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Pipe Stress Analysis of the Steam Pipe of Project Tidore Power Plant (2 X 4 MW) Using CAESAR II

Franky G Pasaribu [1,*], Johny Wahyuadi Mudaryoto [2], and Robert H Pasaribu [3]

[1] Department of Metallurgical and Materials Engineering, Universitas Indonesia, Depok, Indonesia
* Correspondence: frankypasaribu14@gmail.com

Abstract: Pipe stress analysis is an important step to ensure that the piping system can function properly and safely. The main goal is to ensure that the piping design can withstand the pressure and load without failure. Pipe stress analysis is essential because piping systems in power plants are subjected to various loading conditions, including internal pressure, thermal expansion, self-weight, and external forces. Proper analysis helps to prevent excessive deformation, leakage, fatigue, and potential of failured. It also ensures compliance with ASME B31.1 requirements by verifying allowable stresses, flexibility, and support configuration, thereby improving system reliability and operational safety. This analysis follows the guidelines of ASME B31.1 Power Piping, which regulates the design and construction of piping in a Power Plant. The analysis was performed using Caesar II software. This software helps evaluate various working conditions and measure the stresses in the piping system. From the analysis report, no overstress problems were found in the steam piping line. Since the system already meets ASME B31.1 standards, no changes were needed to the number, position, or type of pipe supports.

Keywords: Stress; Load; Overstress; Pipe Support

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1. Introduction

The Indonesian government is striving to increase the development of affordable and efficient power generation systems to meet the country's electricity needs. A piping system in a power plant serves a primary function as a transportation pathway for fluid flow, whether gas or liquid, in hot, cold, or pressurized conditions. A piping system is essentially a system for delivering fluid from one location to another to enable subsequent processes.

However, the piping system is complex, and its design must consider many aspects to achieve an effective and efficient system. Stress that occurs in a pipeline is predominantly caused by the design itself. In a pipeline system, branching may occur, which becomes a critical factor that must be carefully considered due to the stress it introduces. By understanding and analyzing the magnitude of stress, it is possible to minimize it to ensure safe operation and extend the lifespan of the piping system [2].

Today, several software tools are available to assist in stress analysis of piping systems. These tools comply with the standard requirements for stress analysis aids, as they are based on established piping codes and standards. Each software has its similarities and differences.

CAESAR II was used, because this software is one of the most widely used pipe stress analysis software in various industries due to its comprehensive analytical capabilities and strong compliance with international standards such as ASME B31.1. The software allows detailed modeling of piping geometry, simulation of operating conditions, and accurate evaluation of stresses, displacements, and support loads. CAESAR II selected in this study because it offers reliable calculation accuracy, an extensive material database, and user-friendly modeling features that support efficient analysis. CAESAR II provides several advantages, including complete stress analysis functions such as thermal, pressure, occasional, and dynamic loads. CAESAR II also provide clear visualization of results, and can integration with 3D design tools.

Based on the background described, the main issues discussed in this study are the stress analysis of the steam line pipe from the superheated boiler to the steam turbine at the existing PLTU Tidore, North Maluku [6].

The analysis is limited to the steam line route from the superheater boiler to the Main Steam Valve and evaluates the efficiency of the pipe support system. This study refers solely to the ASME B31.1 standard. It does not cover topics such as corrosion, corrosion protection systems, pipe installation processes, detailed calculations of stress, forces, and moments, nor does it consider pressure drop, heat loss, friction loss, or the impact of seismic and wind loads. All welded joints are assumed to comply with the ASME BPV Section IX code and standards [1].

The main objective of this study is to conduct piping stress analysis to ensure that the piping system operates safely and complies with the relevant standards, particularly ASME B31.1 [1] [3]. This analysis is essential to minimize the actual loads (forces, moments, and stresses) occurring on the pipe and equipment nozzles, so they remain within the limits set by international codes and standards such as ASME, ANSI, API, WRC, and NEMA [7][8]. This analysis focuses specifically on static loads, and proper support installation plays a vital role in preventing system failures or damage during operation due to static and dynamic loading conditions [11].

The scope of this analysis falls under the ASME B31.1 (Power Piping) standard, which is widely used in industrial applications such as power plants [2][6]. Stress analysis is carried out to ensure that the piping routes, nozzle loads, and support placements are appropriately designed so that the resulting stress does not exceed the maximum limits specified by the standard ASME B31.1[1]. To perform this analysis, piping engineers commonly use specialized software tools such as CAESAR II [4][5].

