Comparing Material Carbon Steel and Stainless Steel 16” Pipeline Route
Sukowati-CPA (Pipe Stress Analysis and Internal Corrosion)

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ABSTRAK

Pipeline is a way to transporting fluids. Pipeline becomes a special choice because more optimal and easy to operate. There are two common ways to transporting crude oil. Transport vehicles (tanker ships and trucks) or pipeline system. Distribution of crude oil by pipeline system involves many components. Such as, pipes and valves.

This final project will discuss options available for pipeline design by Pipe Stress Analysis and Internal Corrosion. The purpose of this analysis is to determine deflection level of pipe, load applied on the pipe, Metal loss in the pipe and also method to make sure this pipe ready and safe to use. The method was made by reference, i.e. minimum price of pipe and also makes sure that this will comply with the government regulations.

Data required for this case study is a data pipeline along this part by JOB-PPEJ. These data are design reference for pipeline stress analysis calculations that will be passed by fluids of oil and gas. Pipe stress analysis will be done with manual calculation using ASME B31.8 code and will be compared by CAESAR II software for pipeline’s modeling.

Internal corrosion and Net cost flow analysis that used in this final project is to complete the analysis factor. H2S is present in the reservoir and increase the percentage of metal loss. Cost of maintenance more high if internal corrosion happen. Because of this, Internal Corrosion analysis and Net Cost Flow must be complete to make sure pipeline safe and no accident.

Keywords: Pipeline, Pipe Stress Analysis, Internal Corrosion, Net Cost Flow, CAESAR II.

I. Background

Pipeline is a way to transporting fluids. Pipeline becomes a special choice because more optimal and easy to operate. There are two common ways to transporting crude oil. Transport vehicles (tanker ships and trucks) or pipeline system. Distribution of crude oil by pipeline system involves many components. Such as, pipes and valves.

This final project will discuss options available for pipeline design by Pipe Stress Analysis and Internal Corrosion. The purpose of this analysis is to determine deflection level of pipe, load applied on the pipe, Metal loss in the pipe and also method to make sure this pipe ready and safe to use.

For analysis method, this project uses standard rules and codes, such as ASME B31.8, API RP 1102, and Decree of Mines and Energy Minister No. 300,K/38/M.pe/1997 about Pipeline Safety Oil and Gas Suppliers. The method was made by reference, i.e. minimum price of pipe and also makes sure that this will comply with the government regulations.

Pipeline stress analysis is to ensure that the system will be operated safely without an accident. Pipe stress can come from several sources. To ensure the safety of operations, we must combine the effects of all forces. Those forces are:

- Bending moment that occurs between supports. It is caused by the weight of pipe, fluid flow and dynamic conditions.
- Stress is caused by internal pressure in the pipe.
- Buckling moment (linear or tensional) that is caused by the displacement of thermal expansion.

2.1 General

The initial stage of pipeline design is conducted before any work commences on the construction. It is important that environmental and legal considerations are taken into account, for instance an environment impact assessment should be carried out to comply with authorities’ regulations as well as codes such as ASME and API. After the beforehand steps, detailed can be started. Firstly, diameter and inlet pressure are decided according to the maximum acceptable pressure drop along the length of the pipeline. Those parameters are calculated using appropriate flow equations for gas and liquid. Other design parameters will then follow, including choosing an appropriate wall thickness and material grade. Finally the maximum allowable operating stress will be decided according to the location of the pipeline route.

In plants, such as in LNG plant, petrochemical plant, fertilizer plants, nuclear plants, geothermal power
plant, gas plant, and also in the Onshore and Offshore plant, must have a good installation of pipeline design. Pipeline has a function to deliver fluid from one place to another. Material of fluid can be mixed by gas or water that has a certain pressure design and temperature. Because of the piping material is generally made from metal and different temperature in environment, expansion phenomena will be happen in this pipeline system. The pipeline project installation will be conducted using pipeline 16 " from Sukowati A to the CPA as long as 10 km and located adjacent with old pipe installation and constructed by JOB-PPEJ.

Figure 2.1. Flange of old pipe

Figure 2.1 shows a location of the old flange (8") before the pipe is installed transversely across the river. This pipe will be installed at the bottom of the Bengawan Solo river-bed.

The stress distribution analysis (stress analysis) is to find out the most optimum design of the pipeline and to ensure this system can properly and safely operate without any accident.  

2.2 General Explanation of Pipeline

The purpose of pipeline design in general can be classified as follows (Teddy, 2004):

- What kind of material that can be safe in working condition (pressure external / internal, temperature, corrosion, etc.). Material selection is crucial because it determines the overall system of reliability, cost factors and safety.
- What kind of standard code that will be applied in pipeline system design. The right selection of code will determine the direction of the overall design, both in terms of cost, reliability, safety design and stress analysis.

- Calculation and selection the thickness of the pipe cannot be done haphazardly or only based on intuition. Selection the thickness of the pipe (schedule number) must be looked criteria for adequate, safe and availability of stocks in the market.
- How can the pipeline systems will be connected from one to another.
- How planning and routing the system will be done. General arrangement and the routing should be done with due regard to safety aspects of design, pipe consumption to a minimum without disrupting and reducing the capabilities, functions and operations of the connected equipment.

