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A Review of Support Configurations and Their Impact on Stress Distribution in B31.1 Piping Systems

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Abstract*: In the complex world of power plant operations, the reliability and safety of piping systems are paramount. An ASME B31.1 Code for Power Piping provides all required guidelines and detailed information for designing, analyzing, and maintaining all power piping systems to resist the harsh conditions necessary for power generation and distribution industries. This paper explores the topic of piping systems starting with process layout and moving on to the structural and stress analysis as well as the supports of a piping system. Using FEA, dynamic loading analysis, and AI optimization, that improve the accuracy and speed of piping systems. Furthermore, the study brings solutions to thermal stress, compatibility of materials, and problems of access to maintenance. Last of all, the paper provides conclusions and suggestions for further studies. This part of the paper suggests techniques such as machine learning, real-time monitoring, and materials innovations for strengthening the longevity and sustainability of the piping system in power plants.*

Keywords: ASME B31.1, Support Configuration, Stress Distribution, Piping Systems, Hinged supports, Finite Element Analysis

I. INTRODUCTION

The process and power sectors rely on piping systems, which are similar to the circulatory systems in the human body, to ensure the plant runs effectively and lasts as long as possible. The steam piping system is regulated by the ASME B31.1 Power Piping Code, especially the boiler outlet section, which is described in the next sub-section. Reduced to its simplest, a piping engineer may find oneself having several choices of how to design something, and which of the options are safer, cheaper, and code compliant. They ensure that the anti-failure risks associated with the instances resulting from sustained loads during operation, thermal expansion as well as dynamic forces during the design phase [1].

Stress analysis helps the steam piping system avoid failure stress distribution in the piping system by distributing stress safely [2]. Pressure vessels cause applied loads to be tensile on the internal region of the pipe wall and compressive in the external region. These stresses are principal factors that tend to affect plastic deformation. Current practices include using Finite Element Analysis (FEA) to model stress distribution and/ or to test material performance. Some of the common materials include aluminium, steel, iron, copper and polyvinyl chloride (PVC), though the PVC is fast becoming popular due to its inexpensive nature and competency in bearing fluid loads. Suddenly, thermal expansion can crop up as a result of an increase in temperature that and lead to displacements and stresses that require the following to increase pipe life: fluid load limits, pressure, and strain [3].

Roller, pinned, hinged and fixed supports are important for handling dead weight load and for confining pipes against thermal and dynamic loads [4][5]. These supports serve a critical function of providing dimensional stability to the piping system when subjected to forces such as thermal expansion. The nature of the support technique thus depends on the various needs of the system and the presses that it is likely to come up against [6].

This review is motivated by the critical role of support configurations in maintaining the structural integrity and reliability of B31.1 piping systems. Properly designed supports help mitigate stress and prevent failures due to thermal expansion, vibration, and external loads. Despite the ASME B31.1 Code guidelines, there is a need for a deeper understanding of how different support configurations affect stress distribution and system performance. This review aims to fill this gap by synthesising existing research, identifying challenges, and offering insights to optimise support designs, ultimately improving the safety and efficiency of industrial piping systems. The key contributions of this study are as follows:

- Provides a review of the ASME B31.1 Code, focusing on its role in designing and analysing power piping systems.
- Examines the effects of different support configurations (fixed, pinned, roller, and hinged) on stress distribution and thermal expansion.
- Highlights advanced tools like Finite Element Analysis (FEA), dynamic analysis, and AI-driven optimisation to improve support configuration and performance.
- Discusses challenges in support design, including flexibility, thermal stress, dynamic loads, material compatibility, and maintenance access.
- Explores AI techniques, such as Graph Neural Networks (GNN) and K-Nearest Neighbors (KNN), for optimizing design and installation schedules while addressing spatial constraints.

