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COMPUTATIONAL FLUID DYNAMICS ANALYSIS OF UNDERWATER RUBBLE MOUND LEVELING EQUIPMENT AGAINST TIDAL CURRENT LOADING

I. Jang [1], J. H. Ko[1], C. Shin[1], I. Han[1] and W. Kim[1]

ABSTRACT: Underwater rubble mound leveling works usually have been carried out as a preliminary process prior to the installation of caissons and blocks onto the seabed in a harbor and wave energy structures. So far, underwater construction works are mostly depended on divers. These divers are confronted with many difficulties, such as working time limitation due to depth, poor visibility in a working field and so on. These problems can be overcome using machineries in the underwater construction. The practical unmanned underwater equipment for port constructions was newly developed. The equipment can be applicable in underwater leveling works of rubble mound by using its blade and bucket with automatic arms. Also, it can monitor the working environment using sonars and optical devices. The safety analysis considering harsh circumstances such as strong currents is necessary because the equipment is usually mobilized on the seabed. In this paper, the effect of tidal current forces on the behavior of the equipment was investigated by using the Computational Fluid Dynamics (CFD), which is mainly used in investigating the relative movements of fluid and structure. The numerical results reveal that the possibility of overturning and sliding of the equipment can be negligible and the structural stability can be assured under a given current velocity of 1m/s.

Keywords: Underwater rubble mound leveling equipment, tidal current loading, harbor, computational fluid dynamics and stability.

INTRODUCTION

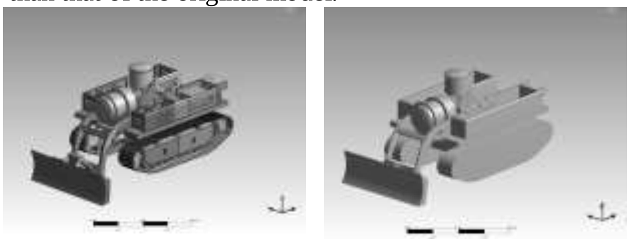
Underwater rubble mound leveling works usually have been carried out as a preliminary process prior to the installation of caissons and blocks onto the seabed in harbor and wave energy structures (I.S. Jang et al. 2011). So far, these underwater construction works are depended on divers in general (Utsumi Makoto et al. 2002). The divers are confronted with many difficulties, such as working time limitation due to depth, poor visibility by turbidity and so on.

To overcome these problems, a project concerning to practical unmanned underwater equipment for port constructions is in progress at Korea Institute of Ocean Science & Technology (KIOST) in South Korea. The equipment being developed can be applicable to underwater works of rubble mound by using its blade and bucket with a multi-purpose arm. Also, it can monitor the working environment using sonars and optical devices.

In this study, structural stability analysis considering the rollover and the sliding for the underwater rubble mound leveling equipment were carried out because the equipment is usually mobilized on the seabed under harsh circumstances such as tidal currents and so on. External forces by tide were calculated by Computational Fluid Dynamics (CFD) analysis. Structural analysis was carried out using CFD analysis results as boundary conditions. FLUENT was used for the CFD analysis and ANSYS was used for the structural analysis.

MODELING

The CAD model of a 05 class underwater equipment is as shown in Fig.1(a). This model is composed of frame, pressure vessels, caterpillar systems, blade and so on. The design of the multi-purpose arm which can install various tools such as an excavation bucket, a grapple and so on is in progress. Hence, the arm is ignored in this analysis. The size of the model is 3000mm (W) x 6220mm(L) x 2520mm(H). To handle the CAD model easily, the model was simplified as shown in Fig.1(b). The simplification is basically done in a conservative sense. In order words, the generated force of the simplified model is expected to be larger than that of the original model.



(a) Original CAD Model (b) Simplified CAD Model

Fig. 1 underwater equipment CAD model

[1] Korea Institute of Ocean Science & Technology, 787 Haean-ro(st). Sangnok-gu, Ansan-si, Gyeonggi-do, South Korea

Boundary conditions are set as shown in Fig.2 and Table 1. Fluid and structural meshes are generated by the setting values as Table 2. The generated mesh model is as shown in Fig. 3. It is assumed that the bottom surfaces of the caterpillars are fixed on the ground.

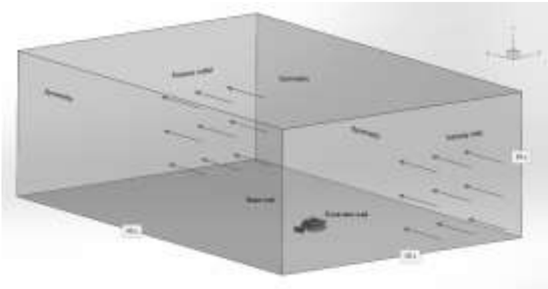


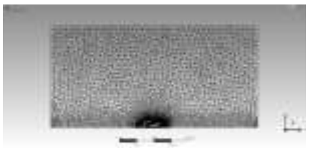
Fig. 2 Boundary condition figure

Table 1 Boundary conditions

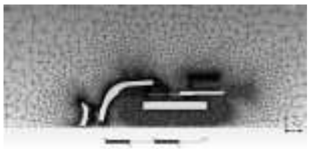
Flow direction	+x direction
Flow velocity	1m/s
Wall condition	Surfaces of base and vehicle
Velocity-inlet	YZ boundary surface from left side of X axis
Pressure-outlet	YZ boundary surface from right side of X axis
Symmetry condition	Other boundary surfaces
Turbulence model	*k*-*ε*
Characteristic length (c)	2600mm

