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An Experimental Study on the Effect of Gill Cells on Very Large Floating Structures

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1. Introduction

Very large floating structures (VLFSs) have attracted the attention of many researchers and engineers working in the offshore and marine industry. They have proposed VLFSs for various applications such as floating airports, bridges, breakwaters, piers and docks, fuel storage facilities, emergency bases, entertainment facilities, recreation parks, mobile offshore military bases, and even for habitation. There are various approaches to decrease differential deflection in VLFS. Increasing structure stiffness in all floating parts by means of increasing the height or the thickness of upper and lower plates is one the possible solutions. Considering the fact that this solution will have an effect on the size and shape of floating structure; it may boost the costs of production. Another solution is stepped floating structures. In this method, the depth of the loaded regions will be increased and that of the pats without loading will be decreased.

Wang et al. 2006 suggested an innovative model for decreasing differential deflection. They made some holes and slits on the floating bottom surface so that water may come into and out of some parts of the structure. Since the flow of water in these slits looks like fish gills, they are called *gill cells*. At gill cells, buoyancy forces are eliminated and with a proper installation of these cells differential deflection is reduced. They modeled a floating container terminal by means of the ABAQUS software, which was 520×470×10m, by using the finite element method. Applying gill cells would decrease stress and differential deflection significantly. Wang et al. investigated a circular structure with 200 m diameters and 2 m heights based on the classic thin plates' theory by using structure deflection analytically. They considered the effect of gill cells numbers by changing diameter and loading amounts. Phame and Wang 2010 investigated a numerical method for optimizing the location and number of cells in desired shapes. They modeled the floating structure based on the Mindlin theory supposing specific size and a uniform loading at the center. Then, they estimated the optimal number and location for gill cells. They presented triangular arrangements of gill cells at the corners of polygonal structures as the optimum arrangement.

Likewise, Gao et al., (2013) combined gill cells and joint connection in order to investigate gill cells performance. In this paper, gill cells were simulated in the laboratory. Gill cells will be introduced more specifically in the following section.

2. Gill Cells Introduction

Very large floating structures are made of waterproof components that provide buoyancy forces. On the other side, gill cells consist of components such that buoyancy forces are eliminated under their surface. Since there are holes and slits at the bottom of these cells, water may come in freely up to the sea level and go out. Fig. 1 represents a floating structure consisting of gill cells. When gill cells are located properly at the structures, bending curvature can be changed and the structure may become flatter.

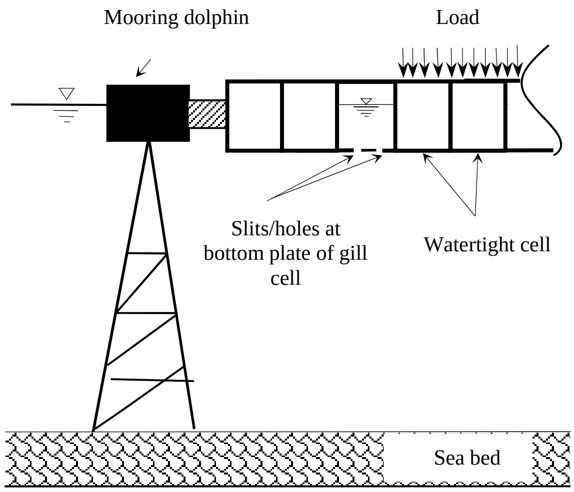

Fig. 1. Gill cell in very large floating structure

3. Description of experiments

The most significant feature of a very large floating structure is its hydroelastic behavior. One of the most influential parameters on a very large floating structure behavior is its bending rigidity that helps the model to be elastic. In order to simulate the behaviors of floating structures, the applied floating structure was chosen to be 300 meters in length, 60 meters in width and its bending rigidity was equal to 4.77×10^{11} Nm^2. The bending rigidity ratio of the model to the prototype was calculated as follows [1]:

$$EI_p = \alpha^5 EI_m \qquad (1)$$

Where EI_p is the bending rigidity of the prototype, EI_m the bending rigidity of the model and α is the scale ratio.