2.3 Basic Theory

2.3.1 Standards and pipeline systems code

Pipeline system must consider the flexibility of technical and economical aspects. Flexibility in technical systems can be done by doing some analysis such as pipe stress analysis. Economic flexibility of the design is dependent on the financial policies of firms or industries. But the result must look codes and standards to ensure safety during the operation.

2.3.2 Load of Pipeline System

Pipeline received many loads, such as sustain load, expansion load, operating expenses and occasional load. Each loads that occurs in the system caused by the different type condition from the material and pipeline design or from the environment around the pipeline system. To make it safe, the loads both of internal and external load must be considered when analyzing this system. Analysis on pipeline systems is to ensure the safety during the life time.

2.3.3 Sustain Load

Sustain load is a load of the pipe that occur continuously. This load is caused by a combination of internal pressure (hoop stress) and heavy loads (weight of fluid and weight of pipe). Pipeline systems must be designed to hold heavy loads and the load of pipeline’s structure itself. In general, pipeline system has internal pressure load because fluids flowing inside. Pressure load has big influence on the stress report that occurs in the wall of pipe. From the data in the table below, the obtained weight pipe with a diameter of 16 "schedule 60 is 107.5 lb / ft and the weight of water 73.4 lb/ft.
Table 2.1 dimensions and weight of pipe

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Diameter outside (in)</th>
<th>Diameter outside (mm)</th>
<th>Weight (lb)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2.105</td>
<td>52.9</td>
<td>41.35</td>
<td>18.74</td>
</tr>
<tr>
<td>20</td>
<td>3.000</td>
<td>76.2</td>
<td>100.56</td>
<td>45.53</td>
</tr>
<tr>
<td>30</td>
<td>3.56</td>
<td>85.9</td>
<td>125.90</td>
<td>56.93</td>
</tr>
<tr>
<td>40</td>
<td>4.55</td>
<td>115.9</td>
<td>170.90</td>
<td>76.93</td>
</tr>
<tr>
<td>50</td>
<td>5.00</td>
<td>127.0</td>
<td>200.56</td>
<td>89.53</td>
</tr>
<tr>
<td>60</td>
<td>5.56</td>
<td>140.9</td>
<td>225.90</td>
<td>102.93</td>
</tr>
<tr>
<td>70</td>
<td>6.35</td>
<td>161.5</td>
<td>270.56</td>
<td>120.53</td>
</tr>
<tr>
<td>80</td>
<td>7.19</td>
<td>182.9</td>
<td>325.90</td>
<td>138.93</td>
</tr>
<tr>
<td>90</td>
<td>8.00</td>
<td>203.2</td>
<td>380.56</td>
<td>156.93</td>
</tr>
<tr>
<td>100</td>
<td>8.83</td>
<td>219.0</td>
<td>435.90</td>
<td>175.93</td>
</tr>
</tbody>
</table>

2.3.4 Expansion Load

Expansion load is a load that incurred as a result of thermal expansion in pipeline systems. Expansion load can be divided into:

- Thermal expansion because of the movement effect restrictions by the pipeline support while experiencing expansion.
- Thermal load because effect of large differences temperature in the wall pipe so as to cause stress.
- Load because differences coefficient of pipe which is composed of two or more different metal materials. Supported pipe installed along the pipeline system to sustain load and occasional, in case installation of 16 inch diameter pipe is restrained pipe along the river by the existing soil at a depth of 2 meters below the riverbed surface. However, if the increase temperature occur in pipeline systems during operating conditions, the pipeline will be expanded so that the cause of high stress in the fittings as well as at the point.

2.3.5 Operating Load

Operating load is a load that received by the pipe during the operation, it is a combination of sustained load and thermal load.

2.3.6 Occasional Load

Occasional load can be interpreted as a load of pipeline system that occur in only part period of the total period in operation of pipeline systems, such as:

- Snow, occur in the pipeline system located in the earth that has winter season. Very thick snow surface on certain sections along the pipe will increase the load that must be retained by the pipeline.
- Natural phenomena, such as hurricanes and earthquakes will cause dynamic condition on pipeline. Dynamic analysis of pipeline systems required to get distribute excess of weight that must be retained by the pipeline.

- Unusual operation plan is a mistake in operating conditions that be happen because negligence of the operator or procedural errors in operating system. In all equations the voltage that occurs in pipeline systems above, can then be combined to obtain the maximum stress values occur on the basis of the types of loading on the pipe. In the calculation of the types of loading pipes taken only.

Stress has a maximum value to obtain the accurate results and can be known whether the pipeline system is in safe operating condition or unsafe. Here is a stress equation based on loading types that occur in pipeline systems.

1. Sustain Load

   Maximum tension of the sustained load = Longitudinal Stress. Because internal pressure has a maximum value implies the value of hoop stress and radial stress.

2. Expansion Load

   Stress of pipe that occurs in the expansion load is a normal. This stress is caused by differences temperature between pipes. Moment and force which is already to be used as one parameter in the stress analysis of expansion load in pipeline systems.

3. Operating Load

   This Load is received by the pipe during the operation, this Load is a combination of sustained load and thermal load, in other words operating load can be written as follows

   Operating load = Expenses load + Sustain load

4. Occasional Load

   Stress at the occasional load = sustain load + occasional force. Occasional stress caused by external forces. Such as wind force, dynamic earthquakes force and gravity of falling objects.

