plate weld. Repair areas failing testing by grinding and welding additional passes.
- Provide re-coating of the repair areas in accordance with the project Work Plan.

3. 6" Slope Line and 6" Steam Line

   - Hydrotest records indicate the 6" slop line and the 6" steam line failed testing.
   - Repair the 6" slop line using a repair that was approved by NAVFAC for other Red Hill tanks by inserting a stainless steel flexible braided hose into the slop line.
   - EEI concurs with re-hydro testing the 6" steam line after it is converted to a slop line. If the 6" steam line fails re-testing, EEI recommends the steam line be repaired by inserting a stainless steel flexible braided hose into the line, prior to returning the tank to service.

4. 8" Steam Line: The hydrotest records indicate new sample lines will be installed in the 8" steam line. Re-hydrotest the 8" steam line after the sampling lines are installed, prior to returning the tank to service.

Near Future Recommended Repairs (Non-Mandatory)

Near future recommended repairs are repairs not mandatory per API 653 or for structural and hydraulic integrity of the tank but should be performed if approved by the government in conjunction with the mandatory repairs, or within a 2-3 year period to preserve the integrity of the tank.

1. The E&I report does not list any recommended near future repairs.

   EEI Comment:

   - No exception taken.

Recommended Repairs for Long Term Serviceability

Long term repairs are repairs that are not critical to the hydraulic and structural integrity of the tank and are not required prior to placing Tank 20 in service. Long term repairs consist of items that should be deferred to the next out of service inspection cycle.

1. Program the tank for the next out-of-service inspection in 20 years (October 2028).

ADDITIONAL COMMENTS AND RECOMMENDATIONS

Inspection of Steel Liner Plates

Per EEI discussions with TesTex not all areas of the steel liner plates could be inspected by L.F.E.T. (Low Frequency Electromagnetic Technique). TesTex reported that the only area of Tank 20 that was not inspected by L.F.E.T. was course F of the upper dome. Course F is the top of the upper dome and is located directly above the central tower. Per TesTex the surface area course F was 100% inspected with an ultrasonic transducer shoe and the welds were inspected with B.F.E.T. Per TesTex no defects found in course F and there were no areas un-inspected in Tank 20.

EEI Comment:

- No exception taken to the extent of inspection performed.

Inspection of Steel Liner Welds

Per TesTex's NDE report the welds in the floor, lower dome, and barrel were inspected using Balanced Field Electromagnetic Technique (B.F.E.T.). TesTex's NDE report lists several flaws in the welds which consist of lack of fusion, pitting, arc gouges, and mechanical gouges. Additionally a 0.75" long crack (Flaw #482) was found in one of the welds of the lower dome.

EEI Comments:

- The crack in one of the welds in the lower dome is a concern as the lower dome is subject to high fluid pressure.
- EEI concurs that the cracked weld be repaired. The method of repairing the crack must be carefully considered to prevent new cracks from forming. Refer discussion on Steel Liner Repair Requirements for EEI recommendations on repairing cracked welds.

Existing Lap Welded Patch Plates

E&I's report states there are numerous lap-welded patch plates throughout the entire tank. Additionally, E&I reported the patch plates vary in size and shape, do not have radius corners, and are smaller than the 6-inch minimum size required by API 653. Per EEI discussions with TesTex, the surface of all patch plates of any kind was inspected by ultrasonic thickness testing (UT). The results are included in the flaw log. Any areas less than 0.250" were noted as "PP". Additionally TesTex reported that all junction welds around patch plate were inspected by B.F.E.T.

EEI Comments:

- No exception taken to the extent of inspection performed.
- Patch plates having non-radius corners and patch plates smaller than 6-inch minimum size required by API 653 do not need to be replaced with new patch plates.

Repair of Leak Detection Piping Penetrations

Archive drawing 294331 dated 1942 shows the original leak detection piping welded to the steel liner with no doubler plate. Record drawing 1311807 (Detail B) dated 1970, shows repairs to the leak detection (telltale) piping connections that consisted of removing some of the leak detection jumper pipes and providing new leak detection pipes. The "new" leak detection pipes consisted of a 1 1/4" diameter hole in the liner plate, a 1 1/2" diameter extra strong pipe welded to the surface of the steel liner plate over the hole, and a 3/8" thick x 5" diameter doubler plate.

