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Effects of Variation Straps Length Towards the Reduction of Liquid Sloshing in a Downscaled Flexitank

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Abstract: This study presents the effects of variation strap length towards the reduction of liquid sloshing in a downscaled flexitank. Liquid sloshing is a major problem with the use of flexitanks and can cause damage or leaks. Although most flexitanks are made with multiple layers, there is still a possibility of leakage due to excessive force caused by liquid sloshing. To overcome this problem, researchers have studied and developed various methods for suppressing the sloshing in fully filled and partially filled rigid tanks, but these methods require installation and modification which can be costly. In this study, the effects of varying strap length on the reduction of liquid sloshing in a downscaled flexitank were tested. The objectives were to test the effectiveness of the straps and measure the forces involved, and to program, calibrate, and install Force Sensing Resistors (FSRs) for measuring the sloshing force. The length of the strap wrapped around the downscaled flexitank was reduced by 0.00 m, 0.014 m, and 0.28 m, and six FSRs were calibrated and installed in a downscaled shipping container to monitor the sloshing force. The experiments were carried out using a transportation simulator at speeds of 5, 10, and 15. Results showed that when the downscaled flexitank was not wrapped with a strap, the force caused by liquid sloshing was highest. As the strap length was reduced from 0.00 m to 0.14 m and 0.28 m, the force caused by liquid sloshing decreased. The greatest reduction in force was observed at a strap length reduction of 0.28 m, followed by 0.14 m and 0.00 m. The findings provide support for the use of varying strap length

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in downscaled flexitanks is effective in reducing liquid sloshing and that the greatest reduction is achieved with a 0.28 m strap length reduction.

Keywords: Flexitank, Straps, Force Sensing Resistor Calibration

1. Introduction

Flexitanks, large flexible bags, are commonly used to transport non-hazardous liquid cargo in shipping containers, as they are affordable and take up less space than conventional packaging [1]. However, a major issue with using flexitanks is the problem of liquid sloshing, which can cause stress on the flexitank and lead to damage or leaks, resulting in financial losses for the shipping industry [2] Various solutions have been proposed, such as internal baffles and anti-sloshing tools [3], but these can be costly and difficult to implement [4].

The use of straps, baffles, and other design components are some of the approaches for reducing liquid sloshing in flexible containers, according to research in the study of sloshing mitigation in flexible containers. Regarding the usage of straps, it is stated that they are a straightforward and efficient approach to reduce sloshing by making the container stiffer and minimizing movement and vibration. Also mentioned are the drawbacks of utilizing straps, such as the requirement to determine the right length and positioning of the straps in order to achieve the necessary amount of sloshing reduction [5]. The use of straps to apply external pressure to the flexitank can significantly reduce sloshing and increase the stability of the liquid cargo, according to research conducted to test the effectiveness of straps in minimizing sloshing in flexitanks under irregular wave circumstances [6]. The more straps were used, the more effective the straps at reducing sloshing. This finding suggests that many straps can be used to reduce sloshing more effectively than a single strap [6]. Additionally, the characteristics of the liquid and the sort of waves experienced determine the ideal amount of straps required to get the greatest outcomes [6].

According to a different study, the sloshing waves' amplitude may be greatly decreased by utilizing straps to provide external pressure to the tank's sidewalls [7]. This decrease in sloshing waves might increase the liquid cargo's stability and lessen the chance of leakage or other sorts of damage during transportation. It was also discovered that the ideal strap tension was closely correlated with the tank's level of filling [7]. This implies that the straps' ideal tension increased together with the amount of liquid in the tank. It is determined that while constructing and operating vessels that transport liquids in bulk, this relation between filling level and ideal strap tension should be taken into consideration [7].

Besides, numerical simulations were conducted to test the effectiveness of straps and baffles in decreasing sloshing in a flexible tank filled with water [8]. The findings revealed that the combination of straps and baffles reduced the amplitude of the sloshing waves more effectively than each approach used alone. It was discovered that the optimal number of strap tension to baffle spacing relied on how full the tank was, with fuller tanks requiring greater strap tensions and tighter baffle spacings [8]. This indicates that the characteristics of the tank and the required level of sloshing suppression affected how well the straps and baffles reduced sloshing. The findings demonstrate the potential of straps and baffles as efficient sloshing reduction solutions in flexible tanks. Additionally, it is claimed that this set of methods may be helpful in a number of situations where sloshing control is crucial, such as when transporting liquids in ships.

