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Development of counter measures against scouring at the toe of offshore wind turbine foundations

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Abstracts

- ✓ It is a well-known fact that in Europe, which has been operating offshore wind farms well ahead of South Korea, most offshore wind turbines installed in shallow waters are suffering from severe scouring problems due to the horseshoe vortex.
- ✓ These facts can serve as a valuable lesson for South Korea. After thorough review, we come to the conclusion that the strength of the horseshoe vortex, the primary sediment transport mode, is proportional to the strength of the standing waves formed in the water near the offshore wind power.
- ✓ Based on this rationale, we propose a hybrid monopile, which is a monopile with an additional light turbine mounted at its toe that can dissipate the incoming wave energy with the rotation that occurs when the turbine is exposed to waves and currents.
- ✓ The weakening of the standing waves in this manner would lead to less sediment transport. We proceeded to carry out the numerical simulation in order to verify the scouring control effect of the proposed hybrid monopile.
- ✓ The results of our study showed that the hybrid monopile remarkably reduced scouring.

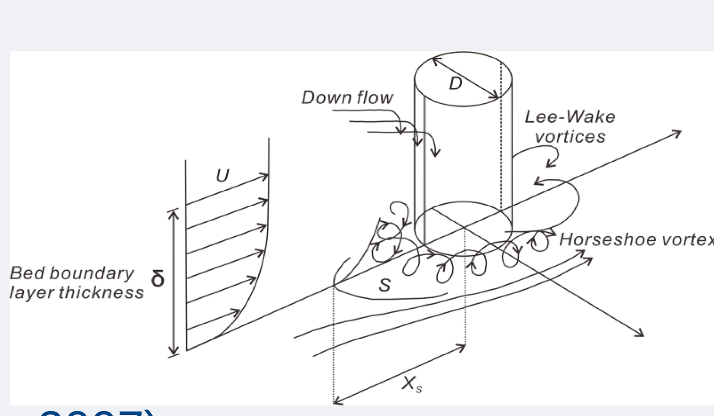
Objectives

- ✓ We developed a more reasonable scour protection method in this study to make offshore wind turbines more affordable.
- ✓ First, we noted that the strength of the horseshoe vortex known to be the driving mechanism of the sediment transport is proportional to the strength of the standing wave formed near an offshore wind turbine.
- ✓ Based on these facts, we propose a hybrid mono-pile that has a turbine mounted to the lower portion of a monopile.
- ✓ If the turbine mounted on a hybrid mono-pile is exposed to a wave or current, the turbine easily rotates in order to dissipate the wave energy.
- ✓ A weakened standing wave with less reflection can lead to less sediment transport.

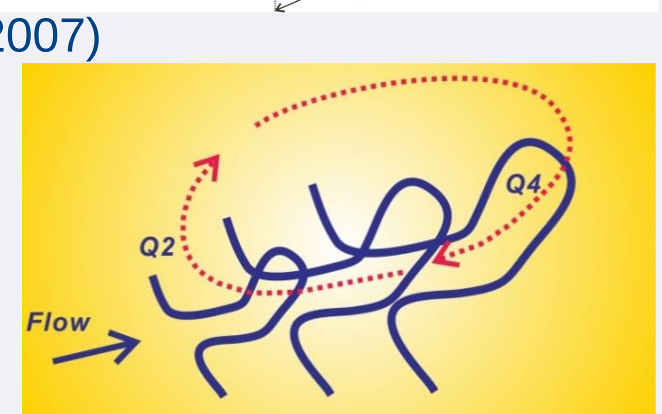
The driving mechanism of the scouring

The driving mechanism of the scouring of the monopile

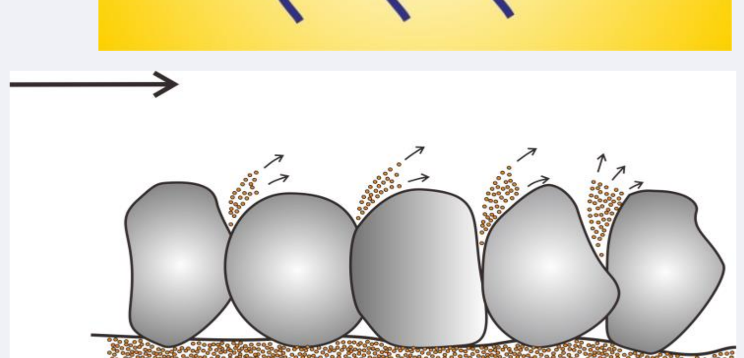
- ✓ Horseshoe vortex



- ✓ Large eddy (Adrian, 2007)



