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Experimental Study on Buoyancy Preflexion on Structural Behavior of Floating Body

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***Abstract* — In this study, experimental study was carried out for the buoyancy preflexion method to enhance the structural performance of floating concrete structures. In order to investigate the buoyancy preflexion effects on structural performance of the floating body, live load test and buoyancy preflexion test were carried out. In the results of this study, it was found that buoyancy preflexion has a significant influence on the structural performance of floating structures. Whereas the floating body indicated sagging behavior under the live loads onto the topside, the floating body indicated hogging behavior under the buoyancy preflexion. Therefore, in case of buoyancy preflexion coupled with live load together, it is expected that the buoyancy preflexion contribute to improve structural performance of floating structure thanks to greater supporting capacity for live loads. The buoyancy preflexion method is simple in both principle and application, and can effectively induce pre-compression on the bottom concrete slab. Therefore, it can be concluded that the buoyancy preflexion method will contribute to the improvement of structural performance and decreasing of the cross-sectional height of floating structures.**

Index Terms*— *Floating Body; Structural Performance; Buoyancy; Preflexion; Hogging; Experiment.

I. INTRODUCTION

Large floating offshore structures such as LNG terminals, storage vessels, and container terminals are exposed to severe offshore environment conditions such as waves, water pressure, and impact loads. To satisfy design requirements, floating offshore structures are constructed for high structural performance in bending and shear to support bending moment and impact loads (Link and Elwi, 1995; Lanquetin et al., 2007).

The floating structure of pontoon type has been widely applied to offshore floating structures because of the many advantages of buoyancy, simple details, storage ability, and economy, etc (Allen et al., 2006; Haveman et al., 2006; Jeong et al., 2010). However, this system is vulnerable to wave-induced bending moment and hydrodynamic motion. In order to satisfy design criteria for strength of floating structures, it should be required to have a large cross sectional height (Jeong et al., 2010; Yao, 2007). Therefore, some studies to overcome disadvantages of pontoon typed floating structures have been performed and these studies mainly focused on high-structural performance and low-hydrodynamic motions.

A floating concrete structure has advantages such as low hydrodynamic motion, durability, and cost efficiency, but it is heavier than a steel structure. Heavier concrete structures require relatively greater draft, which has a negative effect on cost efficiency and serves as the dependent factor for determining water depth for installation (Keppel O & M, 2007). Furthermore, considering the severe marine environment and the design characteristics of the concrete, such as the higher tensile strength in the submerged parts to prevent cracking, it is very important to maintain a certain level of structural performance for floating concrete structures.

For these reasons, efforts to improve the structural performance of floating concrete structures have been applied. Recently, the new structural system with a unique cell-form reinforced grid using UHPC (Ultra High Performance Concrete) has been developed (Keppel O & M, 2007), as presented in Fig. 1, and this system enables the construction of large-sized floating concrete structures. With the use of pre-tensioning technology, it is possible to build light weight, highly durable floating concrete structures with superior structural performance. In order to enhance the structural performance of the floating concrete structure, a study on reducing cross-sectional force by buoyancy has been in process (Yao, 2007; Pham and Wang, 2010). In this study, the cross-sectional force by buoyancy was reduced by removing the buoyancy working on a certain section of the bottom slab by installing Gillcells in the bottom slab at certain intervals, as presented in Fig. 2.

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FIG. 1 HONEYCOMB FLOATING STRUCTURE USING UHPC

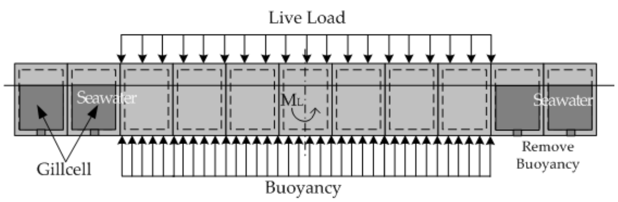

FIG. 2 BUOYANCY REDUCTION BY GILLCELLS

In this study, the buoyancy preflexion method was introduced to enhance the structural performance of floating concrete structures by introducing buoyancy preflexion effects to the floating structure by the difference in buoyancy between the pontoon modules comprising the floating structures. In order to verify the buoyancy preflexion effects, experimental studies were performed. At first, in order to investigate live load dependent structural behavior of the floating body, live load test was carried out. Then, in order to investigate buoyancy preflexion effects of the floating body, buoyancy preflexion test was carried out.

II. BUOYANCY PREFLEXION METHOD

A flowchart for applying buoyancy preflexion to floating concrete structure is illustrated in Fig. 3. Buoyancy preflexion is designed to utilize the difference in buoyancy between the pontoon modules which comprise the floating structures. The pontoon modules used to induce buoyancy preflexion were comprised of three parts; both ends and the central modules. To introduce the buoyancy preflexion effect, the ends modules should have a lower section height than the central module, as shown in Fig. 3 (a), so that the difference in freeboard (d) should occur due to the different buoyancy resulting from the difference in section height and weight when launching two fabricated modules onto seawater.

