[1] Mohd Firdaus Abdul Hamid

[2] Mohd Shukri Yob*

[3] Mohd Juzaila Abd Latif

[4] Fudhail Abdul Munir

[5] Ojo Kurdi

# Experimental and Finite Element Analysis Investigation of Storage Tank Under Hydrostatic Pressure

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***Abstract: -*** Storage tanks are widely used across various industries, such as the food and beverage, plastic and oil and fuel industries. It is important to ensure the structural integrity and safety of these tanks during their operations. To analyze a structure, finite element analysis (FEA) is a popular numerical method in stress analysis as it is cost and time effective. However, the accuracy of FEA is still under investigation due to issues such as the complexity of the structure, local stress concentrators and stress singularities. To understand these phenomena, an investigation on the accuracy of stress on the outer walls of the storage tank using FEA will be compared with experimental data. In the experiment, the stresses at elevations of 990 mm, 740 mm, 490 mm and 240 mm are measured using resistance strain gauges for every increment of water in the storage tank. From this comparison, the accuracy of stress using the finite element model manages to produce up to 94%.

***Keywords:*** Finite element analysis, hydrostatic, storage tank, stress analysis.

## I. INTRODUCTION

Storage tanks are containers that hold liquids, compressed gases, or mediums used for short or long-term heat or cold storage [1]. They are essential components in various industries, such as the food and beverage, plastic and oil and fuel industries for storage purposes. Storage tanks can be categorized based on two primary classifications: shape and placement [2]. Shape includes circular, rectangular, conical, spherical and Intze design, while placement includes above-ground, underground, or elevated/overhead storage tanks.

FEA is a valuable tool in engineering applications for predicting stress in a structure. FEA allows researchers to optimize designs by simulating the stress on models under different conditions in a cost and time effective manner. In the context of storage tank applications, numerous studies have relied on FEA to evaluate the strength of structures. For example, FEA has been used to design the shape of water tanks [3], conduct failure analysis on storage tanks [4-5] and design the head of a pressure vessel [6].

Although FEA is a good way to analyze the stress of a storage tank, the results are questionable due to the complexity of the structure, local stress concentrators and stress singularities. In terms of the complexity of the structure issue, the differences in FEA results are partly attributed by the size of the mesh used and primarily by the displacements of cross sections observed in the model representing the actual structure. A study concluded that the differences in results obtained from the Eurocode design and the FEA using

Abaqus software can be as high as 22.7% for the largest segment of the tank shell and up to 33.7% for normal stress [7]. Furthermore, FEA also does not take into account that there may be local stress concentrators and stress singularities caused by welds [8].

Given the highlighted issues, this paper will investigate the accuracy of stress on the storage tank by comparing FEA results with experimental data. The details of the comparison will be explained in the following section.

## II. METHODOLOGY

To obtain the stress results on the storage tank, an experiment will be conducted under hydrostatic pressure. As a case study, a square-shaped storage tank will be chosen. From this experiment, the stress data will be compared with FEA results. The overall flowchart of this study is shown in Figure 1.

[1, 2, 3] Fakulti Teknologi dan Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100, Melaka, Malaysia

[4] Department of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi PETRONAS, Bandar Sri Iskandar, 32610, Perak, Malaysia

[5] Department of Mechanical Engineering, Faculty of Engineering, Diponegoro University, Semarang 50275, Central Java, Indonesia

* Corresponding Author Email:, [2]mshukriy@utem.edu.my

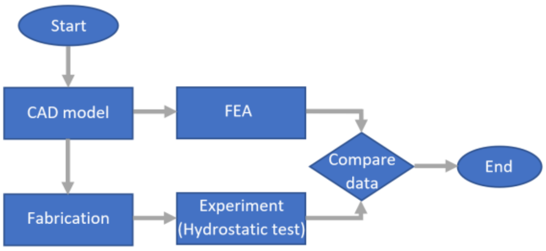


**Figure 1.** Stress comparison flowchart.

*2.1 Sample Preparation*

A square-shaped storage tank will be fabricated using five mild steel plates with a thickness of 2 mm. The square-shaped storage tank has dimensions of 1000 mm x 1000 mm x 1000 mm.

