Research Article

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FATIGUE ANALYSIS OF AN APPARATUS DESIGNED FOR MUSSEL STORAGE

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ABSTRACT: The use of durable apparatuses during harvesting and storage is essential in aquaculture for maintaining operational efficiency and worker safety. The aim of this study was to design a new mussel storage apparatus and determine its optimum dimensions through computer-based analysis. To achieve this aim, the fatigue performances of the apparatus designed in 250x250x100 mm dimensions with two different hole diameters (8 mm and 10 mm) were evaluated. The apparatus was designed in SolidWorks software and analyzed using finite element analysis (FEA) in ANSYS Workbench under different pressure conditions (10, 15, 20, and 25 kPa). FEA was performed using a 2 mm element size. The results indicated that the hole diameter had a significant influence on fatigue life and structural performance. It was also determined that increasing the hole diameter led to a decrease in load-bearing capacity and safety factor. The optimum design was obtained for a hole diameter of 8 mm, a pressure of 10 kPa, and a minimum safety factor of 1.6473. In this study, a durable and ergonomically optimized storage apparatus was designed. Overall, this study provides a reference for future research on mussel storage apparatuses in aquaculture systems.

Keywords: Bivalve, Fatigue test, Finite element analysis method, Hole diameter.

1. INTRODUCTION

Aquaculture has developed with technological advancements in both marine and freshwater resources, becoming a strategic sector in the industry. Globally, demand for aquaculture products is increasing each year due to rising population and protein requirements, which further underscores the sector's importance [1,2]. However, climate change and environmental degradation are causing a decrease in available freshwater resources and a reduction in production areas. Therefore, the development of offshore aquaculture has become a global priority trend within the aquaculture industry [3-7]. In addition, research into alternative technologies enabling the adaptation of fishing and aquaculture systems to offshore is necessary to expand and grow economic activity [8].

Bivalves, which hold specific economic and ecological value within the aquatic products sector, form a critical link in the food chain. Mussels, as members of the bivalve group, are an important food source, especially in countries bordering the sea, due to their high protein content, low production cost, and desirable taste [9]. Mussels are utilized not only for human consumption but also as animal feed, for decorative purposes, and as industrial raw materials. Mussel harvesting is a highly labor-intensive and physically demanding process. Harvesting is mostly done manually, sometimes aided by net scoops; in natural environments, juvenile mussels are carefully collected using collectors.

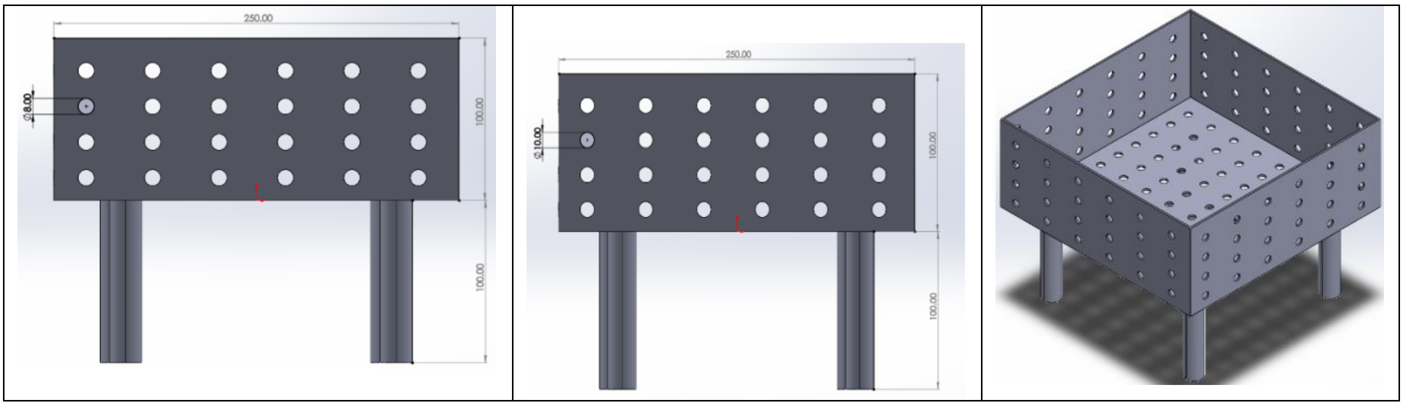
Technological developments have necessitated increasing productivity in aquaculture. The structural strength, ergonomics, and durability of equipment used in harvesting, storage, and transportation are critical for both production efficiency and occupational health and safety [10]. Modern fishing equipment not only increases the catch of aquatic products but also reduces the time lost during fishing operations [11]. Fishing gear is exposed to waves, currents, and long-term marine loads, posing risks of fatigue and deformation [12]. Additional fish farms continue to face the risk of aquaculture disruptions resulting from prolonged operations and exposure to extreme typhoon loads [13]. This underscores the critical importance of engineering optimization in the design phase. Therefore, numerical simulation studies have been conducted to achieve design optimization in bivalve aquaculture [14]. Currently, finite element analysis (FEA) provides one of the most efficient and reliable methods for obtaining rapid results in this area. FEA is widely employed in pre-production design optimization processes. Additionally, FEA is a numerical technique that supports various engineering approaches across multiple disciplines [15]. The finite element method allows the creation of realistic models based on accurate material assumptions and enables modeling with multiple different materials as needed [16]. One of the commonly used software tools for finite element analysis is ANSYS.