The leak detection piping in Tank 20 was removed during the inspection per government direction due to concerns about leaks in the leak detection piping. The piping was cut at the doubler plate, leaving a short pipe stub. Before Tank 20 can be returned to service the openings in the liner at the removed leak detection piping locations need to be closed.

The Red Hill Tanks are engineered reinforced concrete tanks with a steel liner. The steel liner plates are similar to the floor of aboveground storage tank in that the steel liner plates are not

designed to resist internal fluid pressure. The steel liner is supported by reinforced concrete which resists internal pressure from the tank contents. Thus, the requirements of API 653 9.3.2 relating to the closure of openings in tank shells do not apply. It is not necessary to remove the existing doubler to patch the holes in the steel liner at the removed leak detection pipe locations.

Batten Plates over Welds in the Upper Dome

The upper dome has batten plates covering the original welds (referred to as "backing strip" in TesTex's report). TesTex's NDE report states all batten plates and associated welds were scanned.

EEI Comment: No exception taken to the extent of inspection performed.

Barrel to Upper Dome Extension and Expansion Joint

Archive drawings indicate Tank 20 has a vertical extension below the spring line of the upper dome constructed of flat plates. TesTex data indicates the vertical extension is 14 ft high and constructed in four courses. At the bottom of this vertical extension is a joint consisting of a 1/4" thick horizontal plate (Plate J) that projects into the tank. Below Plate J is a 1'-6" tall filler section consisting of rolled plates. The horizontal plate (Plate J) provides a joint where the flat plates of the vertical extension transition to the rolled plates of the filler section. This joint is similar to the barrel to lower dome junction. Below the filler plate is an expansion joint. The expansion joint consists of two 1/4" thick horizontal plates (one on top of the other) that project into the tank. The top plate is welded to the filler section of the upper dome and lower plate is welded to the barrel. The plates are welded to each other with plug welds at 24" on center and a fillet weld along the inner edge to form a hinge.

Per discussions with TesTex all plates and welds of the expansion joint were inspected. No outstanding defects were found. Additionally, the associated welds of the horizontal plate (Plate J) between the vertical extension and filler section were inspected. No outstanding defects were found.

EEI Comment: No exceptions taken.

Barrel to Lower Dome Junction

The barrel to lower dome junction consists of a 1/2" thick horizontal plate that projects into the tank. This horizontal plate provides a transition between the rolled plates of the barrel and the flat plates of the lower dome. Per EEI discussions with TesTex, the welds of the joint were inspected with B.F.E.T. The horizontal plate was also inspected. No reportable defects were found.

EEI Comment: No exceptions taken.

Existing Grout Ports

Per discussions with TesTex, the face and side walls of each grout nozzle was inspected by ultrasonic testing. The welds around each nozzle were B.F.E.T. inspected. Additionally, the steel liner plates around the grout ports were scanned for metal loss and remaining thickness. TesTex found some metal loss in the steel liner plate but no areas were less than the Tmin thickness of 0.170". Remaining thickness of the grout nozzles ranged 0.180" to 0.236". The NDE data indicates none of the nozzles have a remaining thickness less than the Tmin thickness of 0.170".

EEI Comment: No exceptions taken.

Piping Penetrations in Liner Plates

Per TesTex's NDE report, the floor of the lower dome around piping penetrations was inspected using L.F.E.T. The welds around piping penetrations were inspected using the Hawkeye B.F.E.T.

EEI Comment: No exceptions taken.

Interior Coatings

Coating repairs and coating repair systems are being addressed by others.

Hydrostatic Testing of Tank 20 Piping

Information provided by Shaw (and included in E&I's inspection report) indicate the following piping was hydrotested: 16" fuel line, 32" fuel line, 6" slop line, 6" steam line, and an 8" steam line. The sample lines in Tank 20 were removed and thus not tested. The hydrotest records state the piping was hydrotested at 150 psig for 4 hours and observed for leaks. The hydrotest records indicate that the 6" slop line and 6" steam line failed the hydrotest; the 16" fuel pipe, 32" fuel pipe, and the 8" steam pipe passed hydrostatic testing. The hydrotest records indicated the 6" steam line will be converted to a slop line and re-hydrotested. The hydrotest records also indicate the 8" steam line will be re-hydrotested after installing new sample lines inside the steam line.

