Analysis the cause of leakage and repair of floor plates diesel fuel tank 20-D-2 at PT BADAK NGL Indonesia

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Abstract. PT. BADAK Natural Gas Liquefaction or better known as PT. BADAK NGL is a liquefied natural gas (LNG) company in Indonesia with installed capacity 22.5 MPTA of LNG. PT BADAK NGL has LNG, LPG, condensate, and diesel fuel storage tanks. There are two diesel fuel tanks available for supporting diesel equipment such as turbine diesel, marine boats, and vehicles. One of the diesel fuel tank, named 20-D-2, was constructed in 1975 based on standard API 650-Welded Tanks for Oil Storage. In 1996, after being operated for 21 years, plate replacement was needed on the tank floor and had been done as well. But in 2017, during five years of periodic inspection, severe corrosion was found again on the plate of the tank floor. In this paper, the effort to investigate the failure and plate repairment was reported. Visual observation at internal and external side on the plate of the tank floor was conducted based on NDT method (Non Destructive Testing) testing with MFL (Magnetic Flux Leakage). Plate thickness measurement of tank floor was also conducted with UT (Ultrasonic Testing). In addition, chemical analysis of residual fuel on the tank was performed to investigate sulphur concentration that potentially corrodes the plate. Scanning Electron Microscopy (SEM) was also performed to investigate the plate surface that has been corroded. Based on the analysis above, it was known that the leakage of 20-D-2 tank floor was caused by pitting corrosion, general corrosion and crevice corrosion due to rainwater that accumulated on the bottom of tank floor. Direct contact among rain water-soil-plate of tank floor was identified as the main cause of the leakage of tank floor. After leakage mechanism was identified as well, an appropriate method could be formulated to repair the tank to avoid the leakage.

1. Introduction

The operating license certificate knows as SKPP (Sertifikat Kelayakan Penggunaan Peralatan) of hydrocarbon storage tanks in PT Badak NGL had been ended in March 2017. As a recertification program, all hydrocarbon storage tanks (LNG, LPG, condensate, and diesel fuel tank) were inspected in 2017. As a part of this recertification program, Diesel Fuel Tank 20-D-2 was opened for internal inspection purposes. It was inspected externally by visual examination and UT (Ultrasonic Thickness) measurement. Internally, it was inspected by visual examination, Magnetic Flux Leakage (MFL) examination, UT measurement, and pit depth measurement. From external inspection, it showed no major non-conformity found. However, the internal inspection showed a major non-conformity on the floor plates of the tank. Metal loss and scattered pitting corrosion was found on the floor plates of the storage tank. Therefore, proper repair shall be conducted to restore the condition of the tank and to extend the SKPP.

This research was conducted to analyze the causes of corrosion that occur on 20-D-2 tank floor plates by carrying out several testing methods to find the root cause of the problem so that it can make an appropriate repair to this 20-D-2 tank leak.
2. Experimental design
In this paper, the authors examined the causes of corrosion occurred at the bottom plate of the 20-D-2 diesel fuel storage tank. The study began by studying the historical data from the Inspection Section about a 20-D-2 tank. Then the bottom plate sample was taken by cutting the corroded plate of bottom tank 20-D-2 for further analysis. Material and environmental aspects of 20-D-2 tank both visually, by performing non-destructive testing and using laboratory tests. For material, NDT methods like MFL and UT have been performed. In addition, Scanning Electron Microscopy or known as SEM (XRF) and Metal Analizer test were also performed to see the actual metal composition of it. The result of the analysis will be compared with a material composition that conforms to standard specification. Apart from it, the sulfur content of diesel fuel in the tank and the pH of the soil where the 20-D-2 tank stands were checked by laboratory tests.

3. Results and discussion
3.1. Visual observation
Visual inspection was carried out by the Inspection Section through internal inspection when the tank was offline by focusing on the welded parts and floor plates on the tank. From the result of internal inspections, the coating/lining of the bottom plate of the tank floor was peeled off. Pitting corrosion, general corrosion and crevice corrosion was found. Pitting corrosion occurred almost throughout the surface of bottom plate of the tank floor.

In addition, visual inspection was also carried out on the external side of the tank floor plate. From the results were found that the floor plate was seated on the ground with no concrete foundation. This can cause floor plate corrosion due to environmental exposure under the floor.

