International Journal of Applied Science and Engineering

Correlation study between plate thickness and loading of pipe saddle support

Muhammad Arif Rayhan [1], Mohd Shukri Yob [1*], Mohd Juzaila Abd Latif [2], Ojo Kurdi [3], Fudhail Abdul Munir [4]

[1] *Applied Mechanical Design Laboratory, Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Jalan Hang Tuah Jaya, Malacca, Malaysia*
[2] *Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Jalan Hang Tuah Jaya, Malacca, Malaysia*
[3] *Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia*
[4] *Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Perak, Malaysia*

ABSTRACT

Pipe saddle supports are designed to cradle pipes, distributing their load evenly across the supporting structure. These supports are typically classified into three types, these are sliding, guide, and stopper support based on their placement and function within the piping system. This study develops and validates a finite element (FE) model of pipe saddle supports to improve the accuracy of stress prediction. A vertical load test was conducted to validate the finite element analysis (FEA), which resulting in 83.3% accuracy. The validated model was then used to investigate the correlation between plate thickness and applied pipe load, covering pipe sizes ranging from 26 to 56 inches. FEA results revealed that sliding supports required the least plate thickness, followed by guide supports, while stopper supports required the thickest plates to maintain a safety factor of 3. To further validate this correlation, an additional experiment was conducted using a model with 4.5 mm thick plates. With the same design and boundary condition configuration, the FEA achieved 94.6% accuracy, confirming the modelling technique's suitability for industrial application.

Keywords: Finite element analysis, Pipe support, Pipe saddle support, Stress analysis, Vertical load test

OPEN ACCESS

Received: July 31, 2025
Revised: September 22, 2025
Accepted: November 03, 2025

Corresponding Author:
Mohd Shukri Yob
mshukriy@utem.edu.my

Publisher:
Chaoyang University of Technology
ISSN: 1727-2394 (Print)
ISSN: 1727-7841 (Online)

1. INTRODUCTION

Pipe saddle support is a structure that commonly used to support horizontal steel pipes from beneath (Thomopoulos and Bisbos, 1992; Bisbos et al., 1993; Maxey and Pincince, 1998). It functions by distributing pipe loading to adjacent structure, so that it is not caused local failure to adjacent structure (de Barros et al., 2018). Pipe saddle support also typically used to control forces on the pipeline due to thermal expansion, earthquake and other loads (Koorey, 2000).

Several issues related to pipe saddle supports have been identified. These supports can experience significant displacement due to sudden pipe movement caused by insufficient stress analysis, leading to structural failure (Nuthanapati et al., 2018). Other cases show that overloading can cause failure in the pipe saddle structure itself (Rajkumar and Nelluri, 2019). In one instance, an oil and gas company reported overloading on a pipe saddle support, where a 48-inch pipe experienced a load of 300 kN, exceeding the construction standard that allows only 264 kN. This case highlights the need to revise and increase the allowable limits in current piping support construction standards. Additionally, there is a lack of standardized design procedures for pipe saddle supports, particularly for large-diameter pipes (Ranjbaran and Ghalelar, 2017). Given these concerns, accurate stress analysis is required to prevent such failures. While analytical calculations are suitable for common geometries, finite element analysis (FEA) is preferred for analyzing complex shapes like pipe saddle supports (Birhane and Hari, 2002; Mabuchi and Shinohara, 2004). Additionally, with the advancement of computational technology, FEA can provide more accurate and detailed data on stress distribution (Khan, 2008; Nugraha and Kurdi, 2018; Hamid et al., 2024). However, not all oil and gas companies have the resources to perform precise stress analysis using FEA (Bhattacharya, 2013). Furthermore, experiment should be conducted to compare between FEA and experiment result and to validate the FE model (Raj et al., 2023).

This study aims to create FE model for pipe saddle support and compare it with vertical load test results for validation. The validated FE model will then be used to establish a correlation between the plate thickness of the pipe saddle support and the applied pipe loading.