- ✓ Suction removal



Review of scour protection using rocks

Lesson from Horns Rev1

- ✓ According to Nielson (1994), smaller rocks were planned as the filter layer during the early stages of development, but the smaller rocks were removed even before the outer rock armors were placed.
- ✓ Therefore, this regression is assumed in the current design. Using sophisticated protection methods such as those in the Horns Rev1 have significant costs associated with the difficulties in the construction.

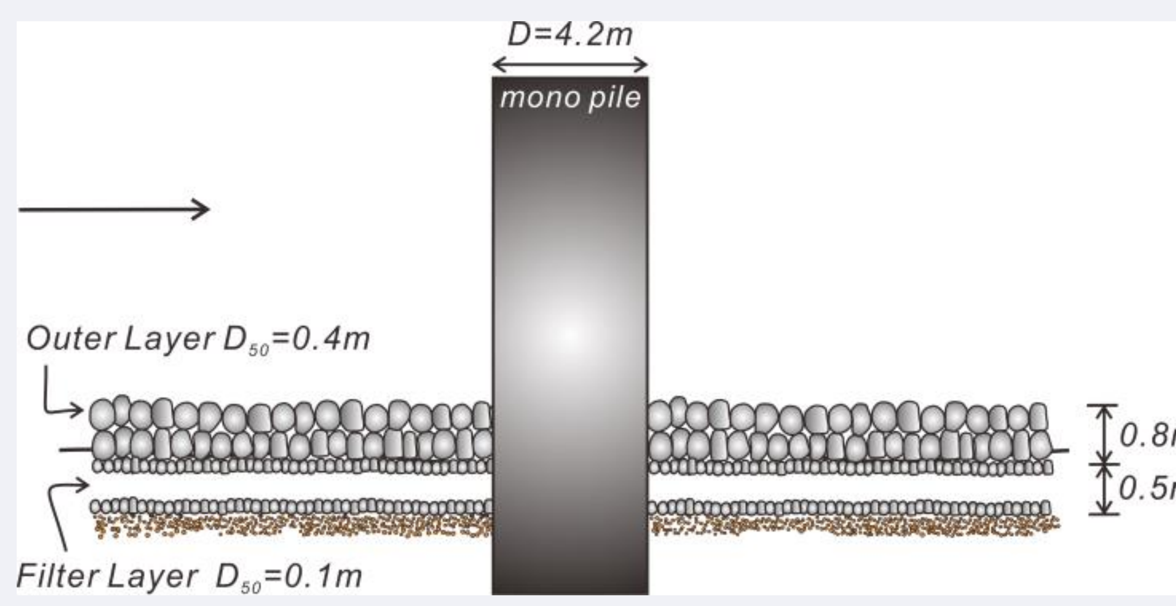


Fig. 1 Schematic sketch of the scouring prevention system of laying finer grade stones as a filter layer under the top scour protection cover

Hybrid monopile

- ✓ Based on the fact that the strength of the horseshoe vortex, the primary sediment transport mode, is proportional to the one of the standing waves in front of an offshore wind turbine, it can easily be deduced that the reflected waves should be minimized in order to mitigate the sediment transport.
- ✓ Based on the rationale used in this study, a hybrid monopile with light turbines mounted at the toe is proposed in order to mitigate the standing waves in front of the pile by diverting the incoming wave energy into mechanical energy with light turbines rotating with respect to the vertical axis of the pile when it is exposed to waves or current.

