ENHANCEMENT OF SEAFARER TRAINING WITH VISUALIZATION OF SHIP MOORING CONDITIONS

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This study focuses on improving maritime education through mooring training using a line tension visualization system and a small vessel. Improper mooring can lead to Snapback, a dangerous phenomenon caused by excessive rope tension, where a broken rope recoils and can injure crew members. Since mooring line tension fluctuates due to weather and sea conditions, continuous monitoring is essential to ensure stability and safety. Traditional mooring training relies on large mooring equipment, which presents safety risks and limits the frequency of hands-on practice. To overcome these challenges, this study introduces a training system that enables students to observe mooring tension in real time. Using six mooring lines equipped with tension sensors, the system allows students to visually assess load distribution during mooring operations. Comparative experiments were conducted to analyze different mooring methods and their effects on load distribution. On April 26, 2024, 21 navigation students participated in six experimental sessions, each lasting 10 minutes. Data was collected at a resolution of 10 points per second, providing a detailed view of mooring tension dynamics. The results indicate that improper mooring leads to excessive load concentration on a single line, increasing the risk of breakage. A post-training survey revealed that over 80% of students demonstrated an understanding of mooring principles, confirming the effectiveness of the training materials. However, some students struggled to interpret tension graphs, as they did not clearly indicate the corresponding forces acting on each mooring line. Future improvements will focus on enhancing the visualization of mooring forces, making data interpretation more intuitive.

Keywords: *Seafarer training, Teaching material, Monitoring moored a ship, Quantification of mooring line tension*

Introduction

When a rope breaks during the mooring of a ship, it causes a phenomenon known as Snapback. Snapback is a dangerous problem because a broken rope rebounds and can cause a serious injury if it strikes a person. According to the Japan Transport Safety Board (2012), approximately 33% of onboard work-related fatalities and injuries occurred during mooring or anchoring operations. Therefore, crews must maintain the mooring lines and properly moor ships to prevent excessive tension on the ropes. Failure to moor a ship properly can result in the continued tension of a single mooring rope, which can lead to the breakage of the mooring rope. The tension on a ship's mooring lines will vary over time and place due to ship movements caused by changes in weather and sea conditions, so the crew must constantly monitor the condition of the lines. The knowledge and ability to properly moor a ship is an important skill for seafarers.

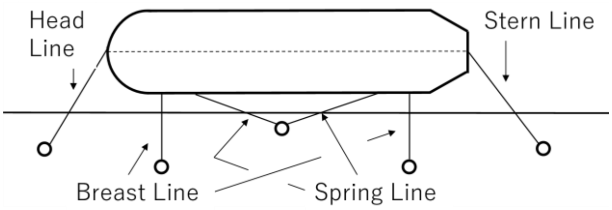

Figure 1. General mooring of a ship at the quay. And the name of each mooring lines.

Seafarers' education institutions now teach students to moor large ships using the mooring equipment installed on training vessels. However, the operation of such large equipment is hazardous, and there are limitations on the number of training sessions and the time available. These concerns have been highlighted in safety guidelines issued by the Ministry of Land, Infrastructure, Transport and Tourism (n.d.), which emphasize the importance of proper training and risk management during onboard engineering operations. This makes it difficult for each student to learn repeatedly over time. In this study, we developed a mooring training material using a mooring line tension visualization device and the small ship "HAMAKAZE" of the Yuge College of Maritime Technology in order to enhance the education of seafarers. The purpose is for students to visualize the condition of mooring ropes, to understand the use of each mooring rope, and to learn the correct mooring method. Figure 1 shows a general mooring arrangement of a ship at the quay, which serves as a basis for understanding the roles of each mooring line. Unlike large equipments, this teaching material uses a small ship and small equipments, which allows students to train as many times as they wish. The educational potential of this teaching material is also being investigated through demonstrations in classrooms on land, since the mooring line tension data recorded in this experiment can be reviewed with the students at a later date, in the classroom.

Materials and Methods

The basic purpose of mooring is to secure a vessel to a quay, buoy, or anchor, making it less susceptible to the influence of wind and tidal currents (IMO, 2024). This involves the following three key elements. Mechanical Stability: Properly arranging mooring lines (ropes or wires) to prevent the vessel from moving. Load Distribution: Evenly distributing the tension in the mooring lines to avoid excessive strain on any single line. Friction and Wear: The material and environmental conditions of mooring lines affect their wear, necessitating regular inspections and replacements. The objective of this study is to create effective instructional materials that help students in the Department of Maritime Technology practically understand the mechanical stability and load distribution of mooring. In developing the instructional materials, simulations were incorporated and combined with hands-on training to create a learning environment where students' understanding could be assessed. As part of this initiative, a system was introduced using an easy-to-operate small vessel to measure the tension in mooring lines. This allows students to learn about load distribution and mechanical stability in mooring operations from both theoretical and practical perspectives. For the tension measurement environment using a small vessel, a system was designed to incorporate tension sensors for real-time data acquisition. Additionally, comparative experiments on different mooring methods were conducted to analyze the effects of load distribution.