2.4 Analysis of stress in the pipe

This analysis can be done by using several approaches that obtained from the formula ASME B31.8.

2.4.1 Hoop Stress

\[
\sigma_h = F_1 S T
\]

Where:
- \( F_1 \) = hoop stress factor design in Table 2.2
- \( p \) = internal design pressure, psi
- \( S \) = specified minimum yield strength, psi at Table 2.4
- \( Sh \) = hoop stress, psi
- \( T \) = temperature derating factor from Table 2.3
- \( t \) = nominal wall thickness, in.
Table 2.2 Design Factors for Offshore pipelines, platforms pipeline, and pipeline Risers

<table>
<thead>
<tr>
<th>Location</th>
<th>F1 Hoop Stress</th>
<th>F2 Longitudinal stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline</td>
<td>0.72</td>
<td>0.80</td>
</tr>
<tr>
<td>Platform Piping and Risers</td>
<td>0.50</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Table 2.3 Construction design factor

<table>
<thead>
<tr>
<th>Factor</th>
<th>Temperature °F</th>
<th>Construction type</th>
<th>Design Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>-200</td>
<td>(1000)</td>
<td>0.72</td>
</tr>
<tr>
<td>0.97</td>
<td>300</td>
<td>(600)</td>
<td>0.60</td>
</tr>
<tr>
<td>0.93</td>
<td>350</td>
<td>(650)</td>
<td>0.50</td>
</tr>
<tr>
<td>0.90</td>
<td>400</td>
<td>(700)</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Table 2.4 Tensile requirements for carbon steel

2.4.2 Longitudinal Stress

\[ |S_L| \leq F_2 S \]  

Where:
- \( A \) = cross sectional area of pipe material, in²
- \( F_a \) = axial force, lbs
- \( F_2 \) = longitudinal stress design factor
- \( M_i \) = in-plane bending moment, in.-lb
- \( M_o \) = out-plane bending moment, in.-lb
- \( M_t \) = torsional moment, in.-lb
- \( S \) = specified minimum yield strength, psi
- \( S_L \) = maximum longitudinal stress, psi
- \( S_a \) = Axial stress, \( \frac{F_a}{A} \)
- \( S_b \) = resultant bending stress, psi

\[ S_b = \left( (M_i)^2 + (M_o)^2 \right)^{1/2} \]

\( ii \) = in-plane stress intensification factor
\( io \) = out-plane stress
\( z \) = section modulus of pipe, in²

2.4.3 Combined Stress

\[ 2 \left( \frac{S_t - S_b}{2} \right)^2 + S_b^2 \right)^{1/2} \leq F_3 S \]

Where:
- \( A \) = cross-sectional area of pipe material, in²
- \( F_a \) = axial force, lbs
- \( F_3 \) = combined stress design factor from Table 2.1
- \( M_i \) = in-plane bending moment, in.-lb
- \( M_o \) = out-plane bending moment, in.-lb
- \( M_t \) = torsional moment, in.-lb
- \( S \) = specified minimum yield strength, psi
- \( S_L \) = maximum longitudinal stress, psi
- \( S_a \) = Axial stress, \( \frac{F_a}{A} \)
- \( S_b \) = resultant bending stress, psi

\[ S_b = \left( (M_i)^2 + (M_o)^2 \right)^{1/2} \]

\( Sh \) = hoop stress, psi

\( S_t \) = torsional stress, psi
- \( S_h \) = hoop stress, psi

2.5 Analysis Pipe from Sukowati to the CPA

Analysis of pipe between Sukowati - CPA regulated by API RP 1102. This analysis is to determine stress of buried pipe in each region and re-check whether the depth specified is not exceed the rules.

2.5.1 Length of Virtual Angkor

The length of virtual anchor is from starting position of pipe into the ground until the position where the pipe does not move because dynamic condition. Benefits of determine virtual anchor length is to know a position of anchor block. Whereas the function of anchor block is to hold the pipe to reduce movement due to thermal loads. Overburden load on the pipe is:

\[ W_c = C_d W B d^2 \]  

Where:
- \( W_c \) = Load on the pipe due to ground cover (lb/ft)
- \( C_d \) = coefficient of load
- \( W \) = density of soil (t)
- \( B \) = width of the buried pipe (ft)
To get the value of $C_d$ we need to consider graphic images like the one below 2.12 this:

![Graph to determine the value of $C_d$ due to soil load]

Total weight of the whole pipe is as below:

$$W_{total} = W_c + W_{fluid} + W_{material} + W_{pipe} \left( \frac{lb}{ft} \right)$$  \hspace{1cm} (2.26)

Total force of soil resistance is:

$$F_{soil} = \alpha W_{total} \quad \hspace{1cm} (2.4)$$

Longitudinal stress due to temperature:

Because of new pipeline locations are built buried in the solu river crossing it is necessary to calculate longitudinal stress due to temperature based on the pipe to get load and its formula can be written as follows:

$$SL = E \alpha (T_2 - T_1) - \sigma SH$$  \hspace{1cm} (2.29)

Style expansion due to temperature:

$$F_{thermal} = SL \times A_{pipe}$$

Where:

- $SL$ = Longitudinal stress, psi
- $SH$ = Hoop stress due to fluid flow, psi
- $T_1$ = Temperature during installation time
- $T_2$ = Maximum or minimum time temperature of operations
- $E$ = Modulus of elasticity, psi
- $\alpha$ = Coefficient linear thermal expansion, in $\frac{\circ}{\circ}F$
- $\sigma$ = Poisson ratio = 0.30 for steel

The starting point where no movement is calculated from the position of the pipe into the ground ($L$) are:

$$L = \frac{F_{thermal}}{F_{slope}} \quad \hspace{1cm} (2.30)$$

### 2.4 Internal Corrosion

Internal corrosion occurring during operational condition. Internal corrosion is caused by water or moisture trapped in the product. Again, this can be in the form of pitting or general corrosion, but the two main mechanisms are:

- Sweet corrosion
- Sour corrosion

These forms of corrosion are present in oil or gas pipelines and dependent on the content of hydrogen sulphide and carbon dioxide in the pipeline. NACE define a partial pressure of 0.05 psia, above which it is termed “sour” operating conditions.

#### 2.4.1 Sweet Corrosion

For sweet corrosions to occur, the pipeline must contain carbon dioxide and only small level of hydrogen sulphide. During this process, carbon dioxide dissolves in free water to form carbonic acid, which corrodes the pipeline wall. As the concentration of carbon dioxide increases, so does the corrosion rate. This type of corrosion tends to form areas of general and pitting corrosion.

#### 2.4.2 Sour Corrosion

As the concentration levels of hydrogen sulphide high, „sour” operating conditions start to prevail. Under these operating conditions the predominant failure mechanism is hydrogen cracking, of which there are several types.

- **Hydrogen-induced cracking (HIC).** HIC is associated with blistering of the pipe and also commonly called hydrogen pressure inducted cracking. During operation in sour conditions, hydrogen sulphide reacts with the pipeline steel to form a thin film of iron sulphide. Under these conditions, as corrosions occur, atomic hydrogen diffuses into the pipeline steel and recombines to form hydrogen gas at discontinuities in the microstructure. These discontinuities are usually areas of manganese sulphide inclusions formed during the manufacturing process or lamination features. Finally, as hydrogen gas begins to build up in these areas, this increases the local stresses, causing the pipe to bulge and form blisters. Crack then form and propagate through the pipe in the form of stepwise cracking.

- **Sulphide stress corrosion cracking (SSCC).** This failure mechanism is by hydrogen embrittlement and forms in a similar way to hydrogen-induced
cracking. Atomic hydrogen forms a solid solution in the steel microstructure, reducing the ductility of the material. Cracking then takes place under conditions. Higher-grade steels are particularly susceptible to this form of damage. In summary:

- SSCC is influenced by operating stress
- HIC is based on material properties
- The formation of crack and failure can be very rapid.

- **Stress-oriented hydrogen-induced cracking (SOHIC).** This form of damage occurs as a combination of HIC and SSCC. Here, stepwise cracks form in areas of high stress caused by build-up of hydrogen (HIC) ad stress cracking occurs owing to embrittlement in these areas.

3. Methodology

This chapter describes systematic measurements that will be done in this study. Methodology includes all activities, rules, codes, software, and analysis that are implemented to solve problems defined on this final project shown in figure 3.1.

![Figure 3.1](image1)

4. Data Analysis and Discussion

4.1 Data Analysis

Sukowati-CPA Pipeline route data that used in this final project is provided by JOB P-PEJ Turban, East Java. Pipelines that will be analyzed are 16-inch which is at normal depth conditions refers to ASME B31.8. as shown on figure 4.1.

4.2 Transfer Production

Crude Oil that will be transfers in this route is from JOB-PPEJ, Mobil Cepu Limited and PERTAMINA EP. Total Crude oil that will be transfers in this route is around 60000 BOPD (Barrel Oil per Day). Cumulative productions by JOB-PPEJ currently around 41,000 BOPD (average production until August 2010).

Transfers crude oil by pipeline is an effective way, because it is considered a safe, economical, and reliable. But installation of pipelines and other supporting have very high investment costs and if the failures happen will have a major impact due to lost such as danger of public safety and environment. Crude oil transmission system in this route is an onshore pipeline with length around 11 km. The standard technique is used as a base reference in the design, construction, operation, and maintenance are: standard ANSI / ASME B31.8 for "Gas Transmission & Distribution Piping Systems" and all this process should be supervised by BP-Migas as the policy holder in the Oil and Gas Indonesia. The Design of Pipeline as shown in Table 4.1.

![Figure 4.1. Pipeline Layouts Sukowati PPEJ-CPA JOB PPEJ](image2)
4.4 Modeling Results of Carbon Steel- API 5L Grd B sch 60

4.4.1 Modeling underground pipe

Before modeling this pipe with buried condition or modeling underground pipe. We must draw this pipe first in software Caesar II and we divide in to several node.

**Figure 4.2. Pipe above the land.**

After complete to drawing the sample, and then convert to an underground pipe (buried pipe). Ground data on underground pipes is like in the Table 4.1. This model has same type of soil model. This means that during the modeling process the input data only has 1 type of soil data according to the conditions and the data have been obtained from the JOB-PPEJ Tuban, East Java.

