

## Analysis of Geothermal Fluid Pipe Behavior in Dry Steam Geothermal Power Plant under Dynamic Load

Helmi Zakaria<sup>1,2,\*</sup>, Raden Dadan Ramdan<sup>1</sup>, & Jooned Hendrarsakti<sup>1</sup>

<sup>1</sup>Institut Teknologi Bandung, West Java, Indonesia

<sup>2</sup>PT PLN (Persero), Jakarta, Indonesia

\*Email: helmizakaria@ymail.com

**Abstract.** This study investigates the dynamic behavior of a dry steam geothermal fluid piping system located in a seismically active region of West Java, Indonesia. Given the potential for resonance under earthquake-induced dynamic loads, modal analysis was conducted using ANSYS finite element software to determine the piping system's natural frequencies and mode shapes. The piping system, spanning 186 meters, was modeled with fixed and roller supports to reflect realistic boundary conditions. Analysis results revealed that while the first mode (10.31 Hz) falls within the critical earthquake frequency range, its low mass participation indicates minimal influence on system response. In contrast, the twenty-fifth mode (31.12 Hz) exhibits deformation patterns more aligned with expected seismic excitation, with its frequency exceeding the dominant earthquake spectrum. Thus, the system is not considered highly susceptible to resonance. This study underscores the importance of modal analysis in assessing seismic resilience and confirms the structural adequacy of the piping design under dynamic loads.

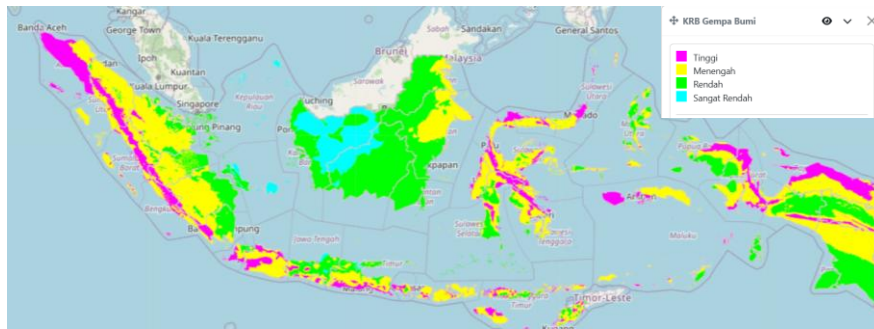
**Keywords:** Piping System, Geothermal Power Plant, Dynamic Behavior, Modal Analysis

### 1 Introduction

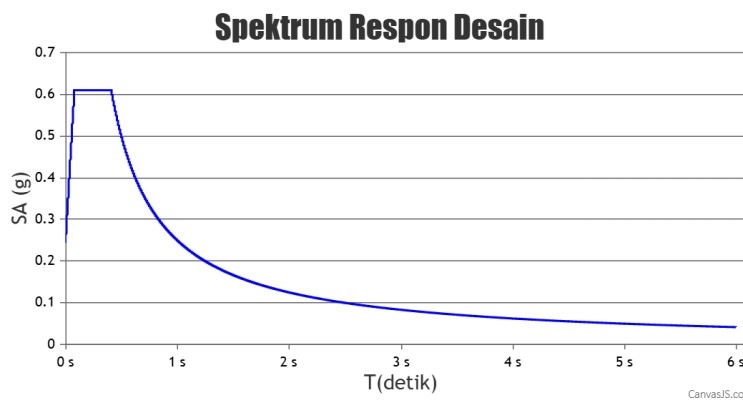
Geothermal systems in Indonesia are predominantly situated along the active subduction zone formed by the interaction of the Pacific, Indo-Australian, and Eurasian plates. This includes geothermal fields in West Java, where the dry steam geothermal power plant in this study is located. According to Earthquake Hazard Zonation Map published by the Center for Vulcanology and Geological Hazard Mitigation (PVMBG), this region is classified as a “moderate” seismic hazard as illustrated in Figure 1. Peak Ground Acceleration (PGA) for the location is 0.4661g, based on the Indonesian Design Response Spectrum Map, with the response spectrum presented in Figure 2.