For the mooring training, the college's small vessel HAMAKAZE (Figure2, Length: 14.9 m, Displacement: 16 tons) will be used. The training will take place at the school's floating pier.

Figure 2. The college's small vessel HAMAKAZE.

Tension load cells are attached to six mooring lines connecting the vessel to the quay to measure changes in tension during mooring (Figure 3). The collected data is transmitted to a computer via a data acquisition system, where the tension variations are displayed in real time. A tension load cell (LTM-1KN, NIPPON TOKUSHU SOKKI Co., Ltd.), an amplifier (NTS-1280, NIPPON TOKUSHU SOKKI Co., Ltd.), and a data acquisition system with an A/D converter (NR-X100, TH-08, KEYENCE) were used. NR-XH1 (KEYENCE) was used as the data acquisition and display software.

During the experimental training, real-time graphing of the measurement results from tension sensors will allow students to intuitively understand changes in the load distribution of mooring lines. Additionally, comparative experiments on different mooring methods will help them learn the role of each mooring line. The experiment was conducted six times, varying the number of mooring lines and the distance between the quay and the vessel. Table 1 shows the experimental conditions. The experimental training was conducted on April 26, 2024, with 21 students from the Maritime Department's Navigation Course. Each experiment lasted 10 minutes, during which data was collected. The temporal resolution of the data was 10 points per second. Therefore, the data was averaged every second to create the analysis dataset.

Figure 3. A tension load cell (LTM-1KN) attached to a mooring line.

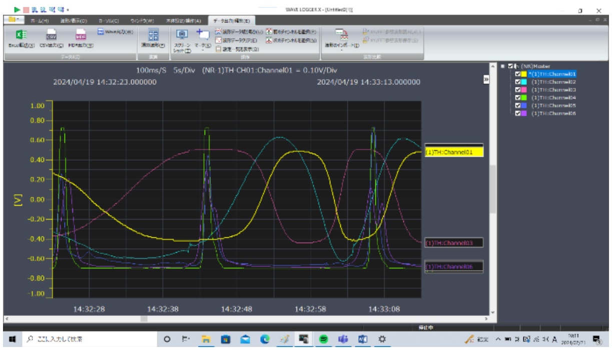

Figure 4. The appearance of the computer screen during mooring line tension measurement (NR-XH1).

Table 1. The experimental training conditions.

Experiment No.	Distance Between Quay and Vessel	Number of Lines	Remarks
1	1m	6	All Lines
2	1m	2	HeadLine, SternLine
3	1m	2	Fore and Aft BreastLine
4	1m	4	HeadLine, SternLine, Fore and Aft BreastLine
5	0m	4	HeadLine, SternLine, Fore and Aft BreastLine
6	0m	6	All Lines

Results and Discussion

At the beginning of the experimental training, students are taught the general theory of mooring, including the roles of each mooring line (IMO, 2024). Figure 5 illustrates the movement directions of a moored vessel and the corresponding mooring lines. The mooring lines that counteract the force attempting to move the vessel forward (Direction A) are Fore Spring Line (a1) and Stern Line (a2). Next, the mooring lines that counteract the force attempting to move the vessel backward (Direction B) are Headline (b1) and Aft Spring Line (b2). These four mooring lines should ideally be positioned at a small angle relative to the quay. Finally, the mooring lines that counteract the force attempting to move the vessel sideways (Direction C) are Fore Breast Line (C1) and Aft Breast Line (C2). These two mooring lines should ideally be positioned at an angle close to 90 degrees relative to the quay.

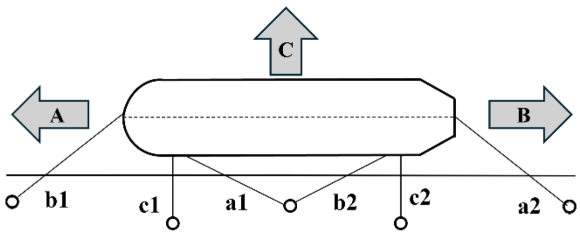

Figure 5. The movement directions of a moored vessel and the corresponding mooring lines.