Another research looked into how various strap types affected liquid sloshing in a flexitank. It was discovered that the type of straps had a substantial impact on the liquid sloshing behavior when the same number of straps were used [9]. According to the results, round-edge straps performed better than flat-edge straps at lowering sloshing amplitude and suppressing liquid oscillation frequency [9]. Moreover, the sloshing behavior greatly improved when the number of straps was increased. Additionally, it was found that the strap type had a substantial impact on the sloshing amplitude for a flexitank filled with a liquid at a high fill level [9]. Overall, the results indicate that a flexitank's liquid sloshing behavior is significantly influenced by the type of strap and the number of straps.

In this study, the use of strap to wrap the downscaled flexitank is studied as a potential solution to reduce liquid sloshing by measuring the force caused by sloshing. Six Force Sensing Resistors (FSR) that are programmed and calibrated are installed in a downscaled shipping container.

2. Materials and Methods

2.1 Materials

Before conducting the experiment, there are a few materials were prepared for safety precautions in this project. These materials include baby swimming pool, large transparent plastic, acrylic perspex, holders, and L brackets [10]. Other equipments such as downscaled flexitank were fabricated and downscaled shipping container were prepared by MYF Sdn Bhd. Besides, water and Transportation Simulation Tester Machine were used in Makmal Sistem Pengujian University Tun Hussein Onn Malaysia campus Pagoh [10]. Six Force Sensing Resistors (FSR) were used to obtain the data for the experiments.

2.1.1 Downscaled Flexitank

The original size of the flexitank can occupy 24000 litres of water is not suitable to conduct the experiments on a Transportation Simulation Tester Machine. Therefore, the flexitank was downscaled to 46.875 litres and fabricated as shown in Figure 1.

Figure 1: Downscaled flexitank

2.1.2 Force Sensing Resistors (FSR)

Six Force Sensing Resistors (FSRs) connected to an Ardunio R3 Board were used to obtain the force caused by the sloshing. The FSRs were programmed and calibrated before they are used in the experiments. The FSRs connected to the Arduino Uno R3 were programmed using an Arduino software. The coding that was developed was compiled and uploaded to the Arduino.

Before the calibration of the force sensor is done, a piece of plywood was cut into 6 pieces with a dimension of 15 mm x 15 mm × 5 mm and a mass of 0.7 g each. Then, each piece of wood was sticked in the middle of each FSR. Figure 2 shows one of the FSRs used and the red dashed line denotes the location where the wood was attached.

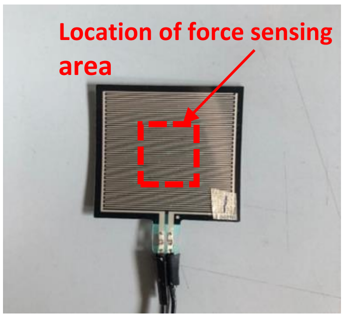


Figure 2: Force Sensing Resistors (FSR)

For the calibration process, a known force ranging from 600 g to 2000 g is applied to each FSR. The load applied used was by using river sand filled in a 1.5 litre plastic bottle. The reason for using a 1.5 litre plastic bottle filled with the river sand is because the mass of the applied load can be easily manipulated when different mass is applied to the FSR. The data collected for each FSR are analog value, voltage value, resistance value, conductance value, and force value. The data collected were used to plot scatter graphs against the mass applied for each FSR. By plotting the graphs, the trendline equation that fits the best to the data points were used to calibrate the FSRs.

2.2 Methods

Before the experiment begin, the material and equipment are set up. The six calibrated force sensing resistors (FSR) were placed and attached with tape on the floor of the downscaled shipping container because the FSRs detect more force on the bottom compared to placing it on the walls after tested. Therefore, A large transparent plastic which acts as a protective layer to the FSRs was also placed in the downscaled shipping container. Figure 3 (a) and Figure 3 (b) shows the location of the FSRs installed and the protective layer of the FSRs.

(a) Location of sensors **(b) Protective layer for FSRs**

Figure 3: (a) Location of FSRs and (b) Protective layer for FSRs

The calibrated force value of each FSR were calculated as the average force obtain from each pair of the FSRs as shown in Figure 3 (a) where the value of force F_1 was obtained by adding the force values of FSR 1 and FSR 2, and dividing by two. The same procedure was applied to F_2 where FSR 5 and FSR 6 are located and $F_3$where FSR 3 and FSR 4 are located.