The scale of 1/150 was utilized for making the model in the research laboratory. According to the

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Eq. (1), the rigidity of the model must be 6.28 Nm^2. In order to provide such rigidity, an aluminum plate of 1.25 millimeters in thickness and 2×0.50m was selected. As shown in Fig. 2, polyethylene was used beneath the aluminum plate in order to provide floating.

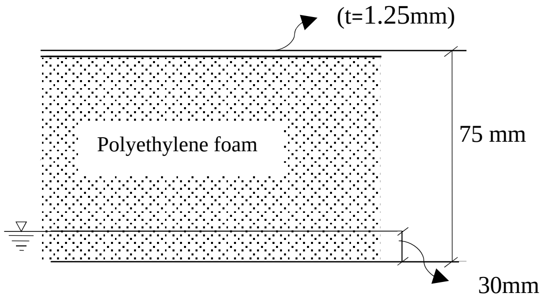

Fig. 2. Cross section of physical model made of aluminum and polyethylene

For stimulating the gill cells, cubic cells were made at the two ends of the model in dimension of 6×6 cm and cell depth is almost 7.5 cm. During the experiments, a specific amount of the cells must be full of water and the rest must be empty.

4. Experiment Method

The experiments were carried out in two parts: statically and dynamical loading. During the first part, stress and displacement under gravitational loadings were examined. At the second part of experiments, the model was tested by waves. In each of the mentioned parts, the experiments were performed on the model without gill cells. Moreover, four different states were considered in order to investigate the effect of gill cells number and arrangement on the structure. It should be noted that water depth was 70 cm in the laboratory.

4.1. Gill Cells Arrangement in Models

According to the number of cells and their arrangement in the structure, some slits were made at the bottom of each cell so that water may enter each cell separately. In the first state, six gill cells were made at each side of the model. In the second state, the number of cells was increased to 12 cells and they were in rectangular shape located at the corners of the model. In the third state, gill cells were located in the two outer rows of the mesh network. And in the fourth state, cell arrangement was triangular but their number was increased to 18 cells at each side.

4.2. Gravitational Loading Experiment (Statically Loading)

In statically loading experiments, 5 steps of loading were performed. In each step, 53 N loads were added to the previous state at the central part. Thus, these experiments were performed for models without gill cell and four gill cell layout to five loads of 53, 106, 159, 212 and 256 N. When oscillations of the model were fixed and the amount of strain became constant, tests were started and variations of displacement and strains were measured. At this experiment, vertical displacement and strains were measured at the two ends and midpoint of the model.

4.3. Experiment with Application of Waves (Dynamical Loading)

Five waves with different period and 2 cm height were made at the laboratory and their direction was perpendicular to the width of the model. Each wave was applied to all layouts of the gill cells in the model; and vertical displacement was measured at 5 points of the model in a distance of 50 cm from each other. Strains were measured at the two ends and the midpoint of the model. The generated waves in the laboratory were sinusoidal and regular. Table 1 represents the features of the waves.

Table 1. Characteristics of the waves imposed to the model in laboratory

Wave Characteristics	Wave 1	Wave 2	Wave 3	Wave 4	Wave 5
Wave length/ length of the structure (–)	0.35	0.50	0.65	0.80	0.95
Wave length λ (m)	0.7	1.00	1.30	1.60	1.90
Wave period T (s)	0.67	0.80	0.91	1.01	1.10
Wave height h (cm)	2				
Wave angle (deg)	90^0				

5. Conclusion

The results of these experiments represent that the gill cells efficiency was more prominent in higher loadings. Regarding differential deflection reduction, the third state had better performance. It can be perceived that when gill cells have farther distance from the center of the structure (loading region), they will have a better performance. Also, the highest amount of bending reduction at the head and center of the model occurs at the first state, which is up to 5% consisting of gill cells. According to the importance of deflection and bending moment parameters, one may elect either the first or the third state. Moreover, one may present a model by combining both of them which would cause less bending and displacement in the structure. The results of gill cell experiments which were tested by waves reflect that gill cells under the influence of waves did not have any significant effect on displacement reduction. In the fourth state which had the highest amount of gill cell area, the bending moment was less. Moreover, it may not have a considerable effect on the reduction of hydroelastic behavior singly. In order to reduce hydroelastic behavior it is better to combine the gill cells approach with other methods such as hinge connections.