When performing the tests, the bottom plate of the tank floor was divided into ten parts with a particular configuration. The visual examination showed many pitting corrosions scattered on almost the entire surface of the tank floor. Visually, the plates at numbers 1/2 and 1/3 had more concentrations of pitting corrosion compared to other number plates. Therefore, a measurement of pitting depth (pit depth measurement) was used to determine the remaining thickness of the bottom plate.

![Figure 1. The layer of paint peeled off.](image-url)
3.2. Non-destructive testing

Non-destructive testing was performed to find out the remaining thickness of the defect on the floor plate. Based on API 653, joints. Identification of defects is carried out using Magnetic Flux Leakage (MFL), while for thickness measurements is done by Ultrasonic Testing (UT).

The result of MFL could be seen in Figure 5. It could be seen that defects were observed on all plates. However, not all defects observed from the MFL were in a critical state, only some of them were in a critical state.

Pit depth measurement was also performed on all plates to determine the deepest possible pitting. After measuring, the deepest pitting is on plate number 2/1, which had a depth of 3.94 mm.
Pitting corrosion was expected to occur due to contact with water accumulation on the internal side of the tank. Accumulation of water was guessed to have been there since the last time the tank was cleaned in 2006. Because the tank bottom plate was not coated at the last inspection resulting in pitting corrosion.

In Figure 5, it can be seen that the blue dot represents the defect on the underside of the tank floor plate. Then from the results of the MFL thickness measurements were made on each plate number using the UT method. Measurements were made on blue dots to determine the minimum thickness remaining on the plate. With the results of these measurements can be known thickness reduction on each plate by reducing the thickness of the initial plate known from the datasheet was 6.5 mm, with the UT reading on the bottom side of the tank floor plate.

After knowing the remaining thickness of the tank floor plate, then we can calculate the required thickness (Minimum Required Thickness) so that we can compare whether the remaining plate thickness is still in accordance with the Standard. Based on API Standard 653, calculating the required thickness minimum can use the formula in Sub-Chapter 2.6.3 regarding the minimum thickness for tank floor plates.

\[
MRT = (Minimum \ of \ RT_{bc} \ or \ RT_{ip}) - Or \ (St_{Pr} + UP_{r}) \quad (1)
\]

The value of Or is based on the next inspection schedule which is 5 years due to the latest conditions that indicate a defect in the previous inspection. Then the value of Or to be filled in Equation (1) was 5 years. StPr and UPr were the maximum corrosion rates on the upper and lower sides of the tank floor plate. The corrosion rate was obtained by dividing the thickness reduction by the total years since the tank was first built. While thickness reduction can be obtained from the maximum pit depth and minimum thickness. Meanwhile, the total year since the 20-D-2 tank was built since 1996 is 21 years.

All of the above data descriptions were used to find the RTbc or RTip value. To make it easier, we can define the minimum remaining allowable minimum (minimum thickness allowed) as RT. The results of these calculations show that many plates are still acceptable for the minimum thickness for the next inspection interval. Since the inspection was carried out with the help of the MFL method, it
can be seen that the highest thickness reduction occurs in plate number 1/2, which was 50% and the lowest thickness reduction occurs in plate 2/2, which was 35%.

3.3. Material composition testing

Material composition testing aimed to see the composition of the actual material composition used for 20-D-2 tank floor plate. In the datasheet, it was known that the material used was ASTM A36. Based on ASTM A36, the composition for A36 material is shown in Table 1.

| Tabel 1. ASTM A 36 material composition. |
|------------------------------------------|
| **Thickness, in. [mm]** | All | To % | Over ½ | Over 1½ | Over 2½ | Over 4½ |
| | | to ½ | to 1½ | to 2½ | to 4½ | to 4½ |
| | | [20] | [20 to 40] | [40 to 65] | [65 to 100] | [100] |
| Carbon, max, % | 0.25 | 0.25 | 0.26 | 0.26 | 0.27 | 0.29 |
| Manganese, % | ... | ... | 0.80-1.20 | 0.80-1.20 | 0.85-1.20 | 0.85-1.20 |
| Phosphorus, max, % | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| Sulfur, max, % | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Silicon, % | 0.40 max | 0.40 max | 0.40 max | 0.15-0.40 | 0.15-0.40 | 0.15-0.40 |
| Copper, min, % when copper steel is specified | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |

Then to determine the composition of the current tank flooring material, it was tested using a Metal Alloy Analyzer and SEM (Scanning Electron Microscopy) testing using the XRF method. The test was carried out by shooting at four points using Metal Alloy Analyzer.