II. OVERVIEW OF ASME B31.1 CODE

ASME B31 code for pressure piping developed by the American Society of Mechanical Engineers – ASME introduced in 1935 is a comprehensive document for piping design. It covers various piping systems, including Power Piping, Fuel Gas Piping, Process Piping, Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, Refrigeration Piping and Heat Transfer Components, and Building Services Piping [7]. Designing and analysing the primary components of a pipe system is the responsibility of the ASME B31 Code, which was formerly known as ANSI B31.1. Pipe structure. Support structure design by hand Systems that use geothermal heat, district heating or power plants all fall within the purview of the B31.1Power Piping code. Its primary focus is on the generating application's steam-water loop. Power and auxiliary service pipe systems for electric generating stations, industrial institutions, central and district heating plants, and other similar facilities are covered in detail, including their design, materials, fabrication, installation, testing, and inspection [8]. Figure 1 represents the visualisation of piping system given below:

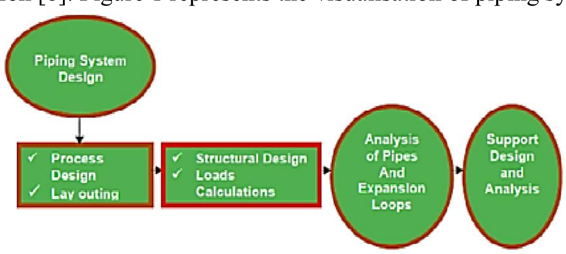

Figure 1: Designing of piping system

The key aspects of piping system design are outlined as follows:

- **Piping system design:** This is the aim of designing a safe, functional, efficient piping system.
- **Process Design and layout**: process design involves determining the requirement of the piping system based on the process needs such as fluid type, Flow rate and operating conditions. Layout refers to arranging the piping system component (Pipes, valves and fittings) within the available space to ensure optimal operation and maintenance accessibility.
- **Structural design and Load calculation:** Focus on the mechanical integrity of the pipes, ensuring they can withstand operating conditions like pressure and temperature. Includes evaluating sustained loads (weight, pressure), thermal expansion loads, and dynamic loads (vibration, seismic forces).
- **Analysis of pipes and Expansion Loops:** Ensures the pipes can handle stress and strain due to internal pressure and external forces. These are designed to accommodate thermal expansion and contraction of the piping system, reducing stress.
- **Support Design and Analysis:** Focuses on designing pipe supports to manage loads, prevent excessive stress at connections, and ensure the system's stability under operating and dynamic conditions [9].

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A. Components of Boiler Plant in A B31.1 Piping System

Power piping in a boiler plant plays a crucial role in ensuring the efficient and safe transport of fluids (such as water, steam, and fuel) required for power generation. A boiler system is typically used in steam power plants in Figure 2 all include some keyword the flow of water and steam through various components, including the economiser, convection and radiant sections, superheater, steam separator, reheater, and turbine.

Key elements of boiler plants are as follows:

- **Boiler:** Feed pump Supplies water to the boiler under pressure.
- **Economizer:** Preheats the feedwater using residual heat from flue gases.
- **Convection and radiant section:** Heat transfer areas where water is converted into steam.
- **Superheater:** Increases the temperature of the steam beyond its saturation point for improved turbine efficiency.
- **Steam Separator:** Removes moisture from the steam to ensure dryness before entering the turbine.
- **Turbine:** Converts thermal energy of steam into mechanical energy.
- **Reheater:** Reheats the steam exiting the turbine to improve efficiency in subsequent stages.
- **Recirculation Pump:** Recirculates water back to maintain proper flow and temperature conditions during startup or low-load operations.