2. METHODOLOGY

The primary objective of this study is to establish a correlation between the load capacity of a pipe and the plate thickness of its saddle support. To achieve this, the research is structured into two main phases. The first phase involves conducting an experiment to determine the relationship between the applied load and the resulting stress in the pipe saddle support sample. The second phase focuses on developing a FE model, which is validated using the experimental data to ensure its reliability for further analysis.

2.1 Pipe Saddle Support Sample Design

In this study, the pipe saddle support sample is fabricated using mild steel with a thickness of 1.5 mm. It consists of three main components, which are base plate, flange plates, and saddle plate. The design of the pipe saddle support model is illustrated in Fig. 1.

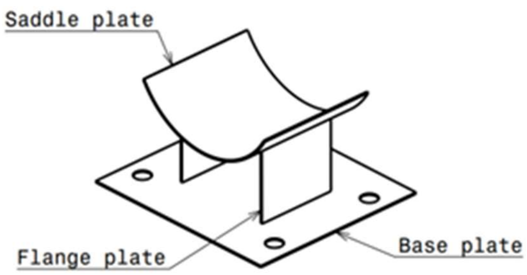


Fig. 1. The design of the pipe saddle support model

The base plate measures 180 mm in length and 200 mm in width. The sample is secured to the base support of the test rig using four M16 bolts through the base plate. Two flange plates are used, each with a height of 70 mm and a length of 80 mm. The saddle plate has a diameter of 6 inches, a wrap angle of 120 degrees, and a length of 120 mm.

On the other hand, the vertical load test is carried out on the pipe saddle support sample to measure the stress distribution on the flange plates. The load is applied to saddle plate incrementally by 1000 N until the pipe saddle support sample fails. It was conducted three times using three different pipe saddle support samples. Additionally, strain gauges are used to measure stress on the flange plate, as seen in Fig. 2.

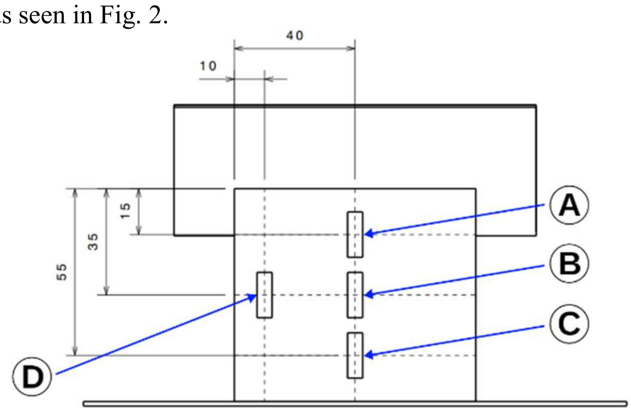


Fig. 2. Strain gauge positioning on the flange plate (side view)

2.2 Experiment Setup of Pipe Saddle Support Vertical Load Test

To investigate the stress that occurred on the pipe saddle support under vertical loading, an experimental setup was prepared. The configuration was designed to replicate realistic loading conditions encountered in service. The setup of the test rig for the vertical load test is shown in the Fig. 3.

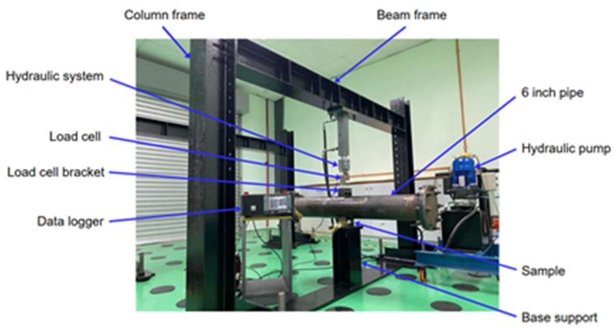


Fig. 3. The setup of pipe saddle support vertical load test rig

The test rig uses a 6-inch pipe, which is pressed downwards against the saddle plate by a hydraulic system to apply vertical load. A load cell is installed at the end of the hydraulic system to monitor the applied force. The hydraulic system is mounted on a rigid portal frame, consisting of a column and beam, to ensure stability and prevent deformation during loading.