**Figure 6.** Corroded sample from top side of 20-D-2 tank floor plate.

**Figure 7.** Corroded sample from bottom side of 20-D-2 tank floor plate.
From the metal alloy analyzer result in Table 1, it can be seen and compared with the A36 material standard in Table 2. Based on Table 2, the reference for the thickness plate was ¼ inch. The following comparison can be seen in Table 3. From the results of reading Table 3, it can be seen that Silicon and Sulfur products had levels that exceed the maximum limit of the ASTM A36 Standard.

### Table 2. Metal alloy analyzer result.

| Element | Point-1 | Point-2 | Point-3 | Point-4 |
|---------|---------|---------|---------|---------|
| Zr      | 0.019   | 0.036   | 0.005   | -       |
| Ti      | 0.054   | 0.043   | 0.034   | 0.124   |
| Si      | 8.49    | 8.01    | 3.21    | 3.45    |
| Mo      | 0.007   | -       | -       | -       |
| Mn      | 0.681   | 0.685   | 0.644   | 0.703   |
| Fe      | 90.61   | 90.93   | 95.84   | 95.5    |
| Cu      | 0.015   | 0.009   | 0.048   | -       |
| Co      | 0.13    | 0.223   | 0.115   | -       |
| Zn      | -       | 0.044   | 0.03    | 0.067   |
| Nb      | -       | 0.006   | -       | -       |
| Cr      | -       | 0.018   | 0.02    | 0.016   |
| S       | -       | -       | 0.052   | 0.112   |
| W       | -       | -       | -       | 0.028   |

### Table 3. Comparison of metal alloy metalizer results with ASTM A36 standard on 20-D-2 tank floor plate material.

| Product | Standard ASTM A36 | Metal Alloy Metalizer pada Corroded Sample | Metal Alloy Metalizer pada Furnished Sample |
|---------|-------------------|-------------------------------------------|---------------------------------------------|
| Cr, max (%) | 0.25 | 0.018 | - |
| Mn, max (%) | - | 0.703 | 0.731 |
| P, max (%) | 0.04 | - | - |
| S, max (%) | 0.05 | 0.112 | - |
| Si, (%) | 0.4 | 8.49 | 0.6 |
| Cu, min (%) | 0.2 | 0.048 | 0.021 |
3.4. Chemical analysis for sulphur content
The diesel fuel inside of 20-D-2 tank was taken as a sample for chemical analysis. The diesel fuel was analyzed by sending the sample to PT PERTAMINA RU V Laboratory to analyze whether there was sulfur content in it. The results of sulfur content analysis were the sulfur content of diesel fuel found 0.14% m/m (1400 ppm) from the maximum limit of 0.30% m/m (3000 ppm)

3.5. pH testing
pH testing was performed by taking soil where the location of the 20-D-2 storage tank is built as a sample. pH testing of soil was carried out in order to find out whether the soil was acidic, alkaline or neutral. Acidic soil tends to be more corrosive than neutral or alkaline soil. After testing the pH using litmus paper, it was found that the soil where the 20-D-2 location was built on alkaline soil with 8 pH values.

Based on the results of the explanation of several tests above, it can be seen in the results of visual inspection that 20-D-2 tank had no tank foundation so that the tank was seated right on the ground which causes accumulation of rainwater entering the gap between the tank floor and the ground resulting corrosion on the bottom plate of tank floor. In addition, from the results of material testing analysis with Metal Alloy Analyzer and XRF method, it can be concluded that the 20-D-2 tank floor material didn’t use standard material accordance with Standard ASTM A36 so the material could be said out-of-spec.

4. Alternative repair method
After knowing the cause of corrosion on the 20-D-2 tank floor plate, the next step was to determine the correct repair method for the 20-D-2 tank floor plate and in accordance with the criteria in API 653 Section 9. Some alternative repair methods that can be applied to tank 20-D-2 was as follows:

A. Repair by installing patch plates
The alternative to the first repair method was to patch the tank floor plate with a thin plate. Based on API 653 Section 9, the plates used for patching can be rectangular, square or circular. To do this patching, there are criteria that must be fulfilled, among others, there was a minimum patching distance between plates and a maximum plate thickness when the plates were stacked in three layers due to the patching plate. From the results of the MFL reading it can be seen that the distance between corrosion was too close to each plate so that the alternative repair method with partial patching on the 20-D-2 tank floor plate was not in accordance with the provisions in API 653 Section 9.