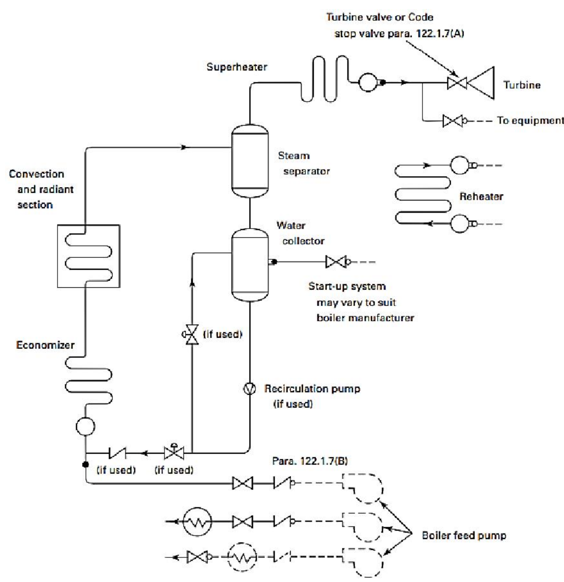

Figure 2: Boiler system

III. IMPACT OF SUPPORT CONFIGURATION ON STRESS DISTRIBUTION

The support configuration of a structure significantly affects the stress distribution within it. This influence arises from how support constrains movement and transfer loads.

Types of Support Configuration and their Effects

It is some types of support configurations on power piping systems are as follows:

Fixed Supports: All three degrees of freedom arrested in Figure 3 shows the fixed support.. Restrict all translational and rotational movements to induce significant reaction force and moments. Common in rigid structures like walls and bridges.

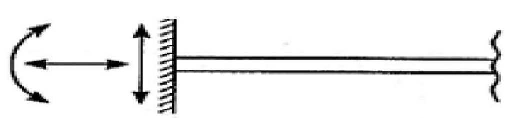

Figure 3: Visualization of Fixed support

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Pinned supports: Allow rotation but restrict translation distribute stresses more evenly compared to fixed supports. The pinned support visualised below is shown in Figure 4:

Figure 4: Pinned Support

Roller Supports: Free to translate in horizontal direction only. Permit movement in one direction while restricting others minimises stress concentration by allowing thermal expansion and contraction. Figure 5 illustrates how to comprehend roller support.

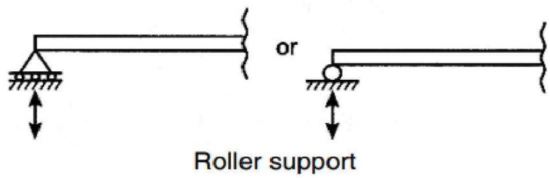

Figure 5: Roller Support

Hinged supports: No translation, but rotation is possible. Allow rotation and partial movement, reducing bending stresses. Useful in systems requiring flexibility, like arches or movable joints [10]. The Hinged support is seen in Figure 6, which may be found below:

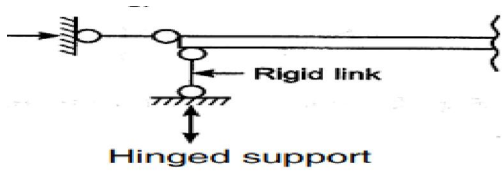

Figure 6: Hinged Support

B. Boundary Support and Stress Distribution

B. Boundary conditions imposed by supports determine how loads are transferred:

Over/Under constrained system: Lead to higher stresses and potential failure due to inability to redistribute loads. Over/Under-constrained system is visualised below in Figure 7:

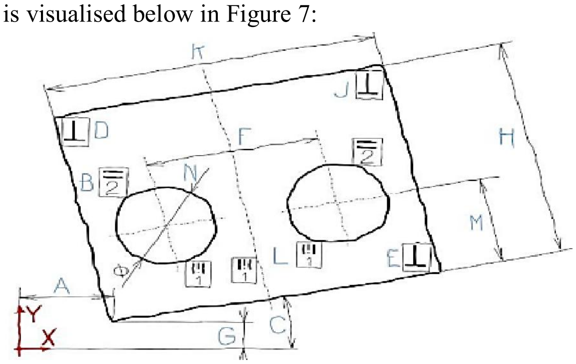

Figure 7: Over/Under Constrained

Cause excessive deformation and stress redistribution, leading to instability. The local coordinate system is represented by the two axes marked X and Y, and the items they come into touch with are affected by the symbols contained inside rectangles, which stand for symmetry, equality, or perpendicular. In an unconstrained state, the symmetry axis does not lie exactly in the middle of the rectangle's long sides [11].