2.3 Finite Element Modelling for Pipe Saddle Support

Mesh sensitivity analysis, welding connection modelling, and boundary condition were conducted in this section. The effects of these factors on the stress results of the pipe saddle support model were defined. The configuration with the highest accuracy from these factors was used in the subsequent section.

2.3.1 Load and Boundary Condition

For this correlation study, two configurations were used, which are loading condition and displacement boundary condition. In this setup, the load was applied to the saddle plate only at a certain contact angle. This configuration was chosen because, in the FEA, when the load was directly applied to the saddle plate, bending tended to occur on the saddle plate. To overcome this, the load applied at a certain angle was expected to reduce the bending and provide the same stress distribution on the flange plate.

The calculation of the contact angle is measured from the flange plate that touch the saddle plate to the center point of the saddle plate. In this case, the angle is divided to the angle inward the flange plate (α) and the angle outward the flange plate (β). The angle α is chose to be 11° while on the other hand, the ratio between α and β (R_{ca}) is chose to 0.83, so the angle β would be 13.2°.

For the displacement boundary condition, it is used where the bolting locks the pipe saddle in place through the holes, preventing any movement or rotation. However, the base plate is still allowed to move or rotate in all directions except vertically. Fig. 4 shows the contact angle loading condition plate with fixed support on the bolting hole and remote displacement on the base plate.

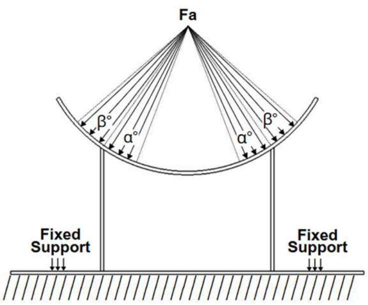


Fig. 4. Loading condition on a contact angle on the saddle plate with fixed support on the bolting hole and remote displacement on the base plate

2.3.2 Mesh Sensitivity Analysis

Mesh sensitivity analysis was conducted by reducing the mesh element size, which will increase the total number of elements. The effect of the number of elements on the resulting stress was analyzed in this study. The most efficient number of elements that provided an accurate result was selected for use in the following section.

2.3.3 Welding Connection Modelling

Weld connection modelling was conducted by replicating the actual fabrication of the weld joints in the pipe saddle support model. This approach aims to investigate the effect of weld thickness (T_w) on the stress results of the pipe saddle support model. The welding connection thickness variations is illustrated in Fig. 5.

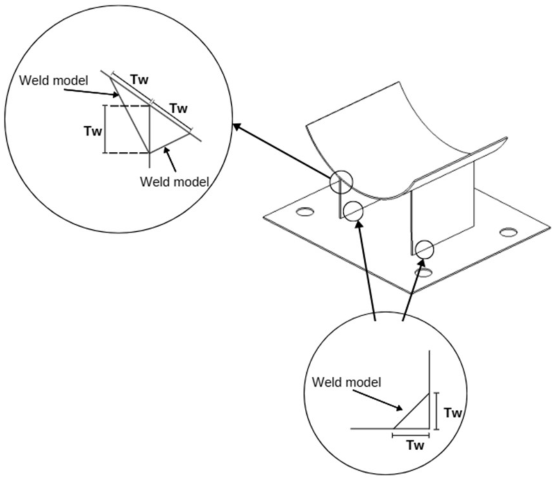


Fig. 5. Welding connection modelling on pipe saddle support model

2.4 Correlation Between Plate Thickness of Pipe Saddle Support and Pipe Loading

FEA was conducted on the pipe saddle support model with consideration of its attachment. Pipe saddle supports attachment are categorized into three main configurations based on their movement restrictions. The sliding plate configurations permitted both lateral and axial pipe movements while providing vertical support. Support guides allowed axial movements but restricted lateral displacements. Stopper supports provided complete fixation by preventing movements in both axial and lateral directions. These attachments did not alter the structural design of the pipe saddle supports, but they influenced the stress analysis results.