2. Materials and Experimental Methods

The following data is inputted into the software and obtained from the isometric drawing with line number 8-LB-20116-F1-H100, from the boiler to the main steam valve of the turbine at the Tidore Coal-Fired Power Plant (PLTU Tidore), North Maluku which is the design and operating condition based on **Table 1**.

Table 1. Pipe Design and Operation

Parameters	Value	Unit
Pipe Identification	8-LB-20116-F1-H100	-
Material	ASTM A 335 P11 Ferritic Alloy-Steel	-
Yield Strength	60,190.7	Psi
Tensile Strength	29,732.7	Psi
Design Code	ASME B31.1	-
Pipe Products	Steam	-
Nominal OD	219.1	mm
Thickness	18.26	mm
CA	3.175	Mm
Design Temperature	500	^{0} C
Operating Temperature	490	^{0} C
Design Pressure	8,296.159	Psi
Operating Pressure	7,541.96	Psi
Insulation	Calcium Silicate	
Insulation Thickness	100	mm

A literature study was conducted to obtain relevant information for this final project. The information was gathered from books, journals, PLTU Tidore data, the CAESAR II manual, and various other sources.

In applying design code standards, engineers must understand the basic principles of pipe stress and related concepts. A pipe is considered to have failed if the internal stress exceeds the allowable stress of the material. Stress is a vector quantity, meaning it has both magnitude and direction. The magnitude of stress is defined as force (F) divided by area (A). To define the direction of stress in a pipe, three principal axes are used, arranged perpendicularly as shown in Figure 1.

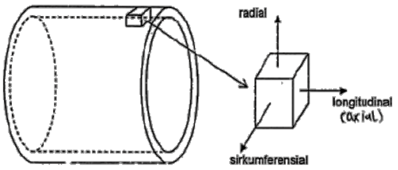


Figure 1. Directional Stress in Piping

Based on this simple definition, two key terms need to be clearly understood: internal stress and allowable stress. Internal stress is caused by external loads such as dead weight, internal pressure, and thermal expansion. It depends on the pipe's geometry and the material used. On the other hand, allowable stress is mainly determined by the material properties and how the pipe is manufactured. These two stress values are compared using failure theories.

When discussing code standards, it is essential to distinguish between the two types of pipe stress:

- Actual pipe stress is obtained by strain gauge measurement or manual/ software-based calculation.
- Code pipe stress, which is calculated using stress formulas defined in a specific code standard.

The axis perpendicular to the pipe wall and pointing outward from the pipe center is called the radial axis. The axis lying along the pipe wall but perpendicular to the longitudinal axis is the tangential or circumferential axis. The longitudinal axis lies in the middle of the pipe wall and runs parallel to the length of the pipe.

2.1 Principle Stresses in Piping

a. Longitudinal Stress (SL)

Longitudinal stress, also called axial stress, acts in the direction parallel to the longitudinal axis of the pipe. This stress is considered positive if compressive (caused by pushing forces). In piping systems, longitudinal stress occurs due to internal pressure forces and bending moments. An illustration of this can be seen in Figure 2.

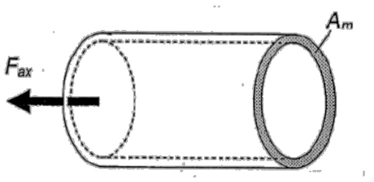


Figure 2. Direction of Pipe Axial Force

$$S_L = \frac{F_{ax}}{A_m}$$

Where:

F_{ax} = internal axial force A_m= cross-sectional area of the pipe material $= \pi d_m t$
d_{md}= mean diameter of the pipe
d_{od} = outer diameter of the pipe
d_{id} = inner diameter of the pipe

b. Effect of Pipe Pressure

For simplicity, this final equation is often written in a conservative form:

$$S_L = \frac{P d_o}{4t}$$

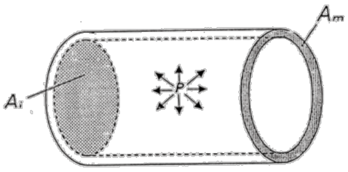


Figure 3. Direction of Force Due to Pipe Pressure

c. Effect of Deflection Moment

$$S_L = \frac{M_b C}{I}$$

Where:

- Ro = outer radius of the pipe
- Z = section modulus (a geometric property of the pipe's cross-section) $= \frac{I}{R_o}$