Before filling water into the downscaled flexitank, the downscaled flexitank was folded inwards to make sure it fits into the downscale shipping container. Once the filling process is done, the tube of the downscaled flexitank is sealed and the downscaled shipping container's door is closed firmly. Then, the experiments were conducted into 4 different sets by reducing the length of the strap wrapped around the downscaled flexitank. Each set of experiments was conducted with three different speed which are 5, 10, and 15. The first experiment was done without the use of strap. The transportation simulator tester machine was set to 5. After the third cycle of the machine is completed, the machine is switched off and the data was recorded at the third cycle only. Then, the procedure of the experiment was repeated with speed of 10 and 15. After the first experiment is done, the same procedure was repeated with the strap wrapped around the downscaled flexitank. The second experiment was conducted without the reduction of strap length which is 0.00 m. Third and fourth experiment was carried out with 0.14 m and 0.28 strap length reduction. Figure 4 (a), (b) and (c) shows the strap wrapped around the downscaled flexitank with 0.00 m, 0.14 and 0.28 strap length reduction.

(a) 0.00 m length reduction **(b) 0.14 m length reduction** **(c) 0.28 m length reduction**

Figure 4: Variation strap length reduction in (a), (b) and (c)

3. Results and Discussion

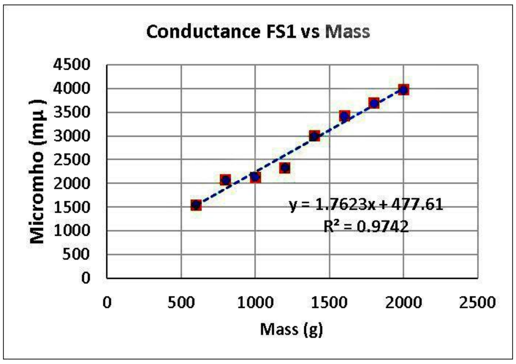
3.1 Force Sensing Resistors (FSR) Calibration Results

Table 1: Results of six FSRs after calibration

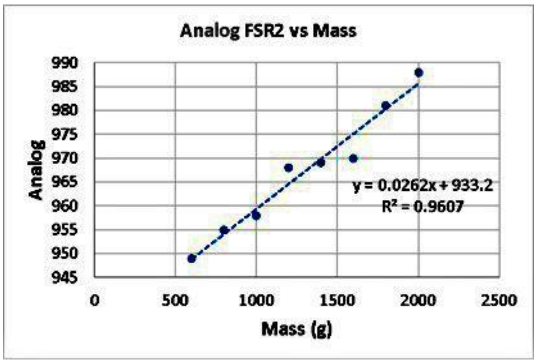
FSR number	Mass (g)	Value	Force after calibrated (N)
FSR 1 (Conductance)	600	1545 ℧	5.9
	800	2074 ℧	8.9
	1000	2123 ℧	9.2
	1200	2331 ℧	10.3
	1400	2994 ℧	14.0
	1600	3424 ℧	16.4
	1800	3690 ℧	17.9
	2000	3968 ℧	19.4
FSR 2 (Analog)	600	949	5.9
	800	955	8.2
	1000	958	9.3
	1200	968	13.0
	1400	969	13.4
	1600	970	13.8
	1800	981	17.9
	2000	988	20.5
FSR 3 (Conductance)	600	1379 ℧	4.5
	800	2028 ℧	10.0
	1000	2074 ℧	10.4
	1200	2272 ℧	12.0
	1400	2331℧	12.5
	1600	2457 ℧	13.6
	1800	2994 ℧	18.1
	2000	3311 ℧	20.8
FSR 4 (Force)	600	10 N	5.8
	800	21 N	8.1
	1000	24 N	8.8
	1200	37 N	12.9
	1400	40 N	14.1
	1600	44 N	15.1
	1800	48 N	17.8
	2000	50 N	18.8
FSR 5 (Conductance)	600	1449 ℧	4.7
	800	1862 ℧	7.9
	1000	2173 ℧	10.4
	1200	2518 ℧	13.1
	1400	2590 ℧	13.7
	1600	2898 ℧	16.1
	1800	2994 ℧	16.8
	2000	3311 ℧	19.3
FSR 6 (Conductance)	600	1336 ℧	5.2
	800	1602 ℧	7.1
	1000	2074 ℧	10.6
	1200	2331℧	12.5
	1400	2457 ℧	13.5
	1600	2898 ℧	16.7
	1800	3086 ℧	18.1