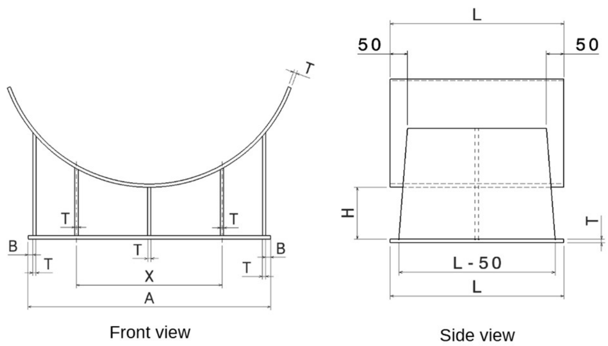


Fig. 6. Modified drawing of piping design standard for pipe saddle support model

Table 1. Allowable applied force for pipe saddle support attachments

Nominal Pipe Size, NPS (inch)	Axial force, F_{Axial} (kN)	Vertical force, $F_{Vertical}$ (kN)	Lateral force, $F_{Lateral}$ (kN)
26	110	140	50
30	140	160	60
36	140	220	70
40	180	270	70
48	180	350	80
56	180	380	90

Table 2. Dimension of pipe saddle support modified drawing

Pipe size, NPS (inch)	A (mm)	B (mm)	H (mm)	X (mm)	L (mm)
26	600	15	150	350	500
30	600	15	150	350	500
36	750	15	150	450	500
40	850	20	200	550	500
48	1000	20	200	700	600
56	1300	20	200	700	600

Each pipe saddle support attachment, corresponding to its respective pipe size, was analyzed using FEA to determine the appropriate plate thickness that achieves a safety factor of 3. The applied force for each model varies based on the type of attachment, as specified in Table 1 and in reference to the Petronas Piping Support Construction Standard (Petronas, 2014).

On the other hand, dimensions of the pipe saddle support are listed in Table 2, these dimensions are also based on the Petronas Piping Support Construction Standard (Petronas, 2014), with a modification that unifies all plate thicknesses to simplify the design.

The drawing of the pipe saddle support from Petronas Piping Support Standard (Petronas, 2014) is shown in Fig. 6. The pipe saddle support in Figure 6 consisted of five trapezoidal flange plates, whereas the experimental model used for FEA validation consisted of two rectangular flange plates. Despite these differences in number and geometry, the application of boundary and loading conditions was not affected. Therefore, the validated experimental conditions were applicable to the pipe saddle support design based on the standard.

3. RESULTS AND DISCUSSION

This chapter presents the results of the pipe saddle support analysis, which form the foundation for a correlation study between the plate thickness of the pipe saddle support and the applied pipe loading. To explore this correlation, the results are divided into three main sections. The first section describes the experiment on the pipe saddle support. The second section explains the validation of the FEA results. Finally, the third section presents the correlation study between plate thickness and pipe loading.

3.1 Experiment on Pipe Saddle Support

Vertical load is subjected to the pipe saddle support sample until it experiences failure. The stress results from experiment for each point of strain gauge A, B, C, and D are shown in Fig. 7.

The experimental stress results indicate that the strain gauge at point D experiences the highest compressive stress, as shown by its negative value. These results are then used to validate FEA of the pipe saddle support model. On the other hand, FEA run by Khan (2010) on saddle support indicates that on the flange plate, the trend for the stress is also increasing linearly as the load increase. Thus, this experiment provides a proper real-world stress result to confirming the simulation done on the FEA.