Given this significant seismic risk, all critical components of the geothermal power plants must be designed to withstand dynamic loading caused by the earthquake, including the dry steam piping system. This piping system serves an important role by transporting dry steam from the Steam Receiving Header to the Turbine #1. The system is supported by a series of structural supports that transfer

operational and dynamic loads to the ground, as explained by Koorey in [1]. However, from the research of Jonsdottir, *et al* in [2], due to its relatively low natural frequency and extensive spatial configuration, the piping system may exhibit considerable movement during earthquake. Of particular concern is the potential for resonance, which may occur if the system’s natural frequencies align with the frequency range of the earthquake. This phenomenon could lead to excessive vibrations and structural failure, according to Saari, *et al.* in [3].



**Figure 1** Earthquake Hazard Zonation Map (PVMBG)



**Figure 2** Response Spectrum Design (Indonesian Design Response Spectrum Map)

Sekacheva, *et al.* in [4] stated that to assess the risk of resonance, a modal analysis is conducted. This analytical approach evaluates the dynamic characteristics of the piping system under seismic excitation by determining its natural frequencies and corresponding mode shapes. These modal parameters are directly influenced by the system’s mass and stiffness, as governed by eigenvalue problem expressed in Eq. 1, as outlined by Peng and Peng in [5].

$$([K] - \omega^2[M])\phi_n = 0 \tag{1}$$

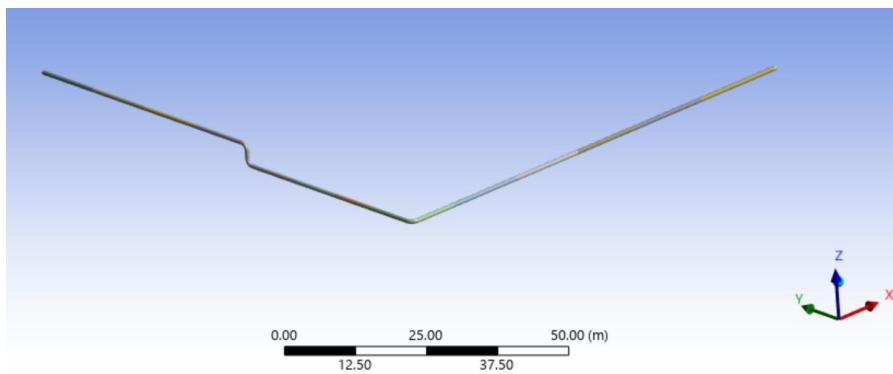
Modal analysis thus serves as an important step to ensuring the structural integrity and seismic resilience of piping systems within geothermal power plants.

## 2 Piping System Simulation

### 2.1 Piping System Overview

This study examines the dynamic behavior of above-ground piping system within dry steam geothermal power plants. Scope of the simulation is limited to the piping system section Steam Receiving Header to Turbine #1 that is transporting dry steam for generating 30 MW of electricity. Under normal operating conditions, pipeline is subjected to high temperature steam (170°C), as well as internal pressure of around 6.5 bar which derived from dry stem flow. Furthermore, the piping system is also susceptible to earthquake loads, where the piping system is situated in active seismic region with Peak Ground Acceleration of 0.4491g.

Total length of the piping system is approximately 186 m. The pipeline is divided into three horizontal spans, one vertical span and interconnected by three elbow to accommodate directional changes in flow path. Pipeline span is supported by two types of support, fixed support that are applied at both of the inlet and outlet ends of the pipe and rolled support in the middle of pipeline span. The layout of piping system is presented in Figure 3, which derived from original Piping and Instrument Diagram (P&ID).



**Figure 3** Piping Layout

The detailed specification and analysis parameter of the pipe are presented in Table 1.