EEI Comments:

- The hydrotests were conducted in accordance Shaw's Work Plan and performed by Dunkin & Bush and witnessed by Shaw. E&I was not present during the hydrotest procedure.
- Repair the 6" slop line using a repair that was approved by NAVFAC for other Red Hill tanks by inserting a stainless steel flexible braided hose into the slop line.
- EEI concurs with re-hydrotesting the 6" steam line. If the 6" steam line fails re-testing, EEI recommends the steam line be repaired by inserting a stainless steel flexible braided hose into the line, prior to returning the tank to service.
- EEI concurs with re-hydrotesting the 8" steam line after new sample lines are installed inside the steam line, prior to returning the tank to service.

SUITABILITY FOR SERVICE EVALUATION

Hydraulic and Structural Integrity

The following table provides an assessment of the hydraulic and structural integrity of Tank 20 based on the E&I inspection data provided to EEI for review and assessment.

HYDRAULIC AND STRUCTURAL INTEGRITY		
Evaluation Item	**Findings**	**Comment**
Lower Dome	A 0.75" long crack in a weld (Flaw # 482) in the lower dome. E&I's inspection report also lists other flaws in the lower dome that require repair. Numerous voids were detected behind 22 plates.	Repair the cracked weld in lower dome. Repair flaws in the lower dome listed in E&I's inspection report. See EEI comments under Mandatory Repair and EEI Added Mandatory Repairs regarding the voids.
Barrel/Lower Dome Junction	TesTex's inspection found no defects in the welds or plate.	
Barrel	E&I's inspection report lists flaws in the barrel that require repair.	Repair flaws in the barrel listed in E&I's inspection report.
Barrel/Upper Dome Junction	The barrel to upper dome joint is an expansion joint. TesTex's inspection of the plates and welds of the expansion joint found no reportable defects. Above the expansion joint is a 1'-6" tall filler section and above the filler section is a 14 ft high vertical extension to the spring line of the upper dome. A horizontal plate forms the joint between the filler section and the extension. Per TesTex, the associated welds of the horizontal plate between the vertical extension and filler section were inspected. No outstanding defects were found.	
Upper Dome	The upper dome has batten plates covering the original welds. Inspection of the welds attaching the batten plates to the dome found no reportable defects. Inspection of the batten plates found one through-wall corrosion hole (Flaw #347).	Repair the hole in batten plate.
Hydrostatic Test of Piping	Hydrotest records indicate the following pipe lines were pressure tested at 150 psi for 4 hours with following results: 16" pipe: pass 32" pipe: pass 6" slop line: fail 6" steam line: fail 8" steam line: pass	No exceptions taken to the results of the hydrotests. Provide repair of the 6" slop line. Hydrotest records indicate the 6" steam line is planned to be converted to a slop line: Provide repair of the 6" steam line.

STEEL LINER PLATE MINIMUM THICKNESS ASSESSMENT

EEI performed a calculation of corrosion rate and the minimum required thickness of the 1/4" thick steel liner plates. This minimum thickness served as the criteria for determining the need to repair thin areas and pits in the steel liner plates for another 20-year interval until the next inspection.

EEI recommended a Tmin = 0.170" be used as the criteria for determining whether thin and pitted areas in the 1/4-inch thick steel liner plates in the upper dome, barrel, and lower dome require repair. This recommendation was reviewed and accepted by the government. The calculation of corrosion rate and Tmin = 0.170" is based on the following:

- Year Tank Constructed: 1942
- Original Thickness of Liner Plates: 0.250"
- Age of tank in 2028 = 2028 - 1942 = 86 years
- Remaining Thickness at the Next Inspection: 0.10" based on the tank having no means to contain a leak
- Interval until the Next Inspection: 20 years maximum

Corrosion Rate and Minimum Thickness Discussion

It is not possible calculate an actual corrosion rate for the Red Hill Tanks because the time interval during which corrosion occurred is unknown and cannot be determined. Depending on the time interval that is assumed, the corrosion rate can be higher or lower compared to the actual corrosion rate. It is possible that conditions causing external corrosion can change over time. Additionally, the rock stratum surrounding the Red Hill tanks varies in type and porosity, thus the water content and corrosivity of the rock can vary from one location to another. Because of these highly variable conditions, selecting areas of the steel liner and measuring the remaining thickness to determine actual corrosion rates would not necessarily be representative of external corrosion conditions throughout the tank. It is possible that more severe corrosion could exist at areas that are not measured.