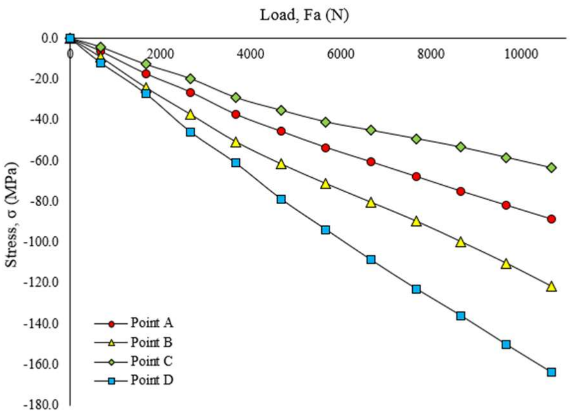


Fig. 7. Stress result from pipe saddle support vertical load test

3.2 Validation of FEA on Pipe Saddle Support

Table 3 presents the FEA accuracy results for boundary condition configuration using contact angle (α) of 11° with ratio contact angle (R_{ca}) of 0.83. In this configuration, point A recorded the highest accuracy at 89%, while point C had the lowest at 70%. The stress distribution pattern closely matched the vertical load test results, with the highest stress occurring at point D and the lowest at point C.

From the stress distribution obtained through FEA, as shown in Fig. 8, the contact angle approach (α) demonstrates that the saddle plate does not experience significant stress. As a result, it has minimal influence on the flange plate, consistent with the experimental findings. In contrast, the approach used by Khan (2010), which applies the load directly to the saddle plate, produces significantly higher stress in the saddle plate that affects the stress measured on the flange plate. This outcome does not align with the actual experiment. Therefore, the present study offers a more accurate simulation that better represents real-world conditions.

3.3 Welding Connection Model

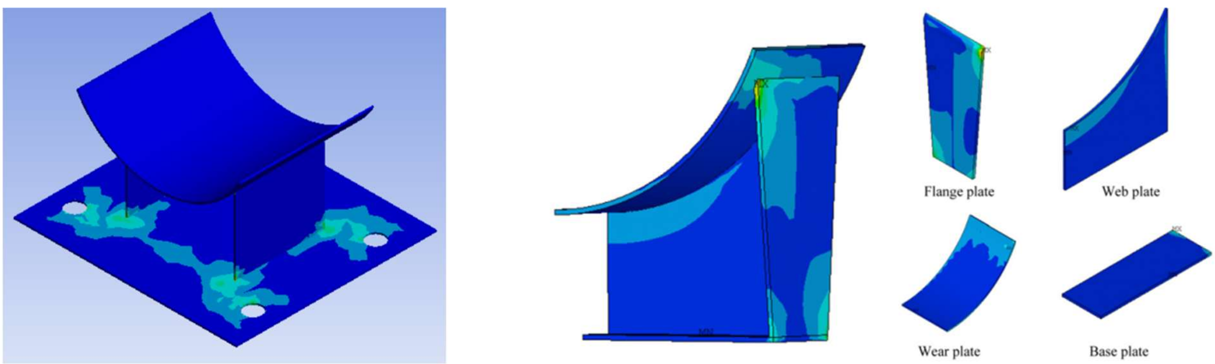
The stress results for T_w ranging from 0 to 5 mm are shown in Fig. 9. The comparison shows minimal variation, with only a 4% difference between the thickest T_w and the model without a welding connection. Therefore, the model without a welding connection was used for subsequent analyses to reduce computational time. This confirms that the presence of weld thickness on the model has a negligible effect on the stress distribution of pipe saddle support.