Table 4.1 Soil Condition model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction Coefficient (Optional if Str entered)</td>
<td>0.4</td>
</tr>
<tr>
<td>Soil Density (Required) (lb/ft^3)</td>
<td>0.069</td>
</tr>
<tr>
<td>Buried Depth to Top of Pipe (ft)</td>
<td>76.74</td>
</tr>
<tr>
<td>Fract. Angle (Sand-22-45, Silt-28-35, Clay-6-90 (deg))</td>
<td>0</td>
</tr>
<tr>
<td>Untrained Shear Strength (Clay) (lb/ft^2)</td>
<td>3.5</td>
</tr>
<tr>
<td>Overburden Compaction Multiplier (x1)</td>
<td>8</td>
</tr>
<tr>
<td>Yield Displacement Factor (x2)</td>
<td>0.015</td>
</tr>
<tr>
<td>Thermal Expansion Coefficient x10^6 (L/L deg F)</td>
<td>8.23</td>
</tr>
<tr>
<td>Temperature Change, install Operating (deg F)</td>
<td>170</td>
</tr>
</tbody>
</table>

After input soil data is completed. We will get a new plot of the buried pipe. We could see stress that received by pipe if buried in normal depth condition (2 meters). Figure 4.7 explains the restrained of pipe in the kind of nodes.

**Figure 4.3 Buried Pipe Model.**

In this soft ware we could see the report of stress that received by the model. The kind of report is such as:

**Figure 4.4 Stress Report of Buried Pipe.**

This stress report explains about the correlation between allowable stress of pipe and maximum stress that received by this buried pipe. And no over stress in this model.

4.4.2 Modeling Stress in Elbow 45 degree, 5D in Pig Launcher and Pig Receiver

Pig Launcher and Pig Receiver have different conditions to modeling. Different conditions happen because this system have part that above the land and buried into the land. So, the model must be complete to show both of those above mentioned conditions.

Before modeling this pipe with buried condition or modeling underground pipe, we must draw this pipe first in software Caesar II and we divide in to several node.

**Figure 4.5 Pig Launcher or Pig Receiver before input parameter condition.**

After complete to drawing the sample, and then convert to an underground pipe (buried pipe). Ground data on underground pipes is like in the Table 4.1. This model has same type of soil model. This means that during the modeling process the input data only has 1 type of soil data according to the conditions and the data have been obtained from the JOB-PPEJ Tuban, East Java

After soil data input is completed. We will get a new plot of the buried pipe. We could see stress that received by pipe if buried in normal depth condition (2 meters). Figure 4.7 explains the restrained of pipe according to the nodes.

**Figure 4.6 Modeling Pig Launcher and Pig Receiver after input stress condition.**

In Caesar 4.2 software we could see the report of stress that received by the model. The typical report is as follow:

**Figure 4.7 Stress Report of Buried Pipe.**
4.4.3 Modeling Stress in Elbow 45 degree, 5D in Pig Launcher and Pig Receiver

Pig Launcher and Pig Receiver have different conditions to modeling. Different conditions happen because this system have part that above the land and buried into the land. So, the model must be complete to show both of those above mentioned conditions.

Before modeling this pipe with buried condition or modeling underground pipe. We must draw this pipe first in software Caesar II and we divide it into several node.

In this software we could see the report of stress that received by the model. The typical report is as follow:

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>BENDING</th>
<th>TORSION</th>
<th>SIG'S</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODES</td>
<td>STRESS</td>
<td>STRESS</td>
<td>IN/OUT PLANE STRESS</td>
</tr>
</tbody>
</table>

Figure 4.7a Stress Report of Pig launcher and Pig Receiver data.

This stress report explains about the correlation between allowable stresses of pipe and maximum stress that received by this buried pipe. And no over stress in this model.

4.4.4 Modeling Stress in Elbow 45 degree, 5D in Shutdown Valve.

In the Shutdown Valves have different conditions to modeling. Different conditions happen because in this system have a part that above the land and buried to the land. So, the model must be complete to show both of those above mentioned conditions.

Before modeling this pipe with buried condition or modeling underground pipe. We must draw this pipe first in software Caesar II and we divide it into several node.

After complete to drawing the sample, and then convert to an underground pipe (buried pipe). Ground data on underground pipes is like in the Table 4.1. This model has same type of soil model. This means that during the modeling process the input data only has 1 type of soil data according to the conditions and the data have been obtained from the JOB-PPEJ Tuban, East Java.

Figure 4.7a Modeling Pig Launcher and Pig Receiver after input stress condition.
model has same type of soil model. This means that during the modeling process the input data only has 1 type of soil data according to the conditions and the data have been obtained from the JOB-PPEJ Tuban, East Java.

After complete the soil data. We will get a new plot of the buried pipe. We could see stress that received by pipe if buried in normal depth condition (2 meters). This picture explains the restrained of pipe in the kind of nodes.

“Piping systems shall be designed to have sufficient flexibility to prevent thermal expansion or contraction from causing excessive stresses in the piping material. Flexibility shall be provided by the use of bends, loops, or offsets, or provision shall be made to absorb thermal changes by the use of expansion joints or couplings of the lip joints type or expansion joints of the bellows type. If expansion joints are used, anchors or ties of sufficient strength and rigidity shall be installed to provide for end forces due to fluid pressure and other causes.” (ASME B31.8: Page 22).