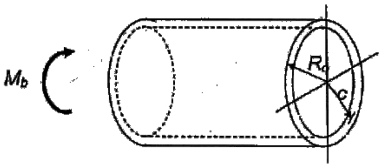


Figure 4. Direction Effect of Pipe Deflection Moment

d. Overall Longitudinal Stress

Overall longitudinal stress can be seen in Figure 5 below:

$$S_L = \frac{F_{ax}}{A_m} + \frac{Pd_o}{4t} + \frac{M_b}{Z}$$

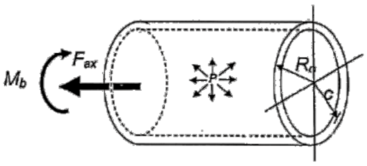


Figure 5. Overall Longitudinal Stress

e. Hoop Stress

$$S_h = \frac{Pd_o}{2t}$$

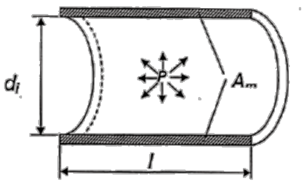


Figure 6. Direction of Circumferential Stress

f. Torsion Moment

$$\tau = \frac{M_T}{2Z_{max}}$$

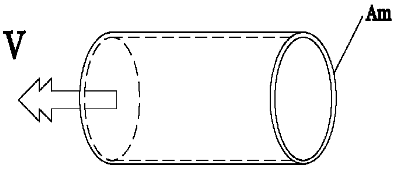


Figure 7. Torsion Moment

2.2 Analysis with ASME B31.1

a. Sustained Load

The stress that occurs due to sustained loads is the total longitudinal stress SL caused by internal pressure, weight, and other sustained loads. This stress must not exceed the allowable stress Sh. It can be expressed mathematically as:

$$SL = \left(\frac{PDo}{4tn}\right) + 1000\left(\frac{0.75iMa}{Z}\right) \leq 1.0Sh$$

b. Occasional Load

The stress that occurs due to occasional loads is the total longitudinal stress caused by internal pressure, weight, and other sustained loads, plus the additional stress from occasional events such as wind or earthquakes. This total stress must not exceed 1.33 times the allowable stress Sh. It can be written mathematically as:

$$So = \left(\frac{PD_o}{4t_n}\right) + 1000\left(\frac{0.75iMa}{Z}\right) + 1000\left(\frac{0.75iMb}{Z}\right) \leq KS_h$$

c. Expansion Load

The stress caused by thermal expansion and/or displacement is referred to as expansion stress Se. This stress arises due to changes in temperature or movement of the piping system, and it is calculated as follows:

$$S_e = 1000\left(\frac{iM_o}{Z}\right) \leq S_a + f(S_h - S_l)$$

This limit ensures that the pipe material can safely withstand the stress caused by thermal growth and displacement cycles without failure due to fatigue or cracking.

$$S_A = f(1.25S_C + 0.25S_h)$$

3. Results and Discussion

3.1 Analysis

To properly design a piping system, every engineer must understand how the system behaves under different loads, as well as the design codes and standards that apply. The behaviours of a piping system can be described using physical parameters such as displacement, acceleration, stress, force, moment, and other related quantities.

Design codes were developed in industrial countries as a response to past failures in piping systems that were not designed safely. Therefore, the main goal of these codes is safety.

Flexibility analysis, as required by the codes, is also aimed at ensuring safety. In general, the main objectives of pipe stress (or flexibility) analysis are:

- To calculate the stress in the pipe and ensure it stays within the allowable limits set by the design codes.
- To calculate the forces acting on equipment nozzles (such as on pressure vessels or tanks) and compare them with the allowable strength of those nozzles.
- To calculate the maximum pipe displacement to prevent interference between pipes or between pipes and nearby structures.
- To optimize the layout and design of pipes and their supports.

3.2 Piping Data Collection

In project design, various supporting documents are needed for the engineering process. These documents are interconnected and serve as simplified summaries of different project specifications and requirements. The key documents include:

- Process Flow Diagram (PFD)
- Piping and Instrumentation Diagram (P&ID)
- Piping Arrangement Drawing
- Isometric Drawing
- Pipe Support Details