In this study, a mussel storage unit was preliminarily dimensioned and modeled in three dimensions using computer-aided design tools. Structural properties and fatigue performance were subsequently analyzed with ANSYS software, which offers significant advantages in pre-production design verification, material selection, and lifespan prediction. The primary objective of the study is to develop a storage apparatus for bivalve organisms that is ergonomically and structurally safe, efficient, and durable. The results of this study are expected to provide a significant reference framework for future research. These results contribute not only to advancements in mussel aquaculture but also in related aquaculture systems and the development of various storage and harvesting apparatus.

2. METHODS

2.1. Design of Mussel Storage Apparatuses with Different Hole Diameters

In this study, storage apparatuses with different hole diameters were designed for use during mussel harvesting. Two different designs characterized by their three-dimensional geometries were modeled. Both designs were configured in a square shape. In the first design the hole diameters were set to 10 mm, whereas in the second design the hole diameters were 8 mm. Each storage apparatus was initially designed as a three-dimensional model. The designs were modeled using SOLIDWORKS drawing and design software. The dimensions of the three-dimensional designs are presented in Figures 1a and 1b, while the perspective view is shown in Figure 1c.



a) b) c)

Figure 1. Three-dimensional design a) 8 mm dimensioning, b) 10 mm dimensioning c) perspective view

As shown in Figure 1a, the column length of each design was set to 100 mm. The mussel storage volume was defined as 250 mm × 250 mm × 100 mm. Due to its originality, this design does not rely on any standard design dimensions and was determined by the author. The purpose of determining these dimensions was to examine the effect of different hole diameters on the same design. Had designs with different overall dimensions been considered, the effect of hole diameter could not have been isolated, and a homogeneous conclusion would not have been possible. Therefore, the influence of hole diameter was directly evaluated on apparatuses with identical geometry and dimensions. As shown in Figure 1b, equal width was used for each design, ensuring homogeneous pressure distribution along all edges. Structural steel was selected as the material, with an elasticity modulus of 200 GPa.

2.2. Finite Element Analysis

Fatigue analyses were conducted using ANSYS Workbench software. For every analysis, the column sections of the storage apparatus were fully fixed to the ground, thereby imposing fixed boundary conditions at their bases. Four distinct pressure values were applied during the simulations. Element size was determined as 2mm. Thus, 277041 nodes and 122859 elements were used in the numerical analysis. The mesh sensitivity was controlled by the software, and the analyses were performed after determining the optimum values. The meshed configuration of the apparatus is shown in Figure 2.

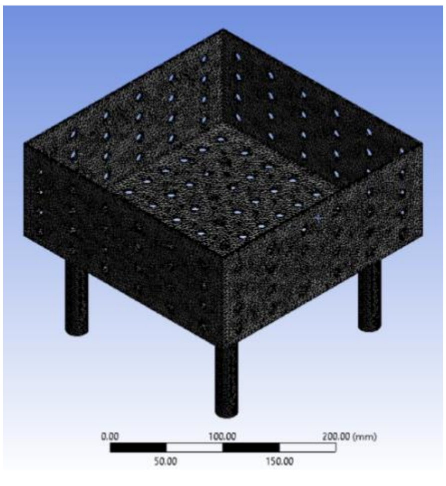


Figure 2. Mesh size of the apparatus

The effects of pressure magnitude and hole diameter on fatigue life were analyzed for two hole diameters (8 mm and 10 mm) under four different pressure magnitudes (10, 15, 20, and 25 kPa). The parameters employed in the analyses are summarized in Table 1. Different pressure values were applied, modeled to act on the internal surfaces of the apparatus. The applied pressure corresponds to the force distributed over the contact area, representing the effect of the mussel weight. Variations in pressure were considered to correspond to differences in mussel weight.