	2000	3086 ℧	18.1

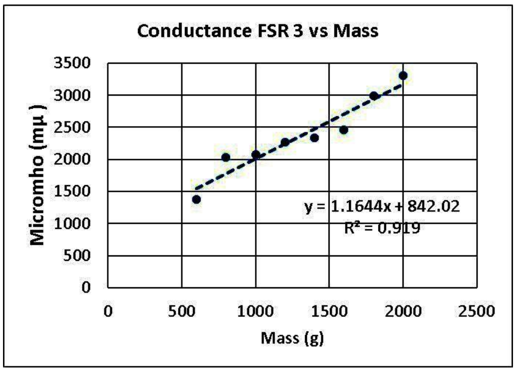
The data presented in Table 1 shows the results of the FSRs after calibration. The value of the calibrated force is calculated based on the equation that fits the best to the trendline shown in Figure 5 (a), (b), (c), (d), (e) and (f).



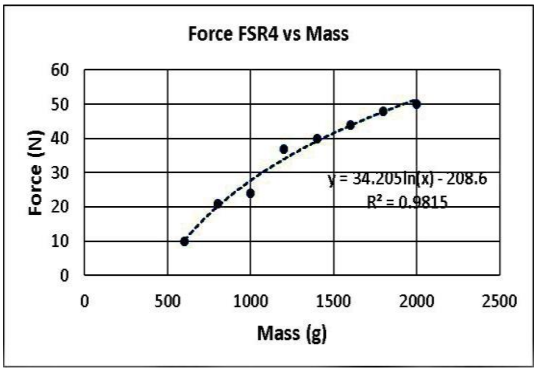
(a) Conductance vs Mass graph for FSR 1



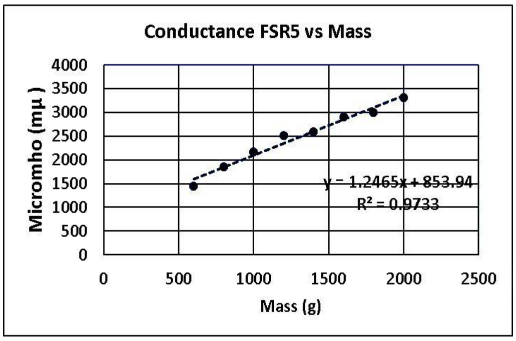
(b) Analog vs Mass graph for FSR 2



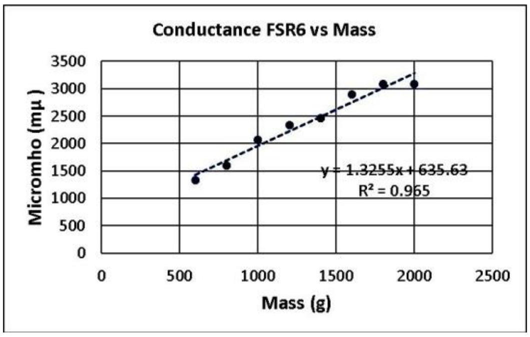
(c) Conductance vs Mass graph for FSR 3



(d) Force vs Mass graph for FSR 4



(e) Conductance vs Mass graph for FSR 5



(f) Conductance vs Mass graph for FSR 6

Figure 5: Best graphs for each FSR (a), (b), (c), (d), (e), and (f)

The graphs in Figure 6 show the trendline that fits the best to the data points. Therefore, the equations generated from each graph was used to find the value of calibrated force. For FSR 1, the conductance against mass graph had the highest accuracy with an R-squared value of 0.9742. For FSR 2, the analog against mass graph had the highest accuracy with an R-squared value of 0.9607. For FSR 3, it was recommended to use the trendline of conductance against mass as it had an R-squared value of 0.91. For FSR 4, the force against mass graph had the highest accuracy with an R-squared value of

0.985. For FSR 5, the conductance against mass graph had an R-squared value of 0.9733 and was recommended. For FSR 6, the conductance against mass graph had the highest accuracy with an R-squared value of 0.965.