3.4 Mesh Sensitivity Analysis

Different mesh densities, ranging from 2,147 to 160,297 elements, produced varying stress results, as shown in Fig. 10. The stress values began to converge at 13,867 elements. However, the difference in stress between this convergence point and the default mesh was only 0.45%, indicating minimal variation. Therefore, the default mesh with the lowest number of elements was used in the correlation study to reduce computational time. In contrast, Khan (2008) conducted a mesh sensitivity analysis on saddle support and used a mesh with number of elements at the convergence point, as the difference between the lowest mesh and the converged result was significantly larger, reaching up to 33%. This comparison confirms that the default mesh used in this study is sufficient to produce reliable results while optimizing computational efficiency.

Table 3. Accuracy of FEA for pipe saddle support under vertical load.

Strain gauge position	Normal stress, σ_n (MPa)		Accuracy (%)
	Experiment	FEA	
Point A	-98.88	-88.75	88.6
Point B	-106.09	-121.47	87.3
Point C	-82.21	-63.38	70.3
Point D	-142.13	-163.70	86.8
Average accuracy (%)			83.3



(a) Contact angle approach on pipe saddle support in this study

(b) Directly to saddle plate (Khan, 2010)

Fig. 8. Stress distribution of pipe saddle supports on FEA

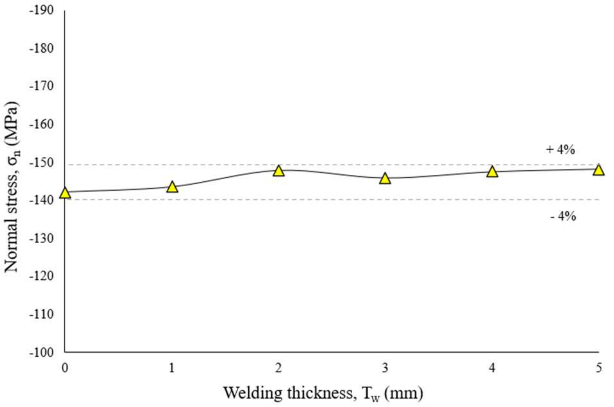


Fig. 9. Welding connection model result for FEA of pipe saddle support

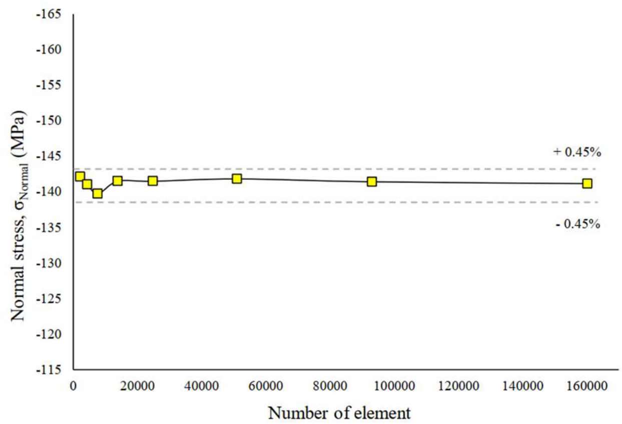


Fig. 10. Mesh sensitivity analysis result for FEA of pipe saddle support

3.5 Correlation between plate thickness and loading of pipe saddle support

The suitable plate thickness for nominal pipe sizes ranging from 26 to 56 inch is presented in Fig. 11. The trend indicates that sliding support requires the thinnest plate thickness, followed by guide support, while stopper support has the thickest plate. This occurs because each support experiences additional loading that required a thicker plate to withstand the applied forces. Furthermore, the trend remains consistent across all support types, where larger pipe sizes require a thicker plate to accommodate the increasing load.

By following the trend lines for each type of support, the required plate thickness can be estimated for fabrication purposes. However, in real-world applications, suppliers may not always provide the exact thicknesses indicated in the graph. In such cases, the design should use the next available thicker plate to ensure the safety of the supports. Overall, this graph is expected to make the design process of pipe saddle supports easier and more practical for the oil and gas industry.