**Table 1** Property of Material ASTM A515 Grade B

No	Property of Material	Unit	ASTM A515 Grade B
1	Density	kg.m <sup>-3</sup>	7,850
2	Coefficient of Thermal Expansion	C <sup>-1</sup>	0
3	Young's Modulus	MPa	200,000
4	Poisson's Ratio		0.29
5	Bulk Modulus	MPa	160,000
6	Shear Modulus	MPa	800,000
7	Ultimate Strength	MPa	448
8	Yield Strength	MPa	205

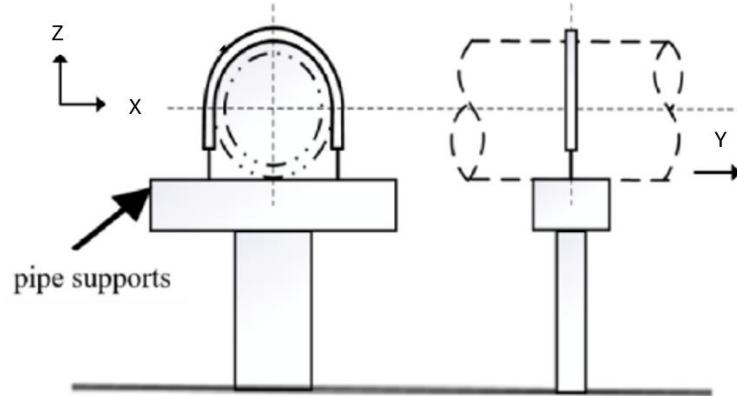
## 2.2 Boundary Condition

In this study, the support of piping system is idealized using boundary constraints to reflect the actual behavior of the support. The pipeline is anchored at two points, one at the interface to Steam Receiving Header and the other one at connection to the Turbine #1. Both of these joints are modeled as fixed supports which impose zero translation and rotational degrees of freedom to obtain a rigid connection. This constrained is mathematically expressed in Eq. (2).

$$u_x = u_y = u_z = \theta_x = \theta_y = \theta_z = 0 \quad (2)$$

The system also supported by roller-type support in the middle of the span which provide constraint by restricting vertical and lateral displacements while only allowing movement along the longitudinal axis of the pipeline. This type of constraint is important for accommodating thermal expansion and reducing

internal stress concentrations without compromising structural integrity and



stability.

Figure 4 give an illustration of the boundary condition associated with the rolled support.

The X-axis represents lateral displacement, Z-axis represents vertical displacements, and the Y-axis (perpendicular to the plane) represents longitudinal displacement. In this coordinate system, displacements at X and Z directions are constrained, while displacement along the Y-axis is permitted, allowing the pipe to expand along its length, The mathematical expression of this boundary condition is provided in Eq. (3).

$$u_x = u_z = 0 ; u_y > 0 \quad (3)$$

Where  $u_i$  is the pipe displacement in  $i$ -direction.

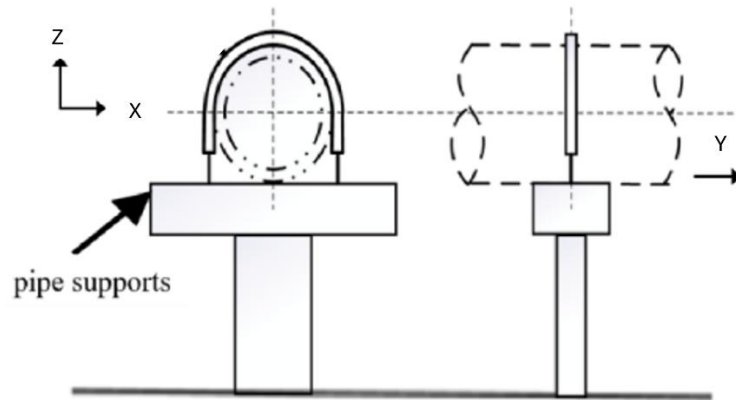


Figure 4 Illustration for rolled support

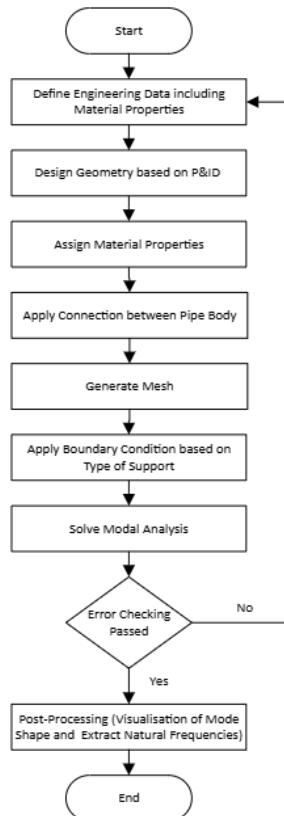
### 2.3 Modeling of Piping System Using ANSYS

Dynamic behavior of the piping system is investigated using Finite Element Method (FEM) based software, ANSYS. ANSYS in [6] described that modal analysis feature within this software enables determining natural frequencies and mode shapes of the piping system. The modeling and simulation process of the piping system is illustrated in Figure 5.