Table 1. Hole diameters and applied pressure values

Variables	Unit	Rankings			
Pressure	kPa	10	15	20	25
Hole diameter	mm	8	10	-	-

3. RESULTS AND DISCUSSION

In this study, different pressure magnitudes were applied to systematically investigate the fatigue performance of the mussel harvesting apparatus. Two hole diameters were also included in the analysis to examine the effect of geometric variations on structural strength. The study explains the relationship between the fatigue response, modulated by the pressure caused by accumulated mussel weight and the hole diameter. The resulting finite element analysis outcomes under these conditions are comprehensively presented in Table 2 and also graphically in Figure 3.

Table 1. Minimum Safety Factor Results

Tests	Pressure	Hole Diameter	Minimum Safety Factor
Test 1	10 kPa	8 mm	1.6473
Test 2	15 kPa	8 mm	1.0982
Test 3	20 kPa	8 mm	0.8237
Test 4	25 kPa	8 mm	0.6589
Test 5	10 kPa	10 mm	1.3909
Test 6	15 kPa	10 mm	0.9273
Test 7	20 kPa	10 mm	0.6954
Test 8	25 kPa	10 mm	0.5564

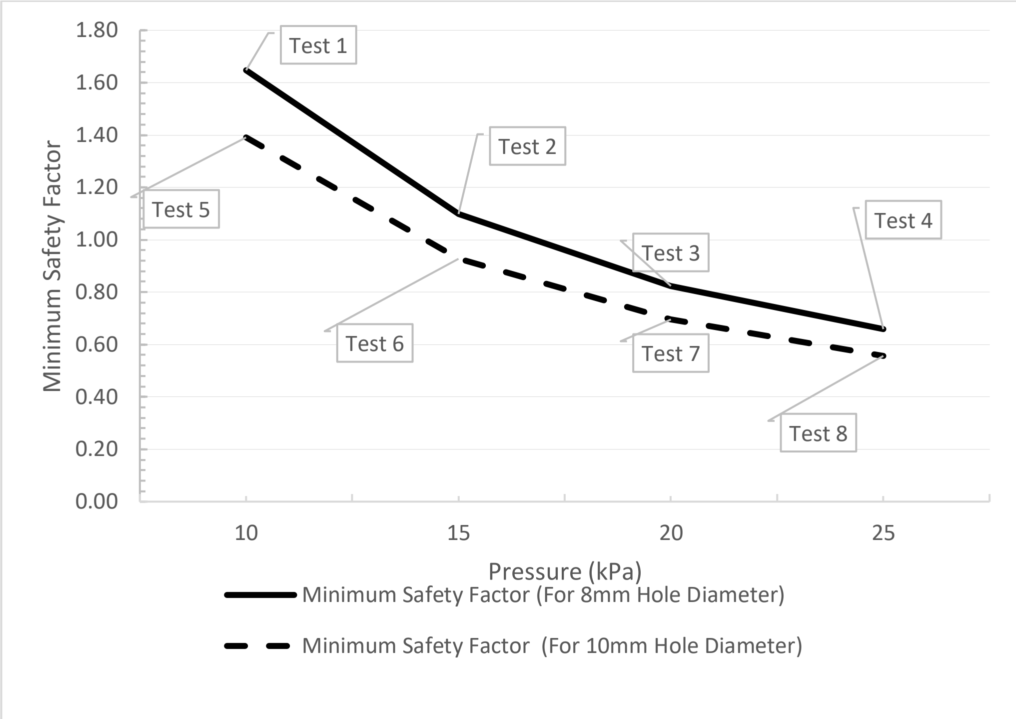
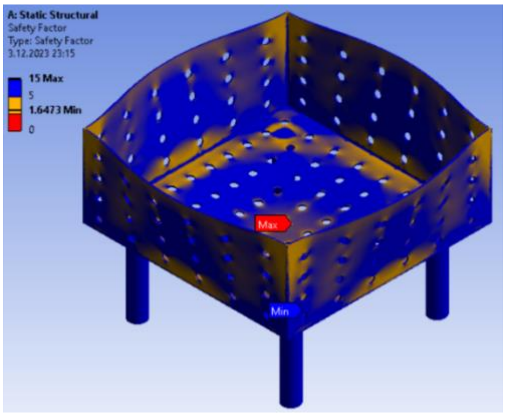
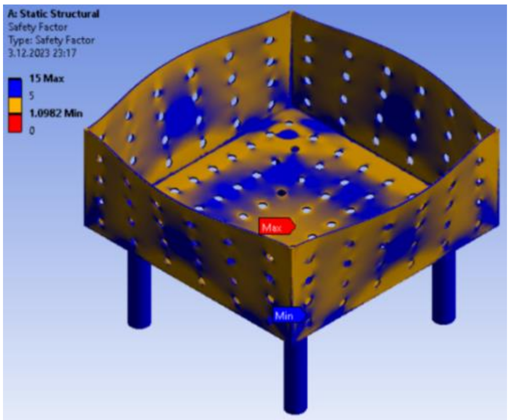