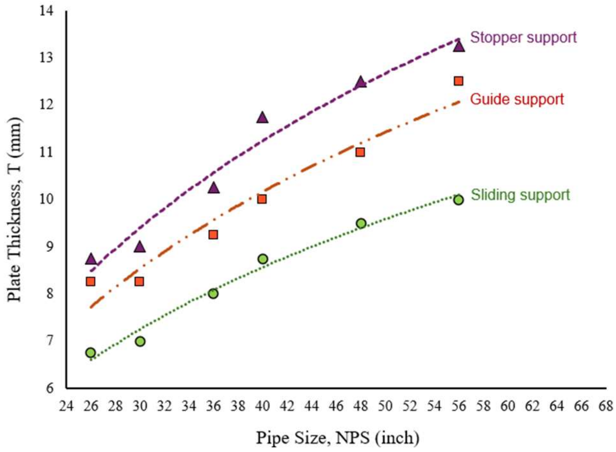


Fig. 11. Graph correlation between plate thickness and pipe size for each type of pipe saddle support

In the context of existing research, previous studies such as Khan (2010) provided valuable insights into saddle support behavior, they did not establish a direct correlation for estimating plate thickness across different pipe sizes. In this regard, the present study offers an extended contribution that supports both analytical evaluation and practical design implementation.

3.5 Validation of Correlation Study Between Plate Thickness of Pipe Saddle Support and Pipe Loading

To improve the accuracy of the correlation study, a follow-up experiment was conducted on a pipe saddle support sample with a plate thickness of 4.5 mm. This new sample was designed identically to the initial 1.5 mm thick sample to validate the pipe saddle support model for a different plate thickness. In this experiment, stress was recorded at point B using a strain gauge. The stress results from the experiment are compared with the FEA results of the pipe saddle support model using 4.5 mm thick plates. Table 4 presents the accuracy of the FEA results for the 4.5 mm plate thickness.

The comparison between stress result from experiment and FEA trends shows a very close match, with an overall accuracy of 94.6% among all the load that applied to the pipe saddle support. Based on these results, the model is considered validated and the modelling technique can be used for industry application for the same geometry and condition as this research. However, further studies under different configurations are recommended to verify the broader applicability of these findings.

Table 4. Accuracy of FEA for pipe saddle support model with 4.5 m plate thickness

Applied load, F_a (N)	Normal stress, σ_n (MPa)		Accuracy (%)
	Experiment	FEA	
0.0	0.0	0.0	100.0
670.3	-1.6	-1.1	66.4
3670.3	-5.9	-5.8	98.3
6670.3	-11.2	-10.6	94.1
9670.3	-15.3	-15.3	99.9
12670.3	-19.8	-20.1	98.7
15670.3	-23.7	-24.8	95.0
18670.3	-27.5	-29.6	92.4
21670.3	-31.9	-34.4	92.3
24670.3	-36.7	-39.1	93.4
27670.3	-41.0	-43.9	92.9
30670.3	-46.6	-48.6	95.8
33670.3	-52.1	-53.4	97.5
36670.3	-57.0	-58.1	97.9
39670.3	-62.3	-62.9	99.1
42670.3	-67.8	-67.6	99.8
Average accuracy (%)			94.6

4. CONCLUSION

This study explores the correlation between pipe loading and plate thickness in saddle supports using a validated FE model. An experiment on pipe saddle support confirmed the accuracy of the FEA with an 83.3% with boundary condition using an 11° inward contact angle and ratio contact angle (R_{ca}) of 0.83. The validated model was then applied to simulate pipe sizes ranging from 26 to 56 inches to determine the minimum plate thickness required for a safety factor of 3.0.