Because of that, the expansion pipe must be given a support to reduce stress that happens by change of temperature. Support is given in the node with “green” color. In Caesar 4.2 software we could see the report of stress that received by the model. The typical report is as follow:

<table>
<thead>
<tr>
<th>CAESAR II STRESS REPORT</th>
<th>FILE: ALL RUNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEMENT</td>
<td>NODES</td>
</tr>
<tr>
<td>BENDING</td>
<td>STRESS</td>
</tr>
<tr>
<td>MAX INTENSITY:</td>
<td>00462.3</td>
</tr>
<tr>
<td>MAX STRESS:</td>
<td>76159.2</td>
</tr>
<tr>
<td>BENDING STRESS:</td>
<td>4537.8</td>
</tr>
<tr>
<td>AXIAL STRESS:</td>
<td>18363.2</td>
</tr>
<tr>
<td>NO MAX INTENSITY:</td>
<td>00462.3</td>
</tr>
</tbody>
</table>

Figure 4.11 Stress on Expansion Pipe.

In this case, pipe is not buried into the soil but only above the land with supports. This kind of pipe is for make sure if pipe is not broken when the temperature down or up. This expansion pipe is given before and after Bengawan Solo River Crossing.

Before modeling this pipe, we must draw this pipe first in software Caesar II and we divide in to several nodes.

4.4.5 Modeling Stress in Elbow 90 degree, 5D in Expansion Pipe.

Before modeling this pipe, we must draw this pipe first in software Caesar II and we divide in to several nodes.

4.4.6 Modeling Stress in Elbow 45 degree, 5D in Buried Pipe.

Before modeling this pipe with buried condition or modeling underground pipe. We must draw this pipe first in software Caesar II and we divide in to several node.

4.4.7 Modeling Stress in Elbow 45 degree, 5D in Underground Pipe.

Before modeling this pipe with buried condition or modeling underground pipe. We must draw this pipe first in software Caesar II and we divide in to several nodes.

After complete to drawing the sample, and then convert to an underground pipe (buried pipe). Ground data on underground pipes is like in the Table 4.1. This model has same type of soil model. This means that during the modeling process the input data only has 1 type of soil data according to the conditions and the data have been obtained from the JOB-PPEJ Tuban, East Java.

After complete the soil data. We will get a new plot of the buried pipe. We could see stress that received by pipe if buried in normal depth condition (2 meters). This picture explains the restrained of pipe in the kind of nodes.
In this software we could see the report of stress that received by the model. The typical report is as follow:

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>STRESS REPORT</th>
<th>FILE: BURIED PIPE</th>
<th>DATE: APR 19, 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODES</td>
<td>BENDING STRESS</td>
<td>15000.0</td>
<td>15000.0</td>
</tr>
<tr>
<td></td>
<td>TORSIONAL STRESS</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>AXIAL STRESS:</td>
<td>3563.2</td>
<td>3563.2</td>
</tr>
<tr>
<td></td>
<td>3D MAX INTENSITY:</td>
<td>9912.8</td>
<td>9912.8</td>
</tr>
</tbody>
</table>

In this software we could see the report of stress that received by the model. The typical report is as follow:

---

4.5 Modeling Results of Stainless Steel- ASTM A 312 304N-S30451

4.5.1 Modeling underground pipe

Before modeling this pipe with buried condition or modeling underground pipe. We must draw this pipe first in software Caesar II and we divide it to several node.

After complete to drawing the sample, and then convert to an underground pipe (buried pipe). Ground data on underground pipes is like in the Table 4.1. This model has same type of soil model. This means that during the modeling process the input data only has 1 type of soil data according to the conditions and the data have been obtained from the JOB-PPEJ Tuban, East Java.

After complete the soil data. We will get a new plot of the buried pipe. We could see stress that received by pipe if buried in normal depth condition (2 meters). This picture explains the restrained of pipe in the kind of nodes.

---

4.5.2 Modeling Stress in Elbow 45 degree, 5D in Pig Launcher and Pig Receiver 1st support

Pig Launcher and Pig Receiver have different conditions to modeling. Different conditions happen because this system have part that above the land and buried into the land. So, the model must be complete to show both of those above mentioned conditions.

Before modeling this pipe with buried condition or modeling underground pipe. We must draw this pipe first in software Caesar II and we divide it to several node.

After complete to drawing the sample, and then convert to an underground pipe (buried pipe). Ground data on underground pipes is like in the Table 4.1. This model has same type of soil model. This means that
during the modeling process the input data only has 1 type of soil data according to the conditions and the data have been obtained from the JOB-PPEJ Tuban, East Java.

After complete the soil data. We will get a new plot of the buried pipe. We could see stress that received by pipe if buried in normal depth condition (2 meters). This picture explains the restrained of pipe in the kind of nodes.

Figure 4.20 Modeling Pig Launcher and Pig Receiver after input stress condition.

In this software we could see the report of stress that received by the model. The typical report is as follow:

<table>
<thead>
<tr>
<th>CASEA II STRESS REPORT</th>
<th>FILE: Pig Launcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE 1 (OPF) Wt1=PI</td>
<td>DATE: JUNE 5, 2011</td>
</tr>
</tbody>
</table>

**--- Stress (lb./sq.in.) ---**

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>BENDING</th>
<th>TORSION</th>
<th>SIF'S</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODES</td>
<td>STRESS</td>
<td>STRESS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IN/OUT PLANE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.21 Stress Reports of Pig Launcher and Pig Receiver.