For a 20-year service interval starting in 2008, the next inspection would be in 2028. Using the API 653 straight-line method of calculating corrosion rates and a 0.10" remaining thickness at the next inspection in 2028, the external corrosion rate is calculated as follows:

> Maximum permissible metal loss = 0.250" – 0.10" = 0.150"
> Age of tank in 2028 = 2028 - 1942 = 86 years
>
> Considering the 0.150" of metal loss occurs over the life of the tank, the hypothetical external corrosion rate is: 0.150" / 86 years = 0.001744 in / year

EEI's calculation of the external corrosion rate follows the procedure outlined in API 653 section 4.4.5, which assumes a linear (i.e. constant) corrosion rate based on the age of the tank. The external corrosion rate was calculated based on the age of the tank in 20-years (i.e. 86 years old in 2028). EEI acknowledges that this calculated corrosion rate is not based on thickness data of the steel liner plates; however as stated above, selecting areas of the steel liner and measuring the

remaining thickness to determine actual corrosion rates would not necessarily be representative of external corrosion conditions throughout the tank.

Following the guidance of API 570 which uses 2 times the corrosion rate to determine the interval until the next inspection, 2 times the corrosion rate results in a Tmin = 0.170 inches as follows:

Two times corrosion rate = (2) (0.001744 in / yr) = 0.003488 in /yr

At two times the corrosion rate, the metal loss that is expected to occur during the next 20 years = (0.003488 in / year) (20 years) = 0.070"

The minimum thickness required in 2008 to have 0.10" remaining thickness in 2028 at twice the corrosion rate of 0.001744 in / yr is:

Tmin = 0.070" + 0.100" = 0.170"

CONCLUSIONS

Based upon our evaluation of the inspection results presented by E&I, Tank 20 is considered suitable for service after mandatory repairs are completed.

APPENDIX A

STEEL LINER PLATE THICKNESS ASSESSMENT

Stephen J. DiGregorio

From: Stephen J. DiGregorio [sjd@eeiteam.com]
Sent: Tuesday, April 22, 2008 8:06 PM
To: Wilfred Chun
Cc: 'Weese, Todd'; 'Dygart, Aaron'; 'Phillips, David'; Steve Brooks; Stacy Kaplan-McMillan
Subject: Red Hill Tank 2 and 20 Tmin Calculation

Wilfred,

My responses to Incheol's comments are provided below. Due to the uncertainty in calculating corrosion rates, applying a factor of safety to Tmin has merit. You will see in the calculations and recommendations that follow, I have recommended a revised Tmin = 0.170 inches. I will revise EEI's formal Steel Liner Plate Minimum Thickness Assessment to reflect the new Tmin calculations and recommendations.

EEI Response to Comments

1. It is not possible calculate an actual corrosion rate for the Red Hill Tanks because the time interval during which corrosion occurred is unknown and can not be determined. Depending on the time interval that is assumed, the corrosion rate can be higher or lower compared to the actual corrosion rate. Additionally, it is possible that conditions causing external corrosion can change over time. Available record drawings indicate the rock face of the barrel of the tanks is lined with gunite and coated with either asphalt paint or "red dirt" paint; and that the space between the gunite lining and the steel liner plates is filled with reinforced concrete. It is known that cracks or other conditions have developed in the gunite or reinforced concrete allowing water to migrate to the steel liner plates and corrode steel liner plates that previously had no indication of external corrosion. This has been going on probably for the entire life of the tank, so it is not new.
2. The rock stratum surrounding the Red Hill tanks varies in type and porosity, thus the water content and corrosivity of the rock can vary from one location to another. Because of these highly variable conditions, selecting areas of the steel liner and measuring the remaining thickness to determine actual corrosion rates would not necessarily be representative of external corrosion conditions throughout the tank. It is possible that more severe corrosion could exist at areas that are not measured.
3. EEI's calculation of the external corrosion rate (0.001744 inches per year) and Tmin =0.140 inches follows the procedure outlined in API 653 section 4.4.7.1, which assumes a linear (i.e. constant) corrosion rate based on the age of the tank. For Tanks 2 and 20, the external corrosion rate was calculated based on the age of the tank in 20-years (i.e. 86 years old in 2028). EEI acknowledges that this calculated corrosion rate is not based on thickness data of the steel liner plates; however as stated above, selecting areas of the steel liner and measuring the remaining thickness to determine actual corrosion rates would not necessarily be representative of external corrosion conditions throughout the tank. On the other hand, there may not be any location on the tank that would have a more aggressive corrosion rate than that determined by our method of calculation, unless there has been a drastic change in conditions. Should areas be present that have a higher corrosion rate than our calculated corrosion rate, the remaining thickness will have a Tmin less than 0.140 inches and would be repaired.
4. EEI has not established a 20-year interval until the next inspection. A 20-year interval was used to calculate Tmin. A shorter interval until the next inspection could be used.