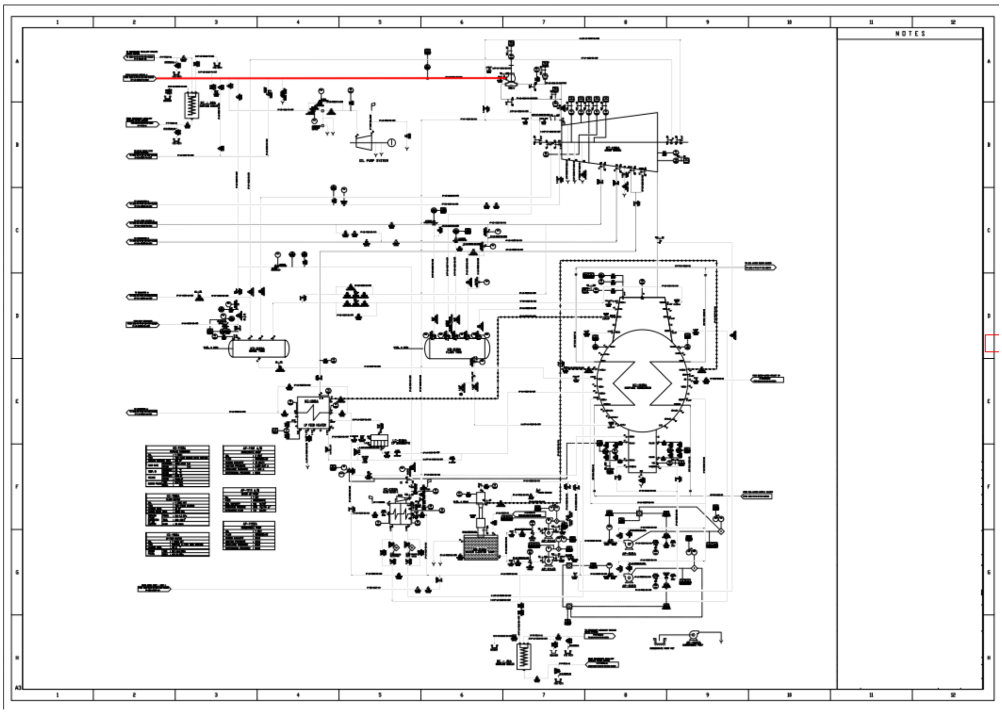


Figure 8. Piping and Instrument Diagram

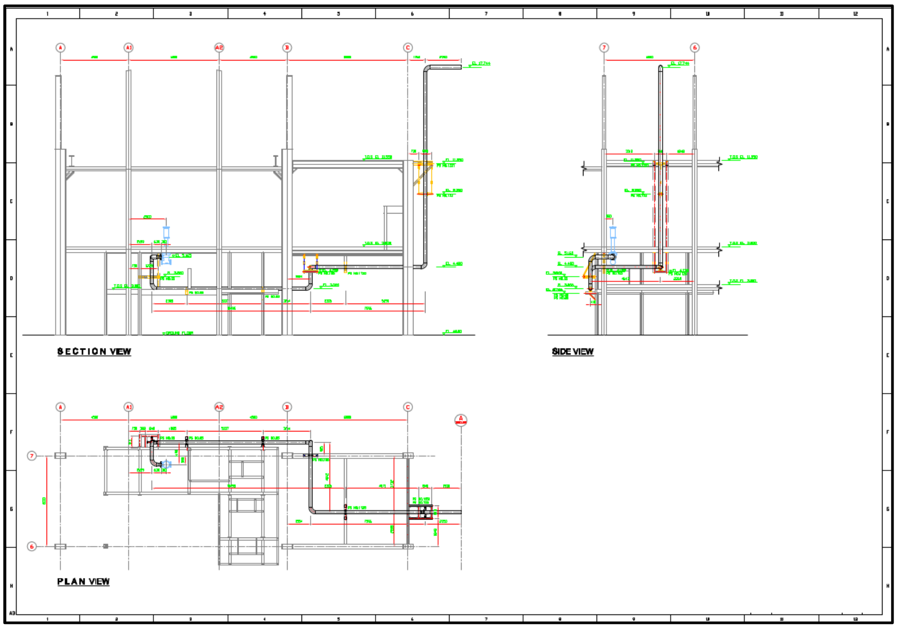


Figure 9. Piping Arrangements Drawing

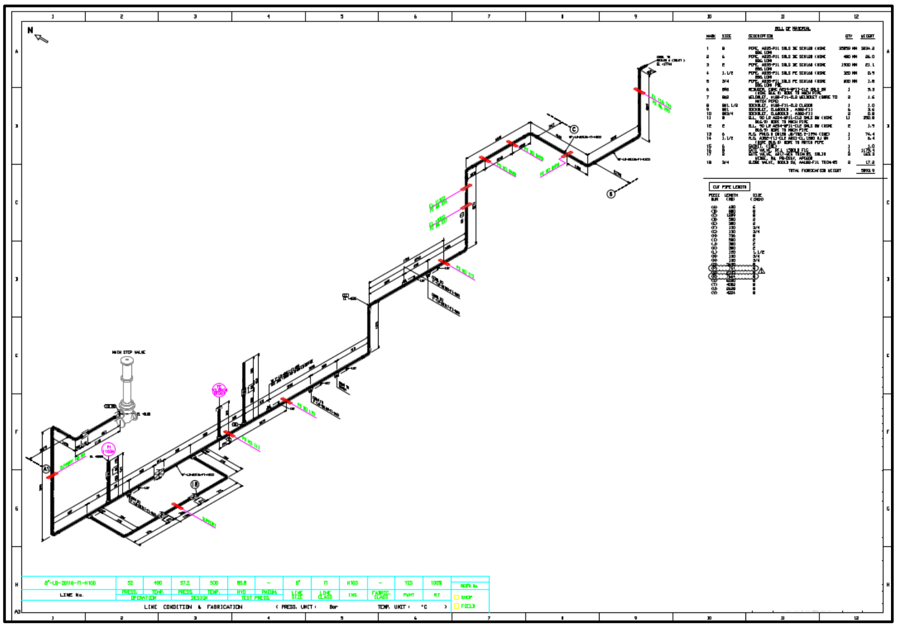


Figure 10. Piping Isometric Drawing

3.3 Piping Data Collection

Table 2. Load Case Definitions

Load Case	Category	Load Combination	Description
1	Hydrotest	L1 = WW + HP	Hydrotest load
2	Operating	L2 = W + T1 + P1 + D1	Load under maximum condition (design pressure & temperature)
3	Operating	L3 = W + T2 + P2 + D2	Load under operating condition with operating pressure & temperature
4	Sustain	L4 = W + P1	Load under maximum condition (design pressure & temperature)
5	Sustain	L5 = W + P2	Load under operating condition with operating pressure & temperature

3.4 Piping Data Collection Pipe Input Data

1) Initial Data Preparation

At this stage, data for the piping system is compiled as the basis for modelling. The necessary data includes piping specifications, and the code standards used.

2) Working Method

The methodology used in completing this paper is an analytical method by modelling the piping system and performing analysis using software CAESAR II. The working method involves literature studies supported by relevant data and expert recommendations.

3) Piping System Modelling
   The modelling process includes:
   a) Input of node numbers (from node to node)
   b) Input of pipe dimensions