*2.2 Hydrostatic Test*

Four resistance strain gauges will be placed at elevations of 990 mm ($SG_1W_x$), 740 mm ($SG_2W_x$), 490 mm ($SG3W_x$) and 240 mm ($SG_4W_x$) on each wall ($W_1$-$W_4$) as shown in Figure 2 and Figure 3. The readings will be recorded at every 100 mm increase in water elevation, up to 1000 mm (fully-filled), by a data logger. The hydrostatic test will be repeated three times to obtain an average reading.

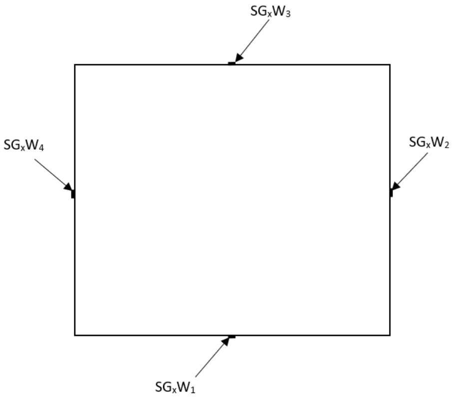


**Figure 2.** Strain gauges position (Plan view).

**Table I:** Force acting on panels.

| Water elevation, h (mm) | Force, F (N) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 |
| 100 | 48.90 | - | - | - | - | - | - | - | - | - |
| 200 | 146.71 | 48.90 | - | - | - | - | - | - | - | - |
| 300 | 244.51 | 146.71 | 48.90 | - | - | - | - | - | - | - |
| 400 | 342.32 | 244.51 | 146.71 | 48.90 | - | - | - | - | - | - |
| 500 | 440.13 | 342.32 | 244.51 | 146.71 | 48.90 | - | - | - | - | - |
| 600 | 537.93 | 440.13 | 342.32 | 244.51 | 146.71 | 48.90 | - | - | - | - |
| 700 | 635.74 | 537.93 | 440.13 | 342.32 | 244.51 | 146.71 | 48.90 | - | - | - |
| 800 | 733.54 | 635.74 | 537.93 | 440.13 | 342.32 | 244.51 | 146.71 | 48.90 | - | - |
| 900 | 831.35 | 733.54 | 635.74 | 537.93 | 440.13 | 342.32 | 244.51 | 146.71 | 48.90 | - |
| 1000 | 929.15 | 831.35 | 733.54 | 635.74 | 537.93 | 440.13 | 342.32 | 244.51 | 146.71 | 48.90 |

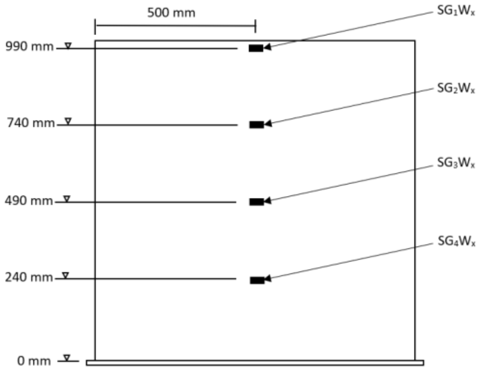


**Figure 3.** Strain gauges position (Side view).

*2.3 Finite Element Modelling (FEM)*

In FEM, each wall is divided equally into 10 panels in the vertical direction. Then, based on Table 1, force will be applied to these panels as shown in Figure 4 to represent the hydrostatic pressure.

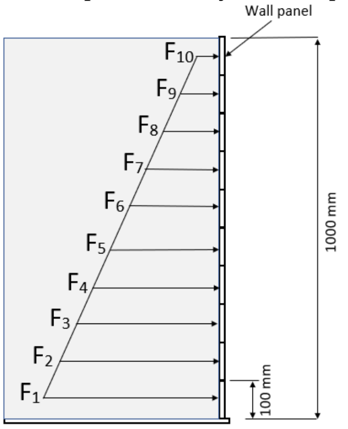


**Figure 4.** Load applied in FEM.

Figure 5 shows the boundary condition in FEA for the fully-filled condition. The fixed support is placed on the bottom surface of the storage tank base.

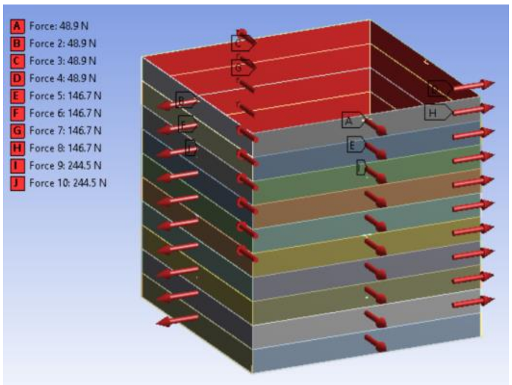


**Figure 5.** Boundary condition from FEA.

## III. Result And Discussion

The stress data graphs from the hydrostatic test and FEA at four elevations can be seen in Figures 6, 7, 8 and 9.