This stress report explains about the correlation between allowable stresses of pipe and max stress that received by this buried pipe. And no over stress in this model.

4.5.3 Modeling Stress in Elbow 45 degree, 5D in Pig Launcher and Pig Receiver 2nd support

Pig Launcher and Pig Receiver have different conditions to modeling. Different conditions happen because this system have part that above the land and buried into the land. So, the model must be complete to show both of those above mentioned conditions.

Before modeling this pipe with buried condition or modeling underground pipe. We must draw this pipe first in software Caesar II and we divide in to several node.

Figure 4.20a Modeling Pig Launcher and Pig Receiver after input stress condition.

In this software we could see the report of stress that received by the model. The typical report is as follow:

<table>
<thead>
<tr>
<th>CASEA II STRESS REPORT</th>
<th>FILE: Pig Launcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE 1 (OPF) Wt1=PI</td>
<td>DATE: MAY 5, 2011</td>
</tr>
</tbody>
</table>

**--- Stress (lb./sq.in.) ---**

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>BENDING</th>
<th>TORSION</th>
<th>SIF'S</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODES</td>
<td>STRESS</td>
<td>STRESS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IN/OUT PLANE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.21a Stress Reports of Pig Launcher and Pig Receiver.

This stress report explains about the correlation between allowable stresses of pipe and max stress that received by this buried pipe. And no over stress in this model.

4.5.4 Modeling Stress in Elbow 45 degree, 5D in Shut Down Valve.

Shutdown Valves have different conditions to modeling. Different conditions happen because in this system have a part that above the land and buried to the land. So, the model must be complete to show both of those above mentioned conditions.

Before modeling this pipe with buried condition or modeling underground pipe. We must draw this pipe first in software Caesar II and we divide in to several node.

Figure 4.19a Pig Launcher or Pig Receiver before input parameter condition.

After complete to drawing the sample, and then convert to an underground pipe (buried pipe). Ground data on underground pipes is like in the Table 4.1. This model has same type of soil model. This means that during the modeling process the input data only has 1 type of soil data according to the conditions and the data have been obtained from the JOB-PPEJ Tuban, East Java.

After complete the soil data. We will get a new plot of the buried pipe. We could see stress that received by pipe if buried in normal depth condition (2 meters). This picture explains the restrained of pipe in the kind of nodes.

Figure 4.19b Pig Launcher or Pig Receiver after input stress condition.

In this software we could see the report of stress that received by the model. The typical report is as follow:

<table>
<thead>
<tr>
<th>CASEA II STRESS REPORT</th>
<th>FILE: Pig Launcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE 1 (OPF) Wt1=PI</td>
<td>DATE: MAY 5, 2011</td>
</tr>
</tbody>
</table>

**--- Stress (lb./sq.in.) ---**

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>BENDING</th>
<th>TORSION</th>
<th>SIF'S</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODES</td>
<td>STRESS</td>
<td>STRESS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IN/OUT PLANE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.20b Stress Reports of Pig Launcher and Pig Receiver.

This stress report explains about the correlation between allowable stresses of pipe and max stress that received by this buried pipe. And no over stress in this model.
After complete the soil data. We will get a new plot of the buried pipe. We could see stress that received by pipe if buried in normal depth condition (2 meters). This picture explains the restrained of pipe in the kind of nodes:

This stress report explains about the correlation between allowable stress of pipe and max stress that received by this buried pipe. And no over stress in this model.

Before modeling this pipe, we must draw this pipe first in software Caesar II and we divide in to several node.

**4.5.6 Modeling Stress in Elbow 45 degree, 5D in Buried Pipe.**

Before modeling this pipe with buried condition or modeling underground pipe. We must draw this pipe first in software Caesar II and we divide in to several node.
After complete to drawing the sample, and then convert to an underground pipe (buried pipe). Ground data on underground pipes is like in the Table 4.1. This model has same type of soil model. This means that during the modeling process the input data only has 1 type of soil data according to the conditions and the data have been obtained from the JOB-PPEJ Tuban, East Java.

After complete the soil data. We will get a new plot of the buried pipe. We could see stress that received by pipe if buried in normal depth condition (2 meters). This picture explains the restrained of pipe in the kind of nodes.

In this soft ware we could see the report of stress that received by the model. The kind of report is such as:

Table 4.2 Report of Pipe Stress Analysis using Caesar II

<table>
<thead>
<tr>
<th>Case</th>
<th>Node</th>
<th>Stress</th>
<th>Node</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>29</td>
<td>3563.2</td>
<td>30</td>
<td>4826.6</td>
</tr>
<tr>
<td>B</td>
<td>115</td>
<td>33915.8</td>
<td>115</td>
<td>47505.8</td>
</tr>
<tr>
<td>C</td>
<td>50</td>
<td>9222.8</td>
<td>50</td>
<td>13592.9</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>7653.2</td>
<td>20</td>
<td>11224.8</td>
</tr>
<tr>
<td>E</td>
<td>40</td>
<td>4098.5</td>
<td>110</td>
<td>5431.6</td>
</tr>
<tr>
<td>F</td>
<td>13</td>
<td>3700.9</td>
<td>30</td>
<td>4037.8</td>
</tr>
</tbody>
</table>

4.7 Internal Corrosion

Because H2S present in reservoir, so effect of corrosion happen in the pipeline system. Metal loss because of Internal corrosion can make this system failure. So we need some analysis to make solution of this phenomena as shown in figure 4.30.