Figure 3. Minimum Safety Factor versus Pressure

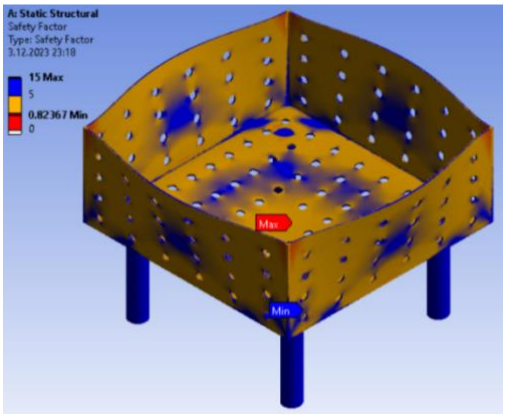
As shown in Table 2 and Figure 3, the Minimum Safety Factor decreases with increasing applied pressure on the mussel storage apparatus. Similarly, an increase in hole diameter results in a reduction of the Minimum Safety Factor. This behavior can be attributed to the diminished strength capacity of the material caused by larger hole diameters. In other words, as the hole diameter increases, the material's load-bearing capacity decreases, leading to a corresponding decline in the safety factor. It is important to note that an increase in hole diameter inherently corresponds to an increase in the number of holes with the same diameter. Since both an increase in hole number and hole diameter reduce the material's strength, they consequently produce a corresponding decrease in fatigue life. It was determined that the apparatus with dimensions of 250 × 250 × 100 mm, featuring 8 mm diameter holes subjected to 10 kPa pressure, represents the optimal design configuration. This conclusion is supported by the results of Test 1 in Table 2. Furthermore, the fatigue life, expressed in terms of the number of cycles, was associated with a safety factor of 1.6473 under the given pressure conditions simulating mussel weight. Visual representations of the analyses corresponding to Table 2 are provided in Figure 4.