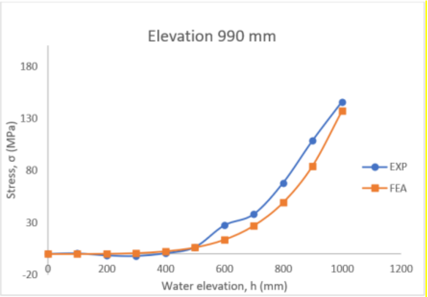


**Figure 6.** Stress comparison at el. 990 mm.

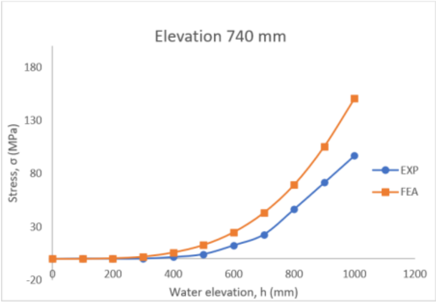


**Figure 7.** Stress comparison at el. 740 mm.

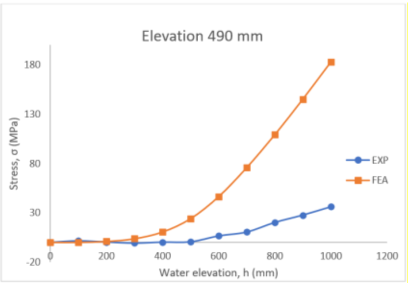


**Figure 8.** Stress comparison at el. 490 mm.

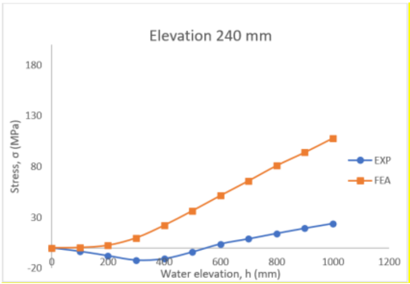


**Figure 9.** Stress comparison at el. 240 mm.

Since the storage tank experienced maximum stress when fully filled, the comparison will be extended to four different elevations. Figure 10 shows the stress result from FEA at elevations of 990 mm, 740 mm, 490 mm and 240 mm. The accuracy of the FEA is calculated in Table 2. It can be seen that the accuracy is good when the stress reading point far from the weld joining, which is at the base of the tank. The accuracy of the FEA significantly drop to zero when comparing stress at elevation 490 mm and 240 mm.

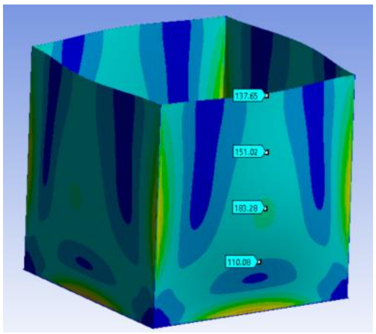

**Figure 10.** Stress result from FEA.

**Table II:** Comparison data between Experimental and FEA.

| Strain gauge | Average stress from SGXW1-4, σEXP (MPa) | Stress from FEA, σFEA (MPa) | Accuracy, a (%) |
|---|---|---|---|
| $SG_1W_{1-4}$ | 145.7 | 137.7 | 94.5 |
| $SG_2W_{1-4}$ | 96.9 | 151.0 | 44.2 |
| $SG_3W_{1-4}$ | 36.0 | 183.3 | 0.0 |
| $SG_4W_{1-4}$ | 24.0 | 110.1 | 0.0 |

## IV. Conclusion

This study was conducted to assess the accuracy of FEA by comparing it to experimental data. The findings show that FEM achieves good accuracy at elevation of 990 mm only. This modelling can be used to predict stress on the outer walls of the storage tank at any water elevation.

These results highlight the need for further investigation into the accuracy of FEA in predicting stress. The study recommends further research to refine and improve FEM at elevations of 240 mm, 490 mm and 740 mm in order to achieve higher percentage accuracy in stress analysis.

## V. Acknowledgement

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