   c) Input of pipe length and orientation (x, y, z coordinates)
   d) Input of pipe material
   e) Input of code standard
   f) Input of temperature and pressure

4) Error Checking in the Model
   a) Physical inspection of the model for drawing errors (coordinate orientation, length dimensions).
   b) Running the error check function in CAESAR II to detect modelling errors and warnings.

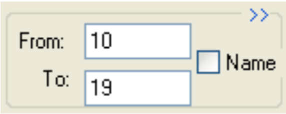
5) Stress Magnitude Analysis
   The magnitude of the loads occurring is analyzed based on the selected code standard (ASME B31.1) using CAESAR II.

6) Explanation of Allowable Stress Types and Load Cases
   a) (OPE) Operating: Stress due to a combination of sustained and expansion loads during operational conditions.
   b) (OCC) Occasional: Stress occurring during the operational life due to sustained loads combined with occasional loads (such as wind, waves, etc.).
   c) (SUS) Sustained: Stress that occurs continuously during operation due to internal pressure and the weight of the pipe and fluid.
   d) (EXP) Expansion: Stress resulting from temperature changes.
   e) (HYD) Hydrotest: Stress due to water pressure during hydrotesting.

7) Input and Modelling Caesar II

As an engineering, CAESAR II is designed to have standardized input formats. Below are the dominant factors affecting inputs in CAESAR II:

a. Node number input (from node to node)