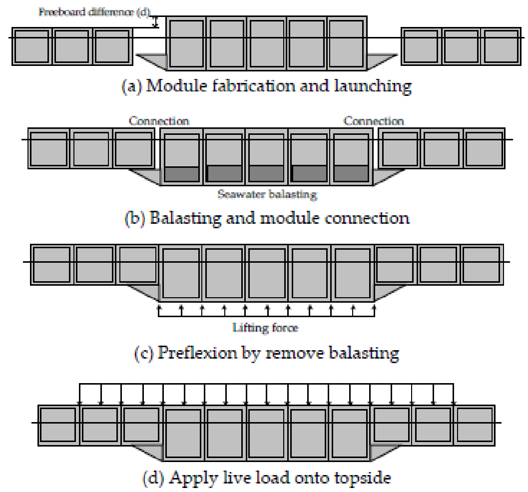

FIG. 3 BUOYANCY PREFLEXION METHOD

To integrate it into a single floating structure, it is necessary to connect the three modules. To connect the three modules, it is necessary to establish an equalized freeboard among the three modules, by sinking the central module as much as the difference in freeboard using seawater ballasting into the central module as indicated in Fig. 3 (b). In general, module connection by prestressing is applied to the concrete structures and by welding is applied to the steel structures.

Then, seawater ballasting in the central module will be removed as illustrated in Fig. 3 (c). When seawater ballasting is removed from the central module, the buoyancy equilibrium in the three parts of a single floating structure integrated by module connection is collapsed and additional buoyancy force toward the seawater surface is applied to the central module. In other words, whereas the central module tends to rise to the initial freeboard in Fig. 3 (a), the modules at both ends tend to maintain their current position which is the initial freeboard of the ends modules. Accordingly, preflexion effect having hogging (-) behavior is transferred to floating structure and pre-compressive stress is transferred to the bottom slab and pre-tensile stress to the top slab.

Finally, for the use of the floating structure, the facilities (live loads) are installed on the topside. According to the live loads, a floating structure indicates the sagging (+) behavior and tensile stress is generated on the bottom slab of the floating structure.

III. EXPERIMENTAL PROGRAM

In order to investigate buoyancy preflexion effect on structural performance of floating body, experimental studies were carried out at the water basin of Korea Institute of the Construction Technology. A small-scale floating body was

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fabricated using steel plate of 4.5 mm and tested under the still water condition. The size of floating body was 5,400 (L) × 1,200 (W) ×375 (H) mm, as presented in Fig. 4. A floating body was fabricated with three modules, two end-side modules and central module, and connected together by the welding. The total weight and draft of the test model were 820 kg and 253 mm, respectively.

In order to measure buoyancy preflexion effects on structural behavior, six strain gauges were attached onto the bottom plate of the floating body, as presented in Fig. 4, and measured deformation strain of the bottom plate during the test.

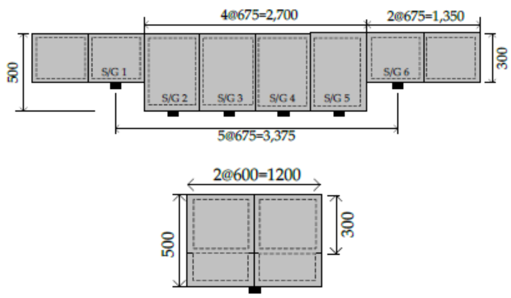

FIG. 4 TEST MODEL AND STRAIN GAUGES

At first, in order to investigate live load dependent structural behavior of the floating body, live of the concrete blocks of 582 kg was loaded onto the topside center and measured deformation strain of the bottom plate, as presented in Fig. 5.

Then, in order to investigate buoyancy preflexion effects of the floating body, buoyancy preflexion test was carried out, as presented in Fig. 6. At first, in order to equalize freeboards of the three modules of the two end-side modules and central module, amount of the water to inject into the central module was calculated. Then the calculated ballasting water was injected into the central module, as presented in Fig. 3 (b). Where, as the ballasting water was removed using small capacity of the water pump, additional buoyancy force toward the seawater surface is applied to the central module. Therefore, as the ballasting water was removed gradually, the deformation of the floating body was measured, as presented in Fig. 6.

FIG. 5 LIVE LOAD TEST

FIG. 6 BUOYANCY PREFLEXION TEST

IV. TEST RESULTS

A. *Live Load Dependent Structural Behavior*

At the results of the live load test, the deformation strain at the bottom plate of the floating body was plotted at the Fig. 7. At the Fig. 7, the final deformation strain of the floating body after the positioning of the live load of the concrete bloaks at the topside center was about 200 sec.