B. Repair by installing proper patch plates
The second alternative repair method was to install patch plates (additional plates) that meet all the rules in the API 653 Section 9. To accommodate all the rules, larger patch plates must be made and had a very large size which covers about half of all floor plates. Although this configuration was in accordance with Standard API 653 Section 9, there were obstacles if an alternative method of repair was carried out because the size of the patching plate was large and quite impossible to be inserted into the tank through the available manway tank. Therefore, the second alternative repair method was more complicated to be done than the first alternative.

C. Repair by replacing entire floor plates
The third alternative repair was by replacing all floor plates. This repair method was acceptable to be done based on API 653. Since the condition of floor plates was severe based on inspection result and calculation, and then it was possible to repair floor plates by replacing all floor plates. However, this alternative was only done if there were no other better alternatives.

D. Additional modification
Referring to the previous leakage in 2006, the 20-D-2 tank floor plate leaked within 10 years from the first replacement in 1996. If repairs were made only by replacing the entire tank slab as it was done in 1996, it was estimated the same case of leakage can occur again in the next 10 years after repairs. To
prevent this in the future, additional modifications based on the mechanism of the tank floor damage must be accommodated.

Based on the damage and leakage analysis described above, two findings are the dominant cause of tank leakage, so the follow-up of these findings is necessary. Some modifications can be made to the 20-D-2 tank as a follow-up as well as an improvement in the 20-D-2 tank so that similar cases do not recur. Follow-up carried out included the following:

1) Foundation Installation on 20-D-2 Tank: Installation of new storage tank foundation shall refer to Section 7 of API 650 – Welded Tanks for Oil Storage. There are four types of foundation mentioned in the standard. These four types of foundation are listed below:
   a) Earth foundation without a ringwall.
   b) Earth foundation with a concrete ringwall.
   c) Earth foundation with a crushed stone and gravel ringwall.
   d) Concrete slab foundation

   Except for the concrete slab foundation type, all these foundations are not directly categorized as a release prevention barrier. Release prevention barrier (RPB) means that if a leak seeps through floor plates, it could be detected immediately from the RPB (foundation) and not contaminates soil at that time. Since the main intention is to eliminate the contact between soil and bottom side of floor plates so corrosion will not occur there, then the concrete slab type foundation is the only type of foundation that could overcome the problem. However, installing the foundation could not directly prevent corrosion on the bottom side of the floor plates if there is still a gap between floor plates and the foundation. This gap could trap water and lead to crevice corrosion. Therefore, a proper seal shall be installed between floor plates and the foundation or at the tip of floor plates, to prevent water entrapment on the bottom of the floor plates.

2) Use of standard materials: From the results of material testing carried out with a metal alloy analyzer and XRF test, it can be seen that the composition of the floor plate material was not in accordance with ASTM A36 Standards so it can be said that the 20-D-2 floor plate material was out-of-spec. For this reason, if 20-D-2 tank floor plate replacement was carried out, it must be ensured that the plate material has an original certificate from the manufacturer concerned so that the material could be guaranteed according to the standard.

5. Conclusion
   • Damage mechanisms on the top side of floor plates were pitting and general corrosion due to the presence of water at the bottom of diesel fuel. Damage mechanisms on the bottom side of floor plates were general, pitting, and crevice corrosion due to direct contact between floor plates and soil.
   • The thickness reduction or thinning allowed in floor plates were varied from 35% to 50% for each plate. All floor plates have metal loss more than the mentioned percentage. Thus, all floor plates shall be repaired.

6. Recommendations
   • To conduct a repair on floor plates Diesel Fuel Tank 20-D-2 by replacing all plates.
   • F&PE Section is requested to design concrete slab as foundation referring to API 650.
   • Use standard material in accordance.

Acknowledgment
The author thanks First, Mr. Wiji Mangestiyono, ST, MT, and Mr. Vicky Indrafusa, ST, MT, as my assigned lecturers who always provide guidance and direction both in lessons and report making. Second, my family, especially my mom, who still supports me all the time. Third, Aan and Niken as my fun time. Fourth, Hani Rahmawati, who is my role model and always encourages me to get an
MSc. Fifth, Ayu Primastuti, who helps to build my confidence to do this Final Project in less than 2 months.

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