3.2 Experimental Results

After the Force Sensing Resistors (FSR) are calibrated, the FSRs are placed in the downscaled shipping container. The position of the FSRs were placed on the floor of the downscaled shipping container to obtain the sloshing force. Then, four sets of experiments with the variation of length reduction were run with different speeds which is 5, 10, and 15. Although there are six FSRs, the average values were obtained from calibrated force values of FSR 1 and FSR 2 which were declared as F_1, for calibrated force values of FSR 5 and FSR 6 were declared as F_2 and FSR 3 and FSR 4 was declared as F_3. The results of F_1, F_2 and F_3 are recorded in Table 2, Table 3 and Table 4. Meanwhile, the results for all forces obtained by each FSR can be referred in Appendix A.

Table 2: Average force values, F_1 for FSR 1 and FSR 2

Variables	Speed	$F_{FSR\ 1}$	$F_{FSR\ 2}$	F_1
	5	13.0	13.1	13.1
Without strap	10	14.0	14.9	14.5
	15	14.5	17.9	16.2
With strap	5	12.6	10.4	11.5
length reduction	10	13.5	13.8	13.7
of 0.00 m	15	14.0	17.1	15.6
With strap length	5	10.7	9.7	10.2
reduction of 0.14	10	13.0	13.1	13.1
m	15	13.5	14.9	14.2
With strap length	5	9.2	8.1	8.7
reduction of 0.28	10	9.4	9.3	9.4
m	15	10.3	13.5	11.9

Table 3: Average force values, F_2 for FSR 5 and FSR 6

Variables	Speed	$F_{FSR\ 5}$	$F_{FSR\ 6}$	F_2
	5	16.1	13.5	13.1
Without strap	10	16.8	16.7	14.5
	15	19.3	18.1	16.2
With strap length	5	13.1	12.5	11.5
reduction of 0.00	10	13.7	16.7	13.7
m	15	16.8	16.7	15.6
With strap length	5	10.4	10.6	10.2
reduction of 0.14	10	11.6	12.5	13.1
m	15	16.1	13.5	14.2
With strap length	5	7.9	8.8	8.7
reduction of 0.28	10	10.7	9.7	9.4
m	15	13.7	12.5	11.9

Table 4: Average force values, F_3 for FSR 3 and FSR 4

Variables	Speed	$F_{FSR\ 3}$	$F_{FSR\ 4}$	F_3
	5	16.0	15.1	15.6
Without strap	10	16.6	17.8	17.2
	15	20.8	18.8	19.8
With strap length	5	15.4	14.1	14.8
reduction of 0.00 m	10	15.4	14.1	14.8

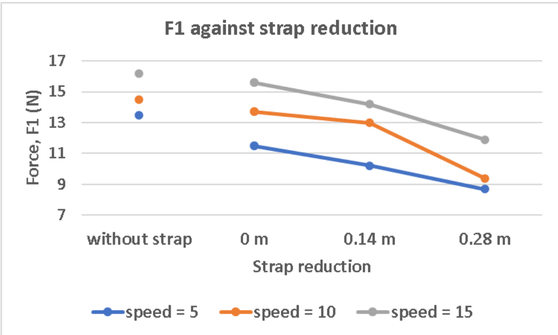
Table 4 (continued): Average force values, F_3 for FSR 3 and FSR 4

	15	2994	18.1
With strap length reduction of 0.14 m	5	2994	14.1
	10	2457	13.6
	15	2747	16.0
With strap length reduction of 0.28 m	5	2331	12.5
	10	2272	12.0
	15	2666	15.4