Initially, in the experimental training, the measurement results from the tension sensors are visualized in real time through graphs, allowing students to intuitively understand changes in the load distribution of mooring lines. Figure 6 shows the time series of mooring lines in Experiment 1. At that time, the weather conditions included wind blowing diagonally from the left rear of the stern at a speed of 3.1 m/s. To counteract the forward-moving force of the vessel caused by the wind from the stern, the load is continuously applied mainly to the stern line and aft spring line, ensuring appropriate load distribution. Next, between 3 and 6 minutes, the vessel experienced hull motion due to waves generated by another ship. This resulted in an even distribution of load across all mooring lines, followed by a gradual reduction in load. From this, it can be inferred that the tension was dispersed among the other mooring lines, effectively stabilizing the vessel at an early stage. Since the aft spring line is the only mooring line counteracting the lateral forces acting on the vessel, a potential countermeasure would be to loosen the aft spring line and redistribute the load onto the two breast lines.

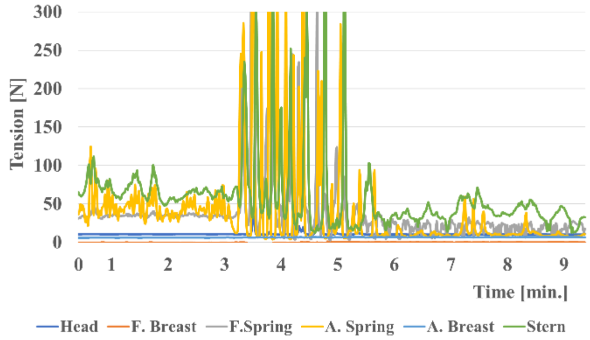

Figure 6. Time series of mooring line tension in experiment 1.

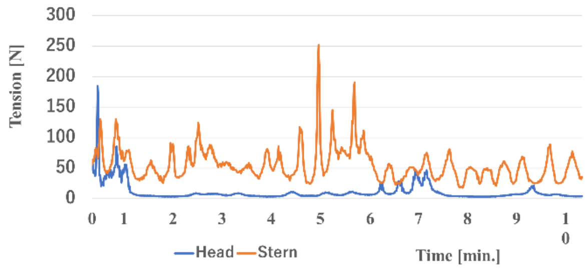

Figure 7. Time series of mooring line tension in experiment 2.

Next, four experiments were conducted to help students understand the role of each mooring line by varying the number of mooring lines. Figure 7 shows the time series of mooring line tension under the condition where only the headline and stern line were used (Experiment 2). In Figure 6, it is necessary to counteract the external force acting on the vessel using two mooring lines, but the load is concentrated only on the stern line. If excessive force continues to be applied to a single mooring line, there is a risk of it breaking. Experiment 3 yielded the same results (no figure available). Therefore, it is clear that two mooring lines are insufficient for maintaining stability.

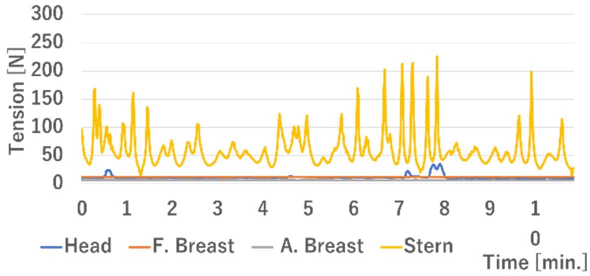

Figure 8. Time series of mooring line tension in experiment 4.

In Experiment 4 (Figure 8), four mooring lines were used; the headline, fore breast line, aft breast line, and stern line. Throughout the experiment, the tension remained on the stern line, making it impossible to distribute the load. The wind was blowing from the stern direction, and since only the stern line was available to counteract this external force, the load was concentrated on a single mooring line. If excessive force continues to be applied to a single mooring line, there is a risk of it breaking. Therefore, it is clear that four mooring lines were insufficient to maintain stability.

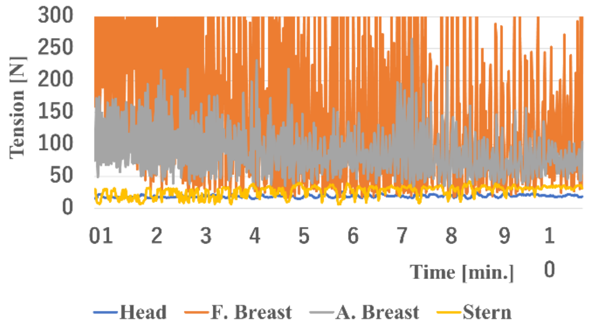

Figure 9. Time series of mooring line tension in experiment 5.