- **Stress concentration near support in piping system:** stress concentration near supports in piping systems is a critical factor in industrial and mechanical engineering.

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- **Geometric discontinuities:** Welds, notches, and abrupt changes in pipe diameter near supports amplify stress concentrations.
- **Material properties:** Variations in material strength or stiffness at support interfaces can lead to stress imbalances. Support configuration significantly influences the stress profile within piping systems.
- Thermal Expansion-Based Piping System
- **Thermal expansion:** The analysis of each buried run of pipe allows one to estimate the thermal displacements at the elbows, branch connections, and flanges of an underground piping system, as well as the stresses and moments that occur from these displacements.
- **Installations with Flexible Couplings:** It is possible to significantly decrease bending moments and stresses by including flexible couplings into pipe lengths that are sensitive to thermal expansion.
- **Installations with Flexible Penetrations:** The interplay between the point-supported section of a subterranean pipe system and the buried run outside of any building penetrations that allow for axial or angular movement [12].

C. Dynamic Loads and Support Response:

- **Vibration Loads:** Induced by rotating machinery, flow turbulence, or unbalanced forces.
- **Seismic loads:** Earthquake-induced ground motions cause dynamic stresses throughout the piping network.
- **Pipe displacement and misalignment:** Excessive movement can lead to joint leakage, flange misalignment.
- **Stress Amplification at support:** Poorly designed supports can concentrate stresses, leading to localised failure.
- **Dynamic loads:** Vibration, water hammer, and transient forces cause fluctuating stresses near supports, increasing fatigue risk.

IV. ANALYTICAL AND MODERN APPROACHES FOR SUPPORT CONFIGURATION

This section highlights the tool and method to enhance the design and analysis of support configuration as follows:

A. Finite Element Analysis (FEA)

Engineering designers often employ FE analysis as a method to determine whether a product's design can resist the loads imposed by the modern environment. Different types of optimisation issues are solved, ranging from simple static analysis that investigates stresses and displacements to complex optimisation problems that aim to determine the optimal design given the available premises. Additionally, FE studies have grown in importance as a tool for failure investigation.
The degree to which needs and expectations of customers are met is a measure of quality.
Quality evolves over time due to the fact that client expectations might vary.

B. Pipe Stress Analysis Software

The results of a pipe stress analysis may be used to strengthen the system and avoid problems like leaks, broken equipment, foundation stress cracks, and anchor bolt failure [13] shown in Figure 8. This preventative action lessens the burden on the system's resources and increases the lifespan of its components.

Figure 8: Pipe stress analysis

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It is essential to begin any study with a model that accurately represents the final design or the pipe system as it was constructed. It may do this by simply uploading the model from CAD software into the pipe stress program [14].

C. Dynamic Analysis

A fluid-filled pipe system's dynamic behavior differs greatly from its static behaviour, and this difference is precisely what dynamic analysis seeks to resolve by studying the system's reaction with regard to time.

A dynamic load is one that varies over time; if the system doesn't have enough time to distribute the load, the forces and moments within it will be imbalanced, leading to pipe movement (because the total of these forces and moments doesn't have to be zero).

D. AI- Driven Optimisation for Piping System

A realistic pipe system installation plan and sequence may be automated and optimised using AI-based optimisation to meet all real-time installation in Figure 9 and limitations in the shortest amount of time possible at any given moment [15]. The four primary parts that make up the framework are: 1) BIM Model Extraction, 2) Hybrid Knowledge-Based System, 3) Spatial Constraint Analysis, and 4) Schedule Generation and Optimization.