Summary and Conclusions

1. It is not possible calculate an actual corrosion rate for the Red Hill Tanks because the time interval during which corrosion occurred is unknown and can not be determined.
2. Selecting areas of the steel liner and measuring the remaining thickness to determine actual corrosion rates would not necessarily be representative of external corrosion conditions throughout the tank because the rock stratum surrounding the Red Hill tanks varies in type and porosity.
3. EEI's calculated Tmin = 0.140 inches is based on the age of the tank in 20-years (i.e. 86 years old in 2028). As stated in EEI's Steel Liner Plate Thickness Assessment, a Tmin = 0.140 inches has no safety factor. If a more conservative approach is desired, a shorter interval until the next inspection (i.e. 10 years) or Tmin based on higher external corrosion rate or both could be used. Given the uncertainty in calculating a

corrosion rate, using factor of safety for Tmin has merit.

Recommendations

1. As it is not possible to establish actual corrosion rates, a factory of safety applied to the previously recommended Tmin = 0.140 inches may have merit. Considering the guidance of API 570, which uses twice the corrosion rate in any remaining life, or pressure capability calculations, the new Tmin, at twice the corrosion rate, would be 0.170 inches. This new Tmin takes into consideration the uncertainty of calculating a corrosion rate and the potential for internal corrosion given the reported condition of the interior coating.
2. EEI, therefore recommends Tmin = 0.170" be used as the criteria for determining whether thin and pitted areas in the 1/4-inch thick steel liner plates in the, barrel, and lower dome require repair.
3. Tmin = 0.170 inches does not apply to the 1/2-inch thick floor (base plate) of the lower dome.
4. As the steel liner plates are not structural elements and should not be relied upon as a structural element to resist hoop and tensile stresses in the barrel and lower dome or compressive stress in the upper dome, consult EEI when voids are found behind liner plates.

Revised Tmin Calculations

Following the guidance of API 570 which uses twice the corrosion rate in any remaining life, or pressure capability calculations, a revised corrosion rate and Tmin is calculated as follows:

Parameters

- Original Thickness of Liner Plates: 0.250"
- Remaining Thickness at the Next Inspection: 0.10" based on the tank having no means to contain a leak
- Interval until the Next Inspection: 20 years maximum
- Year Tank Constructed: 1942

Revised Corrosion Rate and Minimum Thickness

For a 20-year service interval starting in 2008, the next inspection would be in 2028. Using the API 653 straight-line method of calculating corrosion rates and a 0.10" remaining thickness at the next inspection in 2028, the external corrosion rate is as follows:

Maximum permissible metal loss = 0.250" – 0.10" = 0.150"
Age of tank in 2028 = 2028 - 1942 = 86 years

Considering the 0.150" of metal loss occurs over the life of the tank, the external corrosion rate is:

External corrosion rate = 0.150" / 86 years = 0.001744 in / year

Following the guidance of API 570, using 2 times the corrosion rate results in a Tmin = 0.170 inches as follows:

Two times corrosion rate = (2) (0.001744 in / yr) = 0.003488 in /yr

A two times the corrosion rate, the metal loss that is expected to occur during the next 20 years is:

Metal loss during next 20 years = (0.003488 in / year) (20 years) = 0.0.70"

The minimum thickness required in 2008 to have 0.1" remaining thickness in 2028 at twice the corrosion rate of 0.001744 in / yr is:

Tmin = 0.070" + 0.100" = 0.170"

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ENTERPRISE
ENGINEERING, INC.