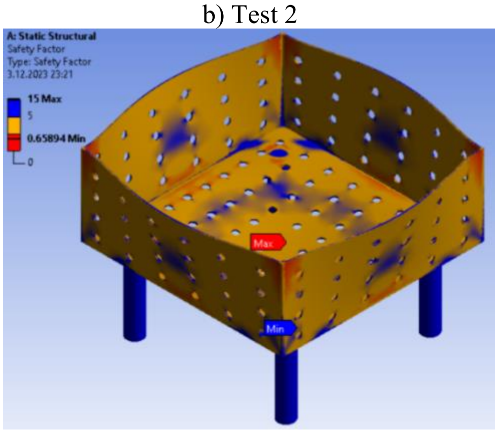
a) Test 1



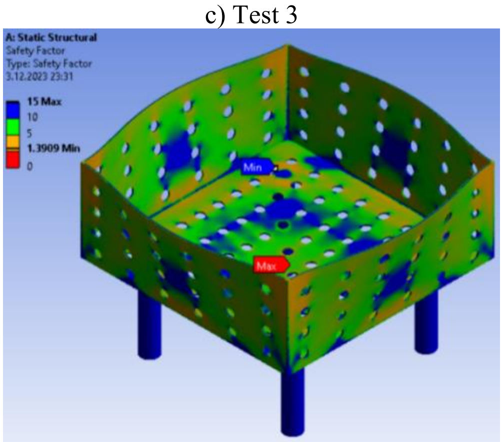
b) Test 2



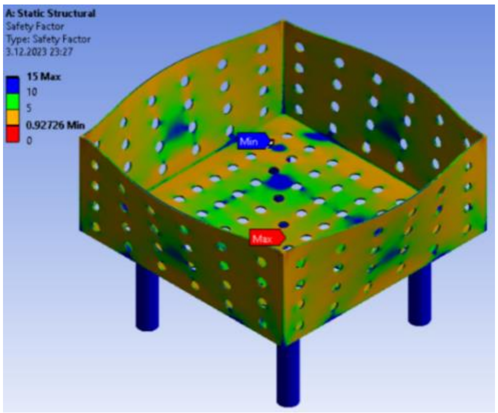
c) Test 3



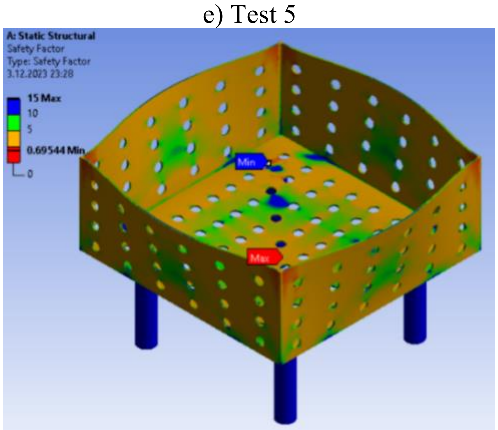
d) Test 4



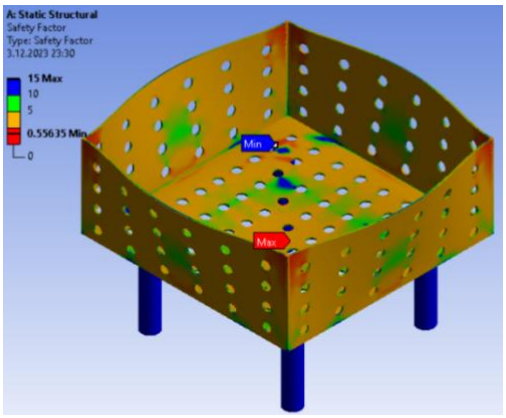
e) Test 5



f) Test 6



g) Test 7



h) Test 8

Figure 4. Images of calculations

According to the literature, the geometry of a material directly affects its fatigue behavior. Fatigue life is reported to be shorter in square or sharp-cornered elements due to stress concentration [17]. The designs in this study employ square geometries, and thus, the fatigue performance of the material is expected to be lower compared to other geometries. However, the use of square geometry was chosen to ensure the structural integrity of the apparatus and to meet its functional requirements. As shown in Figure 4, the highest factor of safety values are observed in the columns of the device (in blue), while the lowest values appear in the corners (in red), displaying a non-homogeneous distribution. The minimum factor of safety values in the corners indicate that these areas are more susceptible to fatigue damage. Therefore, reinforcing these critical areas during experimental fabrication could enhance the overall service life of the apparatus. The literature indicates that the shape of the aquaculture system significantly influences the fatigue behavior of aquaculture systems. By analyzing the fatigue strength of fish cages, initial tensile stresses and the structural design can be directly modified to mitigate fatigue damage and safety concerns [18]. Studies of aquaculture cage unit systems highlight that robust design and geometry significantly increase the device's endurance and service life under dynamic loading [19,20]. This capacity suggests that the geometric design of the apparatus and structural elements used in aquaculture production has an impact on load-carrying capacity and fatigue capacity. The literature indicates that concentrating stress at critical joints or widening these areas can increase the device's service life and durability. Therefore, implementing such measures in regular production and design contributes to the development of long-lasting and safe systems for apparatus.

4. CONCLUSIONS

In the aquaculture industry, various apparatuses are employed for the collection and storage of aquatic organisms. To enhance operational efficiency and minimize labor, there is a critical need for equipment that increases stock density while supporting efficient harvesting operations. This study focused on the design of a novel bivalve storage apparatus and employed finite element analysis (FEA) to evaluate fatigue life variations under operational conditions. Key findings indicate that increasing hole diameter reduces the safety factor and fatigue life. The study identified an optimal apparatus design measuring 250 × 250 × 100 mm with an 8 mm hole diameter subjected to 10 kPa pressure. Applied pressure, corresponding to the force exerted by mussels, affects the safety factor and fatigue life; as mussel weight increases, the safety factor decreases, leading to a shorter fatigue life. The results demonstrated that designing apparatuses under optimal conditions can yield durable and efficient equipment, improving working environments. Finite element simulations identified potential damage-prone regions prior to manufacturing, contributing to cost and time savings. Ergonomic design considerations also support occupational health and safety by producing equipment safer for operators. The results of this study provide a valuable reference for the design of durable and ergonomic mussel storage devices in aquaculture.

5. ACKNOWLEDGEMENTS

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