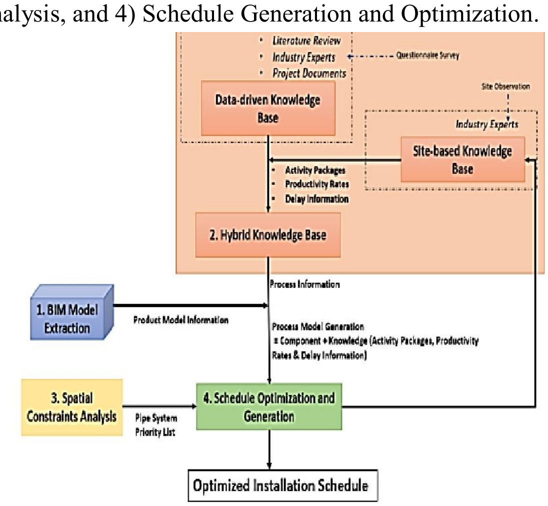

Figure 9: AI-driven optimisation

- **BIM model Extraction:** BIM model serves as a reference model for a plumbing project, including all the semantic and geometric data needed to generate an installation schedule.
- **Hybrid knowledge-based system:** mixed-knowledge system that uses ML to glean relevant data. The development of the hybrid knowledge-based system takes into account both the data-driven and site-driven knowledge bases, allowing for the capture of expert knowledge and constant up-to-date information.
- **Spatial constraint Analysis:** Pipe systems that share space are subject to spatial constraint analysis, which involves comparing their locations.
- **K-Nearest neighbours (KNN):** KNN uncovers the most comparable example for a given category by examining the similarity between various sorts of available cases. It is a supervised learning approach.
- **Graph Neural Network (GNN):** The inputs of GNNs, a kind of deep neural algorithm, are structured data graphs. Thanks to their ability to learn node embeddings, GNNs have radically altered the landscape of graph representation learning [16].
- **Schedule Optimization and Generation:** Schedule optimisation is used to minimise the time necessary to install all the pipe systems in 3D space inside a piping system, taking into account the needs of spatial constraints and the availability of resources.

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V. LITERATURE REVIEW

This section provides a literature review on review of support configuration and their impact of support distribution in B31.1 piping system, summary shows in Table I.

Meyer, Vilminot and Frey (2023) this code gives further information on how to utilise the ASME B31.1 Power Piping Code correctly. The purpose of this chapter is to further clarify and expand upon the Code's correct application. The circumstances or considerations for pipe system design are described first, followed by the foundation for allowed stresses, quality factors, etc., that should be employed in piping system design. The requirements for pressure design of piping components are then explained [17].

Liu et al. (2020) optimisation design of the structure of the failed weld, the finite element stress analysis method was utilised to reasonably calculate the stress distribution at the weld, and the on-site non-destructive testing technology and the support and hanger adjustment technology was accurately guided, and then the peak stress before and after the optimisation of the weld structure was reduced At the same time, the verification requirements of the third strength theory of materials was met, and a reliable safety status risk assessment for the safe operation of the unit was provided [18].

Xu et al. (2023) proposed mechanical stress loading parameters to the fitting curves obtained by the tests; it can be found that the value of the strain of the thinner pressboards is larger than that of the thicker pressboards under the same stress. The different loading speeds will affect the deformation of the pressboards. The faster loading speed in the range considered in the larger strain of the pressboards is. Through analysis, the relationship between the nonlinear coefficient of the mechanical properties of the pressboards and the deformation strength of the winding is a power exponential distribution [19].

Chen et al. (2023) solve these restrictions by adding the OASS into a unique design of wheel pipeline robots. The OASS, which takes its design cues from the skin of the desert iguana, is the perfect skeletal structure for the 146 g robot because of its exceptional stiffness and flexibility in several dimensions. They improve the robot's support and get it to successfully traverse various pipeline topologies by combining the OASS with PLA and resin materials. The robot can successfully navigate various pipeline widths, obstructions, U-turns, and even vertical parts, according to the experimental findings [20].