In this simulation, the engineering data is derived from the material specifications outlined in Table 1. These material properties are essential for defining the mechanical behavior and structural response of the piping system. The pipe is modeled as a solid body element to represent full three-dimensional geometry, allowing for enhanced accuracy of the calculation. The three-dimensional geometry is modeling constructed using ANSYS Design Modeler and imported to ANSYS Mechanical for further analysis.

A finite element mesh is then generated to discretize the solid body into smaller elements, thereby increasing the number of nodes and facilitating more detailed and accurate analysis, as mentioned by Wang, *et al.* in [7]. Boundary conditions are applied by assigning fixed support at both ends of the pipeline to simulate rigid constraints, while rolled supports are modeled by applying constant zero displacements constraints in the X-axis and Z-axis allowing movement only along the Y-axis to accommodate thermal expansion, as discussed by Nakamura and Kasahara [8].

Once all the processes above are completed, modal analysis is executed. ANSYS in [6] noted that iterative simulations are performed to ensure that sufficient number of modes are included such that the cumulative mass participation ratio in each direction reaches at least 90%. After solving the analysis, post-processing is conducted to interpret the dominant natural frequencies and the corresponding mode shapes.



**Figure 5** Flowchart of the simulation in ANSYS

### 3 Modal Analysis of Piping System

#### 3.1 Mass Participation Factor

In this section, the dynamic behavior of piping system is assessed through the evaluation of mode shaped and natural frequencies. According to SNI 1726:2019 in [9] and ASCE 7-10 in [10], the minimum required mass participation factor

for modal analysis is 90% in each X-axis, Y-axis and Z-axis. This threshold is established to ensure that the system's dynamic characteristics are accurately captured, and that the contribution of mass is sufficient to prevent underestimation of the structural response. As indicated in Eq. 1, the natural frequency is influenced by the effective mass of the system. To meet the specified requirements, an iterative approach is employed. In this simulation, the target mass participation ratio of 90% is achieved at mode number 1500. The detailed distribution across each directional axis is presented in Table 2.

**Table 2** Mass Participation Factor

Parameter	X-Axis	Y-Axis	Z-Axis
Mass participation factor	95.02%	95.48%	92%

### 3.2 Natural Frequency and Mode Shapes

The simulation of piping system conducted using ANSYS produced the corresponding natural frequencies and mode shapes, as summarized in Table 3. Typically, the first mode exhibits the lowest natural frequency and is often considered the most dominant in structural dynamics due to its significant contribution to the system's overall response Jonsdottir, *et al* in [2]. On the contrary, higher order modes possess increased frequencies and their influence on dynamic behavior tends to diminish. Deformation of mode one is illustrated in Figure 6.