Based on this result, minimum thickness of carbon steel and stainlees steel is enough to make this pipeline system safe to operate until 20 years.

Stainless Steel has a good result for resistance of corrosion because of percentage Cr element. Some characteristic of stainless steel are:

- Superior resistance to corrosion and heat under various condition
- Superior workability as well as excellent mechanical properties both in low and elevated temp
- Have bad affect of welding on HAZ, Weld metal and Base metal.

Austenite Stainless steel has a few of problem such as:

- Distortion caused by welding
  - High linear expansion makes large deformation.
- Cracking of weld metal
  - Hot Cracking.
- Corrosion of grain boundaries in the HAZ (Weld decay)
  - Intergrualar corrosion
  - Weld decay, Knife line attack
- Stress Corrosion Cracking SCC
Intergranular Corrosion

- Knife line can be prevented by heat treatment to 870 to 900°C allowing the full precipitation of TiC and NbC.

Stress Corrosion Cracking

- Biggest problem of austenite stainless steel are more than 50% are Stress corrosion problem.
- Caused by Residual tensile stress (Residual stress) and corrosion environment.
- SCC occurs in the HAZ and base metal, but less frequently in weld metal caused of ferrite in weld metal.

**HOW TO REDUCE INTERGRANULAR CORROSION**

- Heat treatment should be performed on 1000º to 1500ºC after welding to make chromium carbide decomposed to be solid solution again.
- Low carbon steel 304 L and 316 L and stabilized stainless steel such as 347 type containing niobium can easily form carbide.
- Welding heat input should be reduced or water cooling should be adopted to increase cooling rate to pass 800º-500º quickly.
- Weld metal has a good distribution of ferrite which contain much chromium inter granular make higher corrosion resistance.
- Figure 4.32 show how the ferrite in weld metal influences the intergranular corrosion.

## 4.7 Net Cost Flow

Table 4.3 Report of Pipe Stress Analysis using Caesar II

<table>
<thead>
<tr>
<th></th>
<th>TOTAL INVESTMENT</th>
<th>NET COST FLOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>API 5L Grade B sch 60 + Accessories</td>
<td>USD 2,010,981.6</td>
<td>USD 33,464,218,608.4</td>
</tr>
<tr>
<td>ASTM A 312 304N + Accessories</td>
<td>USD 1,894,801.0</td>
<td>USD 33,464,334,699.0</td>
</tr>
<tr>
<td>Maintenance</td>
<td>USD 1,761,800,500.0</td>
<td></td>
</tr>
<tr>
<td>Total Cost of Project + Maintenance</td>
<td>USD 1,763,391,391.6</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>USD 1,763,275,301.0</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL REVENUE FOR 20 YEARS**

<table>
<thead>
<tr>
<th></th>
<th>USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>REVENUE</td>
<td>35,227,610,000.0</td>
</tr>
</tbody>
</table>

**TOTAL NET COST FLOW FOR CARBON STEEL**

**TOTAL NET COST FLOW FOR STAINLESS STEEL**

Based on this result, carbon steel is cheaper than stainless steel because the cost to install stainless steel pipe is more expensive.

## 5. Conclusions and Suggestion

### 5.1 Conclusions

Based on analysis and calculations according to ASME B31.8, ASME B31.3, APIRP 1102 and modeling with CAESAR 4.2, some point of conclusions in the pipeline design in Sukowati-CPA route are as follow:

1. Stress on the pipe will proportionally increase be as a result of increasing inputs of pressure and temperature.
2. Regarding modeling simulations, at the 665 psi operating pressure, the pipe stress is still under allowable condition. This is due to the maximum allowable pipe stress is 35000 psi. Therefore, all sections of pipeline are not overstress. But, in other condition stainless steel with different support had an overstress. This is happen because of incorrect selection of support. So, other type shall be provided to need for reduce overstress.
3. Both Carbon Steel-API 5L grade B schedule 60 and Stainless Steel ASTM A 312 304N-S30451 are still safe to operate. These conditions have also take in to account the safety factor (thickness material) for metal loss of internal corrosion for 20 years. As shown on below figure.
4. Metal loss rate of carbon steel is faster than stainless steel because chemical composition of stainless steel (Cr, Ni) will reduce corrosion.
5. The use of Stainless Steel ASTM A 312 304N-S30451 is still safe in corrosion condition because of Cr and Ni. But stainless steel has a bad affect of welding i.e. Haz, weld metal and base metal. So need a treatment i.e preheating.
6. The Total Cost of this project will increase if we use carbon steel material, because cost project and maintenance of carbon steel is more expensive than stainless steel. The percentage cost of carbon steel is 6% higher than cost of stainless steel.

### 5.2 Suggestions

There are a few suggestions in this final, among other

1. The value of stress in this system can be decrease if a kind of support is right and built in the right place with the right choice such as material and safety factor.
2. After the stress analysis can proceed with the analysis of reliability and fatigue life calculations.
6. Reference

5. Soewify. Welding of Stainless Steel, Department of Shipbuilding Engineering, Institute Technology of 10th Nopember Surabaya.