Table 2 Properties for fluid and structural meshes

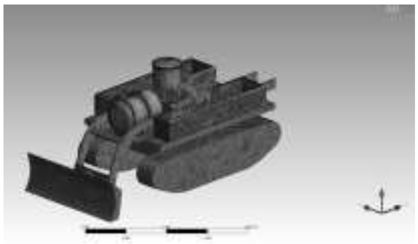
Contents	Value
Global min size	0.005m
Global grow rate	1.2
Vehicle face size	0.03m
Fluid bottom face size	0.75
Number of cells (fluid)	10,359,826
Structural element size (shell)	0.05m
Number of structural nodes	421,540
Number of structural elements	647,504



(a) Global fluid mesh view



(b) Zoom-in fluid mesh



(c) Structural mesh

Fig. 3 Generated mesh model

ANALYSIS RESULTS

CFD analysis results are shown in Fig. 4 and Fig. 5. Fig. 4 shows pressure result on the surfaces of the equipment by the tidal current. Maximum compressive pressure was occurred on the center surface of the tide input side, and the value was 683Pa. Maximum tensional pressure was shown at the upper edges of the tidal current direction, and the value was 1.81kPa. Fig. 5 shows the velocity result on the surfaces by the tidal current. Maximum velocity was occurred at the upper edges of the tidal current direction, and the velocity was 1.91m/s. The magnitude of the flow velocity was increased almost twice more than that of the input flow velocity, 1m/s.

Fig. 4 Pressure result

Fig. 5 Velocity result

Fig. 6 Stress result

Fig. 7 Displacement result

Fig. 6 shows the stress result on the surfaces by the tidal current. Higher stress was occurred at the upper surfaces of the equipment and the blade of the tidal current direction than other surfaces. Maximum stress was appeared at the upper surface, and the value was 12.4Mpa. The value is lower than the material (steel ASTM A36) yield stress of 250Mpa, which means the structural safety of the equipment can be assured. Fig. 7 shows the displacement result of the surfaces by the tidal current. Maximum displacement was occurred at the rear tail part, and the value was 3.0mm. The value can be allowed within a tolerance range.

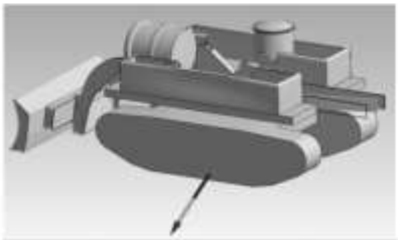
Fig. 8 and Fig. 9 show the reaction force and moment of the ground. The magnitude of the reaction force was 4.8kN and that of the reaction moment was 5.5kN·m. Using the rolling moment, the possibility of rollover of the equipment to the z direction moment can be determined. Rolling moment which is referenced the opposite side of the caterpillar from tidal current direction can be calculated by Eq. (1).

$$M_{rolling} = M_z + (w/2) \bullet F_y = 4942.3 + 2167 \bullet 1.3 \\ = 7.76 \times 10^3 N \cdot M = 0.8 tonf \cdot m \quad , \qquad (1)$$

where w is the area of the lower structure.

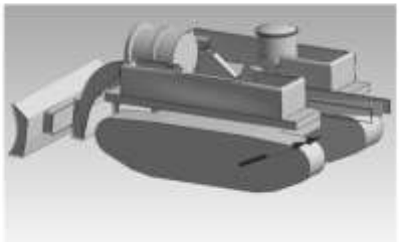
The weight of the equipment in water is predicted as 15ton, the resistant moment will be higher than 19.5 *tonf·m*. Hence, the possibility of rollover of the equipment can be very low under the condition of the tidal current of 1m/s. The reaction forces of the z and x directions are 4.9 *kgf* and 432.9 *kgf*.

It is assumed that the static friction coefficient is 0.5. Hence, the resistance against sliding is 7.5 *tonf*, so that the equipment will not be slipped.



x	y	z	Total(N)
-4242.5	-2167	47.64	4764.2

Fig. 8 Reaction force



x	y	z	Total(N*m)
-472.71	2273.3	4942.3	5460.5

Fig. 9 Reaction moment

CONCLUSION

Computational analysis of the underwater rubble mound leveling equipment was performed in order to investigate the structural safety considering rollover and sliding against a tidal current loading. External forces by the tidal current were calculated by Computational Fluid Dynamics (CFD) analysis. Structural analysis was also carried out using CFD analysis results as boundary conditions. The results are as following.

- It was determined that the possibility of rollover and sliding for the designed equipment can be very low under the tidal current loading of 1m/s.
- If the material, (steel ASTM A36), is used, the equipment will be structurally safe in terms of maximum stress and displacement.

By these computational analysis results, it is demonstrated through the simulation that the structural safety including the resistances of rollover and sliding for the designed equipment are acquired.

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