**Table 3** Natural frequencies and corresponding mode shape

Mode	Natural Frequencies (Hz)
1	10.31
2	10.32
3	11.90

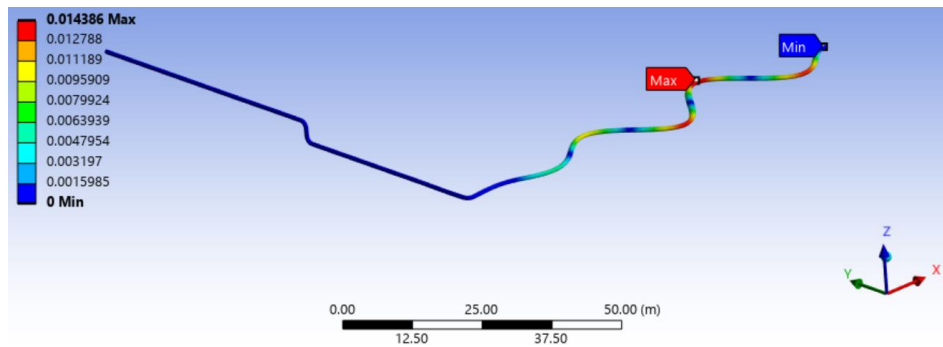


Figure 6 Deformation mode 1

Although the first mode is generally expected to be the dominant mode due to its lowest natural frequency, its deformation pattern does not accurately represent the probable dynamic response of the piping system under seismic excitation. In this context, horizontal earthquake loads primarily act as a one-directional transverse force on the piping system. However, the deformation pattern associated with the first mode displays a back-and-forth motion in the transverse direction, which may not correspond to the realistic displacement behavior under seismic excitation. On the other hand, the twenty-fifth mode, which has a natural frequency of approximately 31.12 Hz, has a deformation pattern that more closely aligns with the realistic response as illustrated in Figure 7. This might be rational, considering that all the supports are assumed to vibrate in the same direction according to the response spectrum. Therefore, mode twenty-fifth should be the most dominant mode.

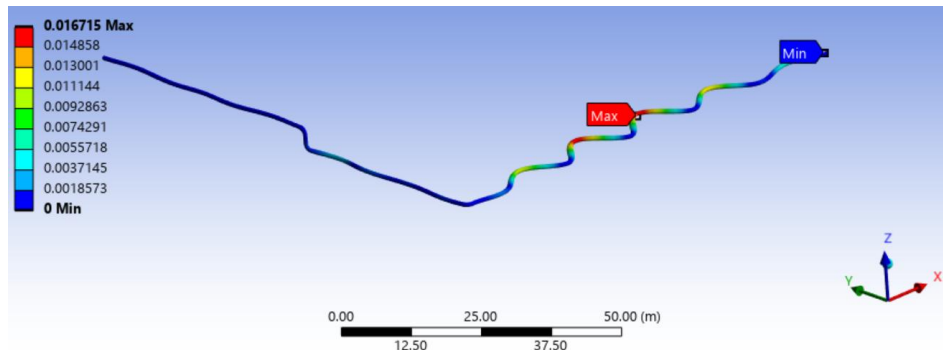


Figure 7 Deformation mode 25

#### 4 Discussion

Understanding the natural frequencies of piping system is essential for mitigating the risk of resonance, which may occur when these natural frequencies fall between the frequencies of the possible earthquake. In this study, the seismic

response spectrum specific to the location of piping system is presented in Chapter 1. As illustrated in Figure 2, the peak spectral acceleration occurs between the periods  $T_0 = 0.08\text{s}$  and  $T_s = 0.41\text{s}$ . Based on the mathematical formulation in Eq. (4), the corresponding earthquake frequency can be determined and is summarized in Table 4.

$$f = \frac{1}{T} \quad (4)$$

**Table 4** Frequency of earthquake

Mode	Natural Frequencies (Hz)
f0	10.31
f2	10.32

Analysis of this frequency range reveals that the first mode of the piping system is 10.31 Hz and falls within the potential resonance region. However, the effective mass participation ratios associated with the first mode in the X, Y and Z directions, as presented in Table 2, are notably small. This suggests that the first mode contributes minimally to the overall dynamic response and may not significantly affect the system's dynamic response. In the other hand, the twenty-fifth mode is predicted as the most dominant mode has a natural frequency 31.12 Hz, exceeding the earthquake frequency range. Therefore, those conditions are indicating that the piping system is not critically susceptible to resonance due to the earthquake.

## 5 Conclusion

Based on the findings of this study, modal analysis proves to be an effective method for evaluating the dynamic behavior of dry steam piping system in geothermal power plants. The dominant mode shapes is identified at twenty-fifth mode which closely represents the expected deformation under seismic excitation. Furthermore, the natural frequency associated with this mode lies above the frequency range of possible earthquakes. Consequently, it can be concluded that the piping system is not susceptible to resonance and is considered structurally safe under seismic excitation.

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