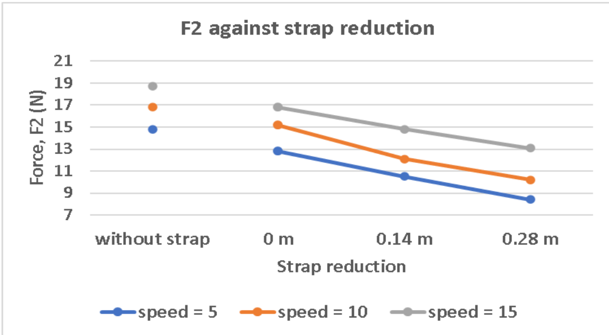
3.2 Discussions on the graphs

3.2.1 Graph of Experiments

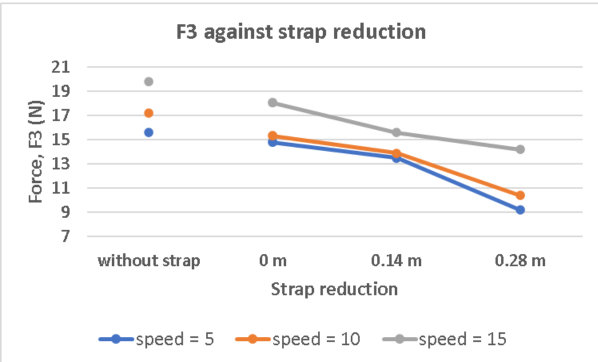
The graphs for the experiments are plotted with the forces against the strap length reduction at a speed of 5, 10 and 15. This is to make it easier to visually display the relationship between the effectiveness of using straps in reducing the force caused by liquid sloshing at different speeds.



(a) F1 against strap length reduction



(b) F2 against strap length reduction



(c) F3 against strap length reduction

Figure 6: Graphs of F_1, F_2, F_3 against strap length reduction

For the experiment without using the strap, in Figure 6 (a), the forces, F_1 caused by the liquid sloshing are 13.5 N at the speed of 5, to 14.5 N at the speed of 10, and 16.2 at the speed of 15. Similarly, with other force values of F_2 shown in Figure 6 (b), the force values are 14.8 N at the speed of 5, 16.8 N at the speed of 10, and 18.7 N at the speed of 15. For F_3 in Figure 6 (c) the force values are 15.6 N at the speed of 5, 17.2 N at the speed of 10, and 19.8 N at the speed of 15.

For the experiment with 0.00 m reduction of the 7.75 m strap required to wrap around the downscaled flexitank, the forces, F_1 caused by the liquid sloshing are 11.5 N at the speed of 5, to 13.7 N at the speed of 10, and 16.2 at the speed of 15. Similarly, with other force values of F_2 shown in

Figure 6 (b), the force values are 12.8 N at the speed of 5, 15.2 N at the speed of 10, and 16.8 N at the speed of 15. For F_3 in Figure 6 (c), the force values are 14.8 N at the speed of 5, 15.3 N at the speed of 10, and 18 N at the speed of 15.

For the experiment with 0.14 m reduction from the 7.75 m strap required to wrap around the downscaled flexitank, the forces, F_1 caused by the liquid sloshing are 10.2 N at the speed of 5, to 13 N at the speed of 10, and 14.2 at the speed of 15. Similarly, with other force values of F_2 shown in Figure 6 (b), the force values are 10.5 N at the speed of 5, 12.1 N at the speed of 10, and 14.8 N at the speed of 15. For F_3 in Figure 6 (c) the force values are 13.5 N at the speed of 5, 13.9 N at the speed of 10, and 15.6 N at the speed of 15.

For the experiment with 0.28 m reduction from the 7.75 m strap required to wrap around the downscaled flexitank, the forces, F_1 caused by the liquid sloshing are 8.7 N at the speed of 5, to 9.4 N at the speed of 10, and 11.9 at the speed of 15. Similarly with other force values of F_2 shown in Figure 6 (b), the force values are 8.4 N at the speed of 5, 10.2 N at the speed of 10, and 13.1 N at the speed of 15. For F_3 in Figure 6 (c) the force values are 9.2 N at the speed of 5, 10.4 N at the speed of 10, and 14.2 N at the speed of 15.

This indicates that using straps as the strap length is reduced around the downscaled flexitank is effective in reducing the force caused by liquid sloshing although the force increased as the speed increased. It can be seen from the graph that with 0.28 reduction of strap length, the forces caused by liquid sloshing is the lowest compared to 0.14 m, 0.00 m and without the use of strap. Therefore, 0.28 reduction of strap length is the optimal length to reduce the forces caused by sloshing although the speed is varied.

4. Conclusion

In conclusion, wrapping strap around the downscaled flexitank is effective in reducing the sloshing force because it helps to constrain the liquid and reduce the amount of movement within the downscaled flexitank. As the strap length was reduced by 0.28 m, it can be concluded that the value of forces caused by the liquid sloshing is the lowest at each speed of the transportation simulation tester machine. However, as the speed of the transportation simulation tester machine is increased, the force of the liquid moving within the tank also increases although the strap length is reduced. This is due to the fact that as the speed increases, the liquid experiences more inertia, which causes it to move more forcefully within the downscaled flexitank. This increase in movement causes the force of sloshing to increase, despite the use of the shorter strap.

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