RED HILL TANKS 2 AND 20
FISC PEARL HARBOR, HAWAII

Steel Liner Plate Minimum Thickness Assessment
April 15, 2008

EEI Project No. 08-4895

GENERAL

Shaw is providing cleaning, inspection, and repair services for Tanks 2 and 20 at FISC Pearl Harbor Red Hill, Hawaii. Shaw has requested Enterprise Engineering, Inc. (EEI) calculate corrosion rates and the minimum thickness of the steel liner plates which will be used as the criteria for determining the need for repair based on a 20-year interval until the next inspection.

Record drawings of the Red Hill tanks indicate the steel liner plates in the upper dome, barrel, and lower dome in all of the tanks are 1/4" thick plate nominal. The floor (referred to as "base plate" on record drawings) of the lower dome in all of the tanks is indicated as 1/2" thick plate. This document prepared by EEI provides a calculation of corrosion rates and minimum required thickness of the 1/4" thick steel liner plates. This minimum thickness will serve as the criteria for determining the need to repair thin areas and pits for another 20-year interval until the next inspection.

RECOMMENDED REPAIR CRITERIA: STEEL LINER MINIMUM THICKNESS

It is reported that a Tmin of 0.19 inches was used on previous projects at Red Hill. EEI is not able to determine how this value was established. EEI recommends the following:

1. A minimum thickness (Tmin) of 0.140 inches be used as the criteria for determining whether thin and pitted areas in the 1/4-inch thick steel liner plates in the, barrel, and lower dome require repair. The upper dome area, with increased potential for atmospheric corrosion on the inside, can also use this Tmin criteria of 0.140 inches if it is determined the coating system is sound, there is no present internal corrosion, and the coating system has a remaining life of 20 years. Note: the Tmin value of 0.140 inches does not include any safety factor that the thickness of the steel liner plates will not be less than a minimum thickness of 0.10 inches at the end of another 20-year service interval. The justification for not using a safety factor is:

    a. API 653 does not use a safety factor.

    b. Tmin is based on a constant rate of corrosion (i.e. corrosion is assumed to not vary over time). Using a constant rate of corrosion is in accordance with API 653 and is considered

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conservative in that corrosion rates generally decrease over time unless conditions change.

c. A safety factor could be added to Tmin; however, this will involve more repairs and is not justified unless desired by the government or conditions are found indicating corrosion rates are higher than calculated.

2. Repair thin and pitted areas in the 1/4-inch thick steel liner plates in the upper dome, barrel, and lower dome having a minimum thickness (Tmin) less than 0.140 inches. Areas having Tmin equal to or greater than 0.140 inches do not require repair for a 20-year interval until the next inspection.

3. Tmin = 0.140 inches does not apply to the floor (base plate) of the lower dome.

4. EEI also calculated Tmin for a 10-year interval until the next inspection and determined Tmin in this case would be 0.120 inches. EEI can evaluate this alternative if desired.

5. Using Tmin = 0.140 inches as determined for 20-year interval until the next inspection and applying this criteria for a 10-year interval is an option as it is conservative and provides a factor of safety.

COMMENTS AND CLARIFICATIONS

EEI's calculation of Tmin is based on the following:

1. A 20-year interval until the next inspection in 2028 as indicated in Shaw's Work Plan.

2. An original plate thickness of 0.250 inches. Our calculation of Tmin does not take into account the original thickness of the plates may be thinner due to plate fabrication tolerances or other conditions. EEI recommends Shaw's inspector obtain ultrasonic thickness measurements of each plate (6 measurements minimum per plate). Submit for EEI review and assessment thickness measurements of plates having an average thickness less than 0.240". The 0.240 thickness is the ASTM A 6/A6M minimum thickness tolerance for 1/4-inch thick plates.

3. The rate of external corrosion was calculated using the API 653 straight line method and assuming metal loss occurring over the life of the tank (86 years) from tank construction in 1942 to the next inspection in 2028. The calculated rate of external corrosion does not take into consideration potential areas of concentrated corrosion caused by artifacts, welding rods, debris, rocks, microbial induced corrosion (MIC) in the form of small "worm-like" corrosion trails, or other conditions on the exterior of the liner plates the would cause concentrated corrosion. If these conditions are found, contact EEI for interpretation.