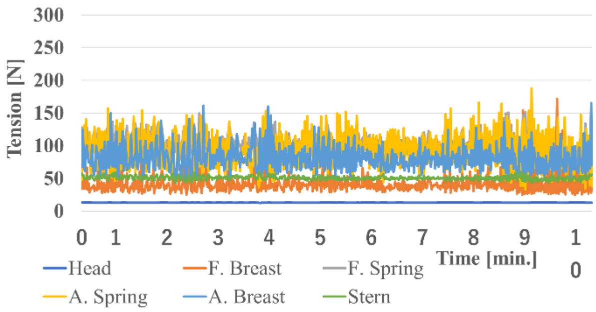

Figure 10. Time series of mooring line tension in experiment 6.

In Experiments 5 and 6 (Figures 9 and 10), measurements were conducted with the distance between the vessel and the quay set to 0m. This mooring method prioritizes cargo operations by ensuring that the vessel remains stationary. As a result, it was confirmed that strong and continuous loads were applied to two specific mooring lines. When using this method, the risk of mooring line breakage must be considered. Therefore, in addition to the six existing mooring lines, increasing the number of mooring lines would be an appropriate measure for secure mooring.

A survey was conducted with 21 students from the Maritime Department's Navigation Course who participated in the experimental training. Table 2 lists the survey questions. Additionally, Table 3 presents the response options for the survey.

Figures 11 shows the survey results. It was found that over 80% of students demonstrated understanding for each question item. Therefore, the objective of the training materials has been achieved. However, in Question 1, four students had difficulty understanding how to interpret the displayed graphs on the computer. The main issue appears to be that the graph showing the tension of six mooring lines does not clearly indicate which mooring line corresponds to which force. Therefore, as shown in Figure 5, it was determined that adjustments should be made to display each mooring line in relation to the movement of the moored vessel, improving clarity and comprehension.

Table 2. Survey questions.

Question Number	**Survey Questions**
Q1	Was the diagram displayed on the screen easy to understand?
Q2	Did you understand how to use the experimental equipment?
Q3	Did you understand the handling of mooring equipment and mooring lines?
Q4	Did you understand the role of each mooring line?
Q5	Did you understand the required number of mooring lines?
Q6	Did you understand the appropriate arrangement of mooring lines?
Q7	Did you understand the appropriate distance between the vessel and the quay?
Q8	Did you understand the effects of wind and tidal currents on mooring lines?

Table 3. Survey response options.

Response Number	**Description**
0	Did not understand
1	Understood
2	Can explain to others
3	Can explain to others and apply the knowledge

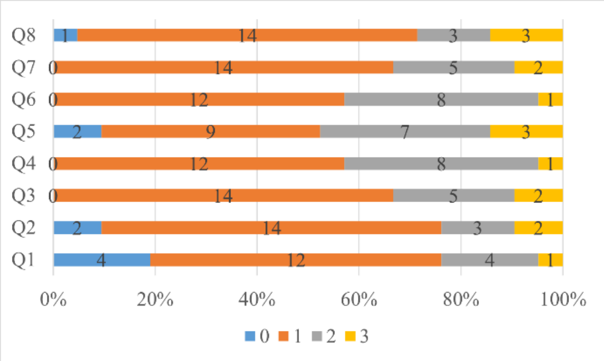

Figure 11. Survey responses for Q1–Q8.

Conclusions

Students conducted an experimental training in which they safely arranged mooring lines using a small vessel and measured and displayed their tension in real time.The survey question results indicate that over 80% of students demonstrated a clear understanding of the concepts covered, confirming the effectiveness of the instructional materials. However, some students encountered difficulties in interpreting the displayed graphs and identifying specific mooring lines, suggesting a need for improved visual representation. Based on these findings, adjustments will be made to enhance clarity, ensuring better comprehension in future training sessions. We would like to consider ways for students to reproduce and analyze the collected data in the future.

Acknowledgements

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References

Japan Transport Safety Board. (2012). JTSB Digest No. 3: Analysis of marine accidents involving injuries during ship operations. Ministry of Land, Infrastructure, Transport and Tourism. Retrieved from https://jtsb.mlit.go.jp/bunseki-kankoubutu/jtsbdigests/jtsbdigests_No3/No3_pdf/jtsbdi-03_all.pdf

Ministry of Land, Infrastructure, Transport and Tourism. (n.d.). Safety management manual for each type of engineering work onboard ships. Retrieved from https://www.mlit.go.jp/common/000114450.pdf

IMO. (2024). Revised Guidance on Shipboard Towing and Mooring Equipment (MSC.1/Circ.1175/Rev.1). International Maritime Organization.