Mansouri et al. (2020) The effectiveness of forced convection mode on 12 mm copper water heat pipes installed on horizontally orientated heat sinks is examined in this research. The following are the results of computational and experimental investigations into a heat sink that is "blank," or devoid of any heat pipe, as well as two heat sinks that are "impaired," or have heat pipes embedded in them but use different embedding techniques: 1) The first model of the heat sink is a heat pipe heat sink whose base plate is gun-drilled in the exact middle to accommodate the embedded heat pipes. 2) An alternative design for a heat sink is a heat pipe heat sink, which has heat pipes that are flush with the base plate's surface [21].

Table 1: Present a comparative analysis of literature review based on Support Configurations and Their Impact on Stress Distribution.

References	Key Findings	Challenges	Limitations	Future Work
Meyer, Vilminot, and Frey (2023)	Explores the ASME B31.1 Power Piping Code, providing insights into its proper use, design considerations, allowable stresses, quality factors, and pressure design requirements.	Ensuring accurate interpretation and application of the Code across diverse piping systems.	Limited to theoretical guidance without practical implementation examples.	Develop practical case studies and examples to validate the recommendations in real-world scenarios.
Liu et al. (2020)	Optimised weld structure design using finite element stress analysis, non-destructive testing, and support adjustments, reducing peak stress and ensuring compliance with material strength	Accurately modelling complex stress distributions at welds and integrating various optimisation technologies.	Focused on a specific weld failure scenario, limiting generalizability to other types of	Expand the study to include other welding methods and materials to improve general applicability.

	theory.		weld failures.	
Xu et al. (2023)	Identified the impact of loading speed and pressboard thickness on deformation strength, establishing a power exponential relationship between mechanical properties and deformation strength.	Managing variations in pressboard material properties and accurately measuring deformation under stress.	Results are specific to the tested pressboards and may not apply to other materials or loading conditions.	Investigate additional material types and loading conditions to broaden the applicability of findings.
Chen et al. (2023)	Introduced a lightweight pipeline robot using Origami Anisotropic Stiffness Structure (OASS), capable of navigating diverse pipeline configurations, including U-turns and vertical sections.	Designing robots that balance rigidity and flexibility for varied pipeline conditions.	Limited to specific materials (PLA and resin) and pipeline scenarios, which may not represent all real-world conditions.	Explore alternative materials and further test the robot in more complex pipeline environments.
Mansouri et al. (2020)	Evaluated the performance of heat sinks with embedded copper heat pipes under forced convection, using two embedding technologies to improve thermal performance.	Optimising embedding methods for consistent heat transfer performance.	Focused on a specific heat sink configuration, limiting the study's applicability to other heat sink designs and materials.	Test additional embedding technologies and investigate different heat pipe materials and configurations.

VI. CONCLUSION

To keep industrial operations safe and efficient to operate, pipe systems must be carefully designed and analysed. For power pipe systems to be designed, analysed, and maintained in a way that guarantees safety, efficiency, and structural integrity, the ASME B31.1 Code offers a thorough framework. By addressing key aspects such as process design, structural analysis, and stress distribution, the code facilitates the effective management of complex piping networks in power plants. Advanced tools like Finite Element Analysis, dynamic analysis, and AI-driven optimisation enhance the design and evaluation process, enabling precise modelling and improved decision-making. However, challenges such as thermal stress interaction, dynamic loads, and material selection remain critical areas requiring ongoing attention.

Future research can focus on integrating advanced technologies such as machine learning and real-time monitoring systems to enhance predictive maintenance and operational efficiency of power piping systems. Additionally, exploring innovative materials with higher resistance to thermal and dynamic stresses could improve durability and reduce maintenance costs. Further advancements in AI-driven optimisation and the application of digital twins can revolutionise the design, simulation, and performance assessment of piping systems, paving the way for more resilient and sustainable solutions.

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