4. The rate of external corrosion and Tmin does not apply to the heat-affect zone of liner plates adjacent to welds (within 1 inch of the weld). As the corrosion rate in the heat-affected zone can be higher than areas outside the heat-affected zone, a higher Tmin value may be needed for the heat-affected zone. Information on plate thickness in the heat affected zone is needed to determine corrosion rates and Tmin of the heat affected zones of the steel liner plates. EEI

recommends Shaw's inspector obtain ultrasonic thickness measurements in the heat-affected zone in random areas in each quadrant of the upper dome, barrel, and lower dome for EEI assessment. Given the large quantity of welds in the liner plate joints, EEI recommends 20 UT thickness measurements be obtained in the heat-affected zones in each quadrant. Additional UT measurements may necessary if results are not consistent. Additionally, EEI recommends that we be notified when the remaining thickness in the heat-affected zone is less than 0.200 inches as additional assessment may be necessary.

5. The corrosion rate of product side corrosion is assumed to be 0.00 inches per year. This assumption is only valid if the existing interior coating is in serviceable condition and its service life is equal to or greater than the 20-year interval until the next inspection. If the interior coating is not expected to last another 20 years, product side corrosion may occur and thus the Tmin will need to be recalculated and increased. It should be noted that product side corrosion is not of concern when the tank is filled as areas are covered by product except at a water bottom in the lower dome. The 0.00 inches per year product side corrosion rate also does not take into consideration potential atmospheric corrosion of the steel liner plates if the coating is failing and not repaired and liner plates are exposed to atmosphere. Additional information is needed on the condition of the interior coating and whether atmospheric corrosion is present. This additional information may result in a greater Tmin of the upper dome, where atmospheric corrosion, and or degraded coatings is present.

6. A minimum thickness of 0.10 inches at the next inspection is used in the calculation of Tmin. A 0.10 inch minimum thickness is used as the steel liner plates are a hydraulic barrier and are not relied upon as a structural element to resist hoop and tensile stresses in the barrel and lower dome or compressive stress in the upper dome. The 0.10-inch criteria is similar to API 653 criteria for tank floors that have no means for containment of a leak.

7. As the steel liner plates are not structural elements and should not be relied upon as a structural element to resist hoop and tensile stresses in the barrel and lower dome or compressive stress in the upper dome, consult EEI when voids are found behind liner plates.

8. Our calculation of Tmin does not include any safety factor. A safety factor could be added to Tmin; however, this will involve more repairs and is not justified unless desired by the government or conditions are found indicating corrosion rates are higher than calculated.

9. Consult EEI when areas of thinning or pitting are found that exceed 12" in diameter.

CALCULATIONS

Parameters

- Original Thickness of Liner Plates: 0.250"
- Remaining Thickness at the Next Inspection: 0.10" based on the tank having no means to contain a leak
- Interval until the Next Inspection: 20 years maximum
- Year Tank Constructed: 1942
- Product Side Corrosion Rate: Assumed to be 0.00" per year based on the tank interior being coated and the life of the coating expected to exceed the interval until the next inspection

Corrosion Rate and Minimum Thickness

For a 20-year service interval starting in 2008, the next inspection would be in 2028. Using the API 653 straight-line method of calculating corrosion rates and a 0.10" remaining thickness at the next inspection in 2028, the external corrosion rate is as follows:

Maximum permissible metal loss = 0.250" – 0.10" = 0.150"
Age of tank in 2028 = 2028 - 1942 = 86 years

Considering the 0.150" of metal loss occurs over the life of the tank, the external corrosion rate is:

External corrosion rate = 0.150" / 86 years = 0.001744 in / year

Using this external corrosion rate, the expected metal loss that would have occurred thus far, (1942 to 2008) is:

Number of years from 1942 to 2008 = 66 years
Metal loss over 66 years = (0.001744 in / year) (66 years) = 0.115"

The minimum thickness required in 2008 to have 0.1" remaining thickness in 2028 at a corrosion rate of 0.001744 in / year is:

Tmin = 0.250" – 0.115" = 0.135"

Thus if Tmin = 0.135" in 2008; using an external corrosion rate of 0.001744" / year, the remaining thickness in 20 years (2028) is:

Metal loss occurring over the next 20 years = (0.001744" / yr) (20 years) = 0.035"
Remaining thickness at the end of the next 20 years = 0.135" – 0.035" = 0.10"
Use Tmin = 0.140" (0.135" rounded to 0.140")

Prepared by:
//signed/
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