From: 10
To: 19
☐ Name

Figure 11. Node Input in CAESAR II

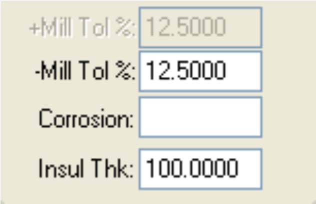
b. Piping design and dimension input

DX:
DY: 3000.000 mm
DZ:
☐ Offsets

Diameter: 219.0750
Wt/Sch: 18.2626

Figure 12. Pipe Dimension Input in CAESAR II

c. Corrosion and insulation input



+Mill Tol %: 12.5000
-Mill Tol %: 12.5000
Corrosion:
Insul Thk: 100.0000

Figure 13. Corrosion and Insulation Input in CAESAR II

d. Temperature and pressure input

☐ Bend ☐ Reducer
☑ Rigid ☐ SIFs & Tees
☐ Expansion Joint

☑ Restraints ☐ Displacements
☐ Hangers ☐ Flange
☐ Nozzles

☐ Forces/Moments
☐ Uniform Loads
☐ Wind / Wave

Figure 14. Temperature and Pressure Input in CAESAR II

e. Pipe Support Input

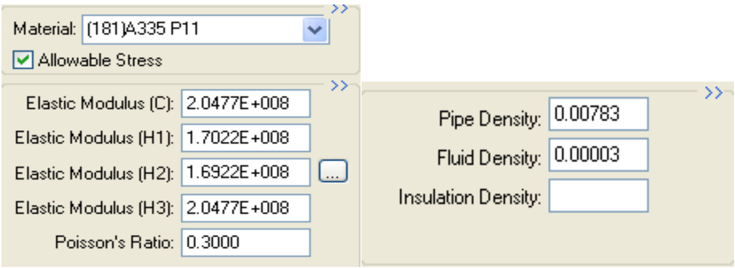
☐ Bend ☐ Reducer
☑ Rigid ☐ SIFs & Tees
☐ Expansion Joint

☑ Restraints ☐ Displacements
☐ Hangers ☐ Flange
☐ Nozzles

☐ Forces/Moments
☐ Uniform Loads
☐ Wind / Wave

Figure 15. Pipe Support Input in CAESAR II

f. Pipe material input



Material: (181)A335 P11

☑ Allowable Stress

Elastic Modulus (C): 2.0477E+008

Elastic Modulus (H1): 1.7022E+008

Elastic Modulus (H2): 1.6922E+008

Elastic Modulus (H3): 2.0477E+008

Poisson's Ratio: 0.3000

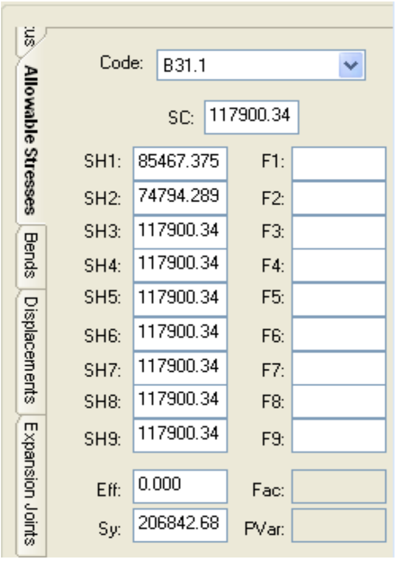
Pipe Density: 0.00783

Fluid Density: 0.00003

Insulation Density:

Figure 16. Pipe Material Input in CAESAR II

g. Code standard input



Code: B31.1

SC: 117900.34

SH1: 85467.375

SH2: 74794.289

SH3: 117900.34

SH4: 117900.34

SH5: 117900.34

SH6: 117900.34

SH7: 117900.34

SH8: 117900.34

SH9: 117900.34

F1:

F2:

F3:

F4:

F5:

F6:

F7:

F8:

F9:

Eff: 0.000

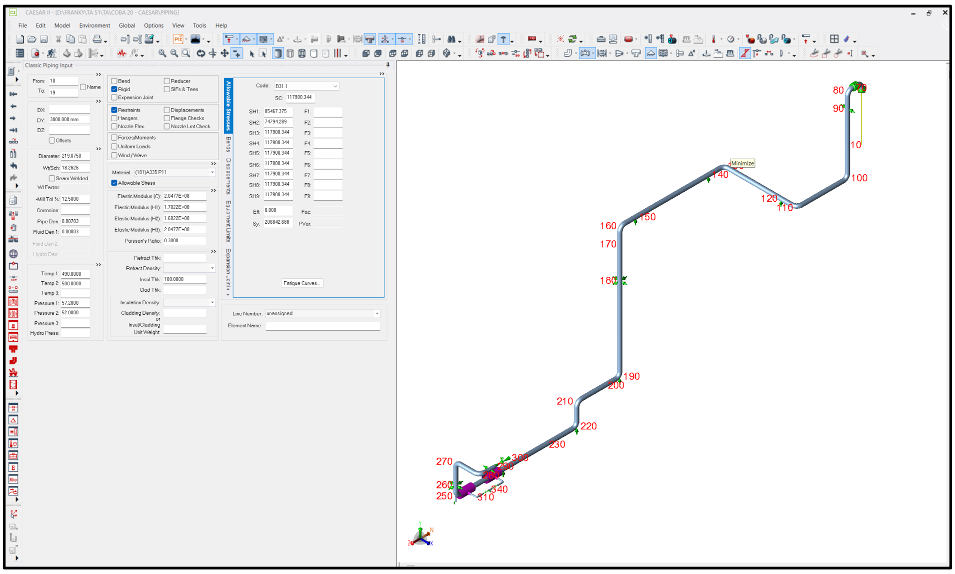
Sy: 206842.68

Fac:

PVar:

Figure 17. Code Standard Input in CAESAR II

8) Caesar Modelling


CAESAR II - [D:\FRANKY\TA S1\TA\COBA 20 - CAESAR\PIPING]

Classic Piping Input

From: 10
To: 19
☐ Name

DX:
DY: 3000.000 mm
DZ:
☐ Offsets

Diameter: 219.0750
Wt/Sch: 18.2626
☐ Seam Welded
Wl Factor:
-Mill Tol %: 12.5000
Corrosion:
Pipe Den: 0.00783
Fluid Den 1: 0.00003
Fluid Den 2:
Hydro Den:

Temp 1: 490.0000
Temp 2: 500.0000
Temp 3:
Pressure 1: 57.2000
Pressure 2: 52.0000
Pressure 3:
Hydro Press:

☐ Bend ☐ Reducer
☑ Rigid ☐ SIFs & Tees
☐ Expansion Joint

☑ Restraints ☐ Displacements
☐ Hangers ☐ Flange Checks
☐ Nozzle Flex ☐ Nozzle Lmt Check

☐ Forces/Moments
☐ Uniform Loads
☐ Wind / Wave

Material: (181)A335 P11
☑ Allowable Stress

Elastic Modulus (C): 2.0477E+08
Elastic Modulus (H1): 1.7022E+08
Elastic Modulus (H2): 1.6922E+08
Elastic Modulus (H3): 2.0477E+08
Poisson's Ratio: 0.3000

Refract Thk:
Refract Density:
Insul Thk: 100.0000
Clad Thk:
Insulation Density:
Cladding Density:
or
Insul/Cladding Unit Weight:

Allowable Stresses

Code: B31.1
SC: 117900.344
SH1: 85467.375 F1:
SH2: 74794.289 F2:
SH3: 117900.344 F3:
SH4: 117900.344 F4:
SH5: 117900.344 F5:
SH6: 117900.344 F6:
SH7: 117900.344 F7:
SH8: 117900.344 F8:
SH9: 117900.344 F9:
Eff: 0.000 Fac:
Sy: 206842.688 PVar:

Line Number : unassigned
Element Name :

Figure 18. Modelling in CAESAR II

Figure 19 below shows the steam line model, where both ends are connected to a gate valve from the boiler superheater and to the turbine's main steam valve.

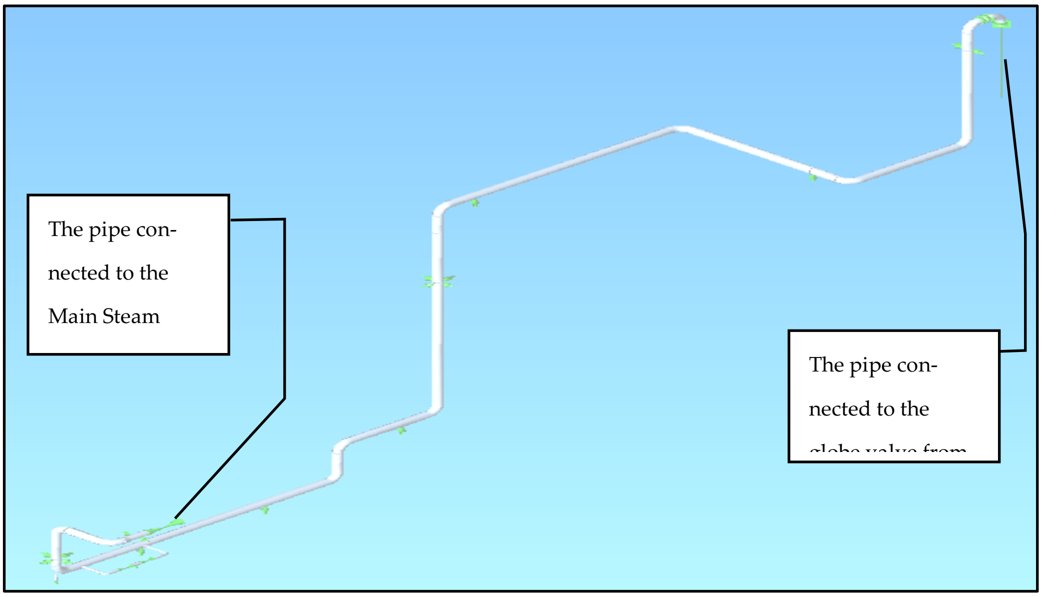


Figure 19. Piping System Caesar Model

3.5 Pipe Stress Results using CAESAR II

The stress analysis results indicate that the piping has sufficient flexibility to avoid overstress. The wall thickness is adequate to withstand the sustained loads, and the pipe supports are sufficient to prevent excessive stress based on ASME B31.1. The Stress Summary results for each load case are shown and summarized in the table below:

Table 3. Code Stress Summary

Case	Category	Load Combination	Node	Max. Stress (Psi)	Allow. Stress (Psi)	%	Status
1	Hydrotest	L1 = WW + HP	249	7260.4	27000	26.9%	Passed
2	Operating	L2 = W + T1 + P1 + D1	159	18908	-	-	Passed
3	Operating	L3 = W + T2 + P2 + D2	159	18472.4	-	-	Passed
4	Sustain	L4 = W + P1	249	7147.1	10848	65.9%	Passed
5	Sustain	L5 = W + P2	249	7146.3	10848	65.9%	Passed
6	Expansion	L6 = L2 - L4	159	18947.4	43484.5	54.4%	Passed
7	Expansion	L7 = L3 - L4	159	18513.6	36779.9	50.3%	Passed

The allowable stress values used as a benchmark in the results above are taken from Appendix Table A-2 of ASME B31.1.

3.6 Pipe Displacement Results using CAESAR II

From the Displacement Report, it can be observed that there are no significant displacements in the pipe system.

Table 4. Maximum Displacement

Case	Max Dx (mm) [Node]	Max Dy (mm) [Node]	Max Dz (mm) [Node]	Remark
Hydrotest	1.35 [270]	-6.2 [290]	-3.89 [290]	Passed
Sustained	-27.49 [130]	68.23 [158]	-68.01 [189]	Passed
Operating	-26.71 [130]	66.25 [158]	-66.37 [189]	Passed

3.7 Pipe Support Load Results using CAESAR II

Table 5. Restraint Summary

NODE	FX lb.	FY lb.	FZ lb.	MX ft.lb.	MY ft.lb.	MZ ft.lb.	Pipe Support Type
10	-2570	-779	-2191	-9099.8	-6349.0	29997.4	Rigid ANC
20	-2570	-779	-2191	12460.7	-6349.0	4703.8	Rigid ANC
90	4074	0	0	0.0	0.0	0.0	Rigid -X
90	0	0	0	0.0	0.0	0.0	Rigid +X
120	-438	-1461	-12	0.0	0.0	0.0	Rigid +Y
140	0	0	0	0.0	0.0	0.0	Rigid +Y
150	0	0	0	0.0	0.0	0.0	Rigid +Y

NODE	FX lb.	FY lb.	FZ lb.	MX ft.lb.	MY ft.lb.	MZ ft.lb.	Pipe Support Type
180	-1315	0	0	0.0	0.0	0.0	Rigid X
180	0	0	-929	0.0	0.0	0.0	Rigid Z
190	0	0	0	0.0	0.0	0.0	Rigid +Y
220	38	-6257	-184	0.0	0.0	0.0	Rigid +Y
240	16	-2337	-68	0.0	0.0	0.0	Rigid +Y
260	0	0	3282	0.0	0.0	0.0	Rigid Z
260	-2354	0	0	0.0	0.0	0.0	Rigid X
288	2286	0	0	0.0	0.0	0.0	Rigid GUI
340	0	0	0	0.0	0.0	0.0	Rigid +Y
2491	296	-1042	101	0.0	0.0	0.0	Rigid +Y

From this table we can see that loading data bigger in node 10 and node 20 mean this node is connection from Boiler. Specifically, this loading data will be use to select and design what kind of pipe support need and can withstand the load.

4. Conclusions

Based on the analysis conducted with CAESAR II on the main steam pipe at Power Plant PLTU Tidore, North Maluku, several important findings were obtained regarding the structural integrity and operational reliability of the piping system.

The piping stress analysis was performed refer to ASME B31.1 for Power Piping design code. The evaluation meets to the and engineering standards. The results indicate that all calculated stress values including sustained stress, thermal expansion stress, and occasional loads are below the allowable limits specified for the pipe (Table-3). This confirms that the piping system is capable of withstanding the applied loads during operation without risk of overstress or material failure.

Others evaluation of the support configuration also shows compliance with the relevant standards. The location, spacing, and type of supports used in the steam pipe is effectively control pipe displacements and loads at critical points (Table-4).

The analysis results demonstrate that the movements occurring along the piping steam system, including thermal expansion and operational displacement, remain within acceptable limits and do not create excessive loads or moments on equipment such as turbines or boilers (Table-5). No significant deformation or misalignment was detected that could lead to leakage, fatigue, or mechanical failure of the piping system.

Therefore, based on these findings, no modification is required regarding the position, distance, or selection of pipe supports. The existing design is considered safe, reliable, and fully compliant with ASME B31.1 standards for the current operating conditions.

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