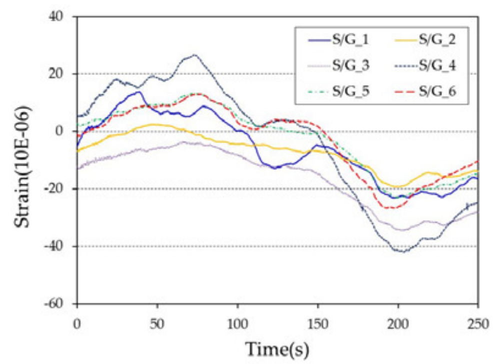

FIG. 7 LIVE LOAD DEPENDENT STRUCTURAL BEHAVIOR

Accorging to the live load, the strains at the center (S/G 3 and S/G 4) of the floating body were about 35~42 με, whereas the strains near the each end-side (S/G 1 and S/G 6) of the floating body were about 22~25 με. Therefore, the floating body indicated sagging (+) behaviour under the live loads on the topside, and the strain difference was about 13~17 με under the live loads of the 582 kg.

B. *Buoyancy Preflexion Behavior*

At the results of the buoyancy preflexion test, the deformation strain at the bottom plate of the floating body was plotted at the Fig. 8. Fig. 8 (a) presented measured time history strains and Fig. 8 (b) presented strain distribution along to the length of the floating body according to the amount of the water ballasting.

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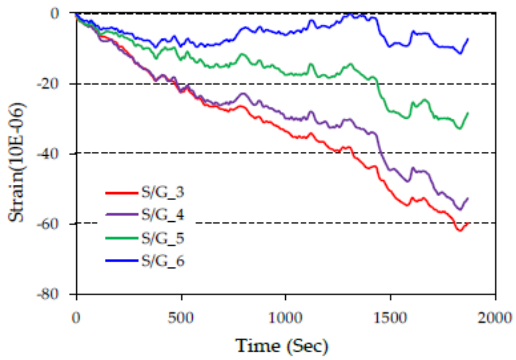
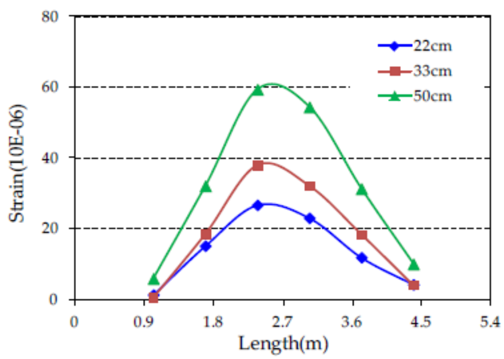


(a) Measured time history strains



(b) Strain distribution along to the length

FIG. 8 BUOYANCY PREFLEXION STRUCTURAL BEHAVIOR

During the buoyancy preflexion test, compressive stress persisted at the bottom plate of the floating body, as presented in Fig. 8 (a). Deformation strains at the center (S/G 3 and S/G 4) of the floating body were about 55~60 με, whereas the strains near the each end-side (S/G 6) of the floating body were about 10 με and the strain between the center and the end-side was about medium level of 32 με. Therefore, it was found that the floating body indicated hogging (-) behaviour under the buoyancy preflexion, as presented in Fig. 8 (b). The strain difference was about 45~50 με under the fully buoyancy preflexion of the ballasting water depth in 50 cm, and about 25 με under the actural buoyancy preflexion of the ballasting water depth in 22 cm, which was corredponding to the freeboard difference between the both ends and central modules.

C. Benefit from Buoyancy Preflexion

In case of buoyancy preflexion coupled with live load together, it is possible to maintain compressive stress at the bottom plate of floating structure. Therefore, it is expected that the buoyancy preflexion contribute to improve structural performance of floating structure thanks to greater supporting capacity for live loads onto the topside.

Also, when buoyancy preflexion was applied to floating structures with reducing section height of the ends modules in response to total Bending Moment Diagram (BMD), as illustrated in Fig. 9, it should be possible to enhance structural performance as saving material amount. Therefore, it is expected that the buoyancy preflexion should bring benefits in terms of both safety and cost.

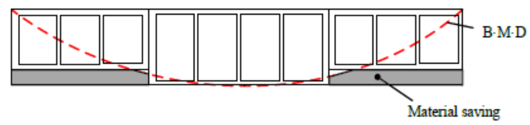


FIG. 9 DIAGRAM OF REDUCTION IN MATERIALS

V. Conclusion

In this study, experimental study was carried out for the buoyancy preflexion method to enhance the structural performance of floating concrete structures. In order to investigate the buoyancy preflexion effects on structural performance of the floating body, live load test and buoyancy preflexion test were carried out.

In the results of this study, it was found that buoyancy preflexion has a significant influence on the structural performance of floating structures. Whereas the floating body indicated sagging (+) behavior under the live loads onto the topside, the floating body indicated hogging (-) behavior under the buoyancy preflexion. Therefore, in case of buoyancy preflexion coupled with live load together, it is expected that the buoyancy preflexion contribute to improve structural performance of floating structure thanks to greater supporting capacity for live loads.

The buoyancy preflexion method is simple in both principle and application, and can effectively induce pre-compression on the bottom concrete slab. Therefore, it can be concluded that the buoyancy preflexion method will contribute to the improvement of structural performance and decreasing of the cross-sectional height of floating structures.

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