The validated model was subsequently used to conduct a correlation study between plate thickness and pipe loading, with the objective of refining the existing piping support construction standard developed by Petronas (Petronas, 2014). The results show that maintaining a safety factor of 3 requires thicker plates as pipe loads increase. Among the support types, sliding supports required the least plate thickness, followed by guide supports, while stopper supports demanded the greatest thickness to meet safety requirements. To further validate the correlation, an additional experiment was performed using a model with 4.5 mm thick plates. Using the same design and boundary condition configuration, the FEA achieved an accuracy of 94.6%, demonstrating the suitability of the modelling technique for industrial application.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENT

The authors express their gratitude to the Applied Mechanical Design Laboratory, Faculty of Mechanical Technology and Engineering, and Universiti Teknikal Malaysia Melaka for providing the facilities and support necessary to conduct this study.

REFERENCES

Bhattacharya, A. 2013. Stress analysis of pipe support attachments: a comparison of analytical methods and finite element analysis for circular and non-circular attachments. Proceedings of the ASME 2013 Pressure Vessels and Piping Conference. American Society of Mechanical Engineers, 55676, V003T03A016.

Birhane, A.H., Hari, Y. 2002. Finite element analysis and design of a horizontal tank on saddle supports. Proceedings of PVP2002 2002 ASME Pressure Vessels and Piping Conference, 46504, 275–281.

Bisbos, C.D., Thomopoulos, K., Tzaferopoulos, M. 1993. Computing the frictional contact loads of horizontal steel pipes, loosely resting on saddles. International Jornal of Pressure Vessel and Piping, 58, 75–85.

de Barros, S., Meniconi, L.C.M., Perrut, V.A., Reuther de Siqueira, C.E. 2018. Oil industry. In Handbook of Adhesion Technology: Second Edition. Springer International Publishing, 2,1533–1555).

Hamid, M.F.A., Yob, M.S., Vishnu, J.S., Izahar, M.M. 2024. Development of large-scale bending and torsional test rig using strong floor anchorage system for structural analysis. Journal of Physics: Conference Series, 2784, 012021.

Khan, S.M.A. 2008. Initial investigation into optimizing design of a pressure vessel saddle. PVP2008 ASME

Pressure Vessels and Piping Division Conference, 1–4.

Khan, S.M.A. 2010. Stress distributions in a horizontal pressure vessel and the saddle supports. International Journal of Pressure Vessels and Piping, 87, 239–244.

Koorey, K. 2000. Determination of the optimal pipe support spans for geothermal pipelines. Proceedings World Geothermal Congress 2000, 1361–1364.

Mabuchi, T., Shinohara, M. 2004. Recent design approaches of large bore piping exceeding 100 of ratio D/T. Design and Analysis of Pressure Vessels, Heat Exchangers, and Piping Components, 46725, 477.

Maxey, R., Pincince, R. 1998. Surmounting design problems in a complex piping system for groundwater remediation. Environmental Progress, 17, 38–47.

Nugraha, A.Y., Kurdi, O. 2018. Studi Upaya Penghematan Energi Listrik Pada Gedung Asthabrata PT Mekar Armada Jaya. EKSERGI Jurnal Teknik Energi, 14, 25–30.

Nuthanapati, S., Adel, K., Al Maskari, J. 2018. Swift solutions to avert major structural failures. Abu Dhabi International Petroleum Exhibition and Conference. Piping Supports Construction Standard, D031S069R003 1–9.

Raj, V.Y., Yob, M.S., Ab Latif, M.J., Kurdi, O., Kassim, M. S., Izhar, M.M. 2023. Design and analysis of four-point bending test rig for ladder frame. Journal of Applied Science and Engineering, 26, 323–329.

Rajkumar, P., Nelluri, V.R. 2019. Design of pipe shoe support for horizontal large bore lines. International Journal of Innovative Research in Science, 8, 10514–10524.

Ranjbaran, S., Ghalelar, A.D. 2017. Stress of large diameter piping system shoe support. Proceedings of the ASME 2017 Pressure Vessels and Piping Conference, 57946, V03AT03A051.

Thomopoulos, K., Bisbos, C.D. 1992. Unilateral contact stresses at steel pipe saddles. Thin-Walled Structures, 15, 305–319.