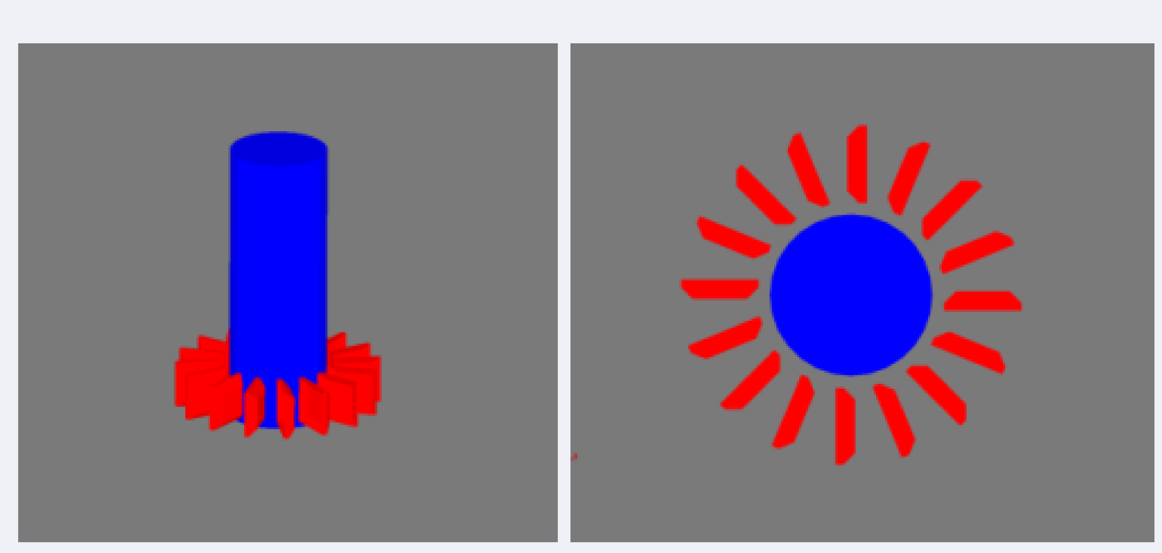


Fig. 2 Layout of Hybrid monopile

Numerical Model

$$\frac{V_f}{\rho c^2}\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}(uA_x)+\frac{\partial}{\partial y}(vA_y)+\frac{\partial}{\partial z}(wAz)=0$$

$$\frac{\partial u}{\partial t}+\frac{1}{V_F}\left\{uA_x\frac{\partial u}{\partial x}+vA_y\frac{\partial u}{\partial y}+wA_z\frac{\partial u}{\partial z}\right\}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+G_x+f_x$$

$$\frac{\partial v}{\partial t}+\frac{1}{V_F}\left\{uA_x\frac{\partial u}{\partial x}+vA_y\frac{\partial u}{\partial y}+wA_z\frac{\partial u}{\partial z}\right\}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+G_y+f_y$$

$$\frac{\partial w}{\partial t}+\frac{1}{V_F}\left\{uA_x\frac{\partial u}{\partial x}+vA_y\frac{\partial u}{\partial y}+wA_z\frac{\partial u}{\partial z}\right\}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+G_z+f_z$$

Numerical Results

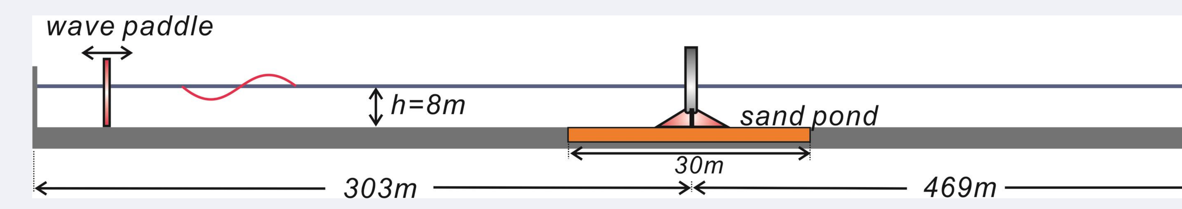


Fig. 3 Numerical wave flume

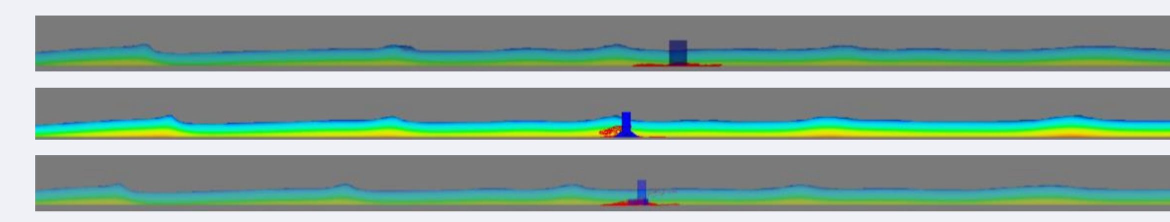


Fig.4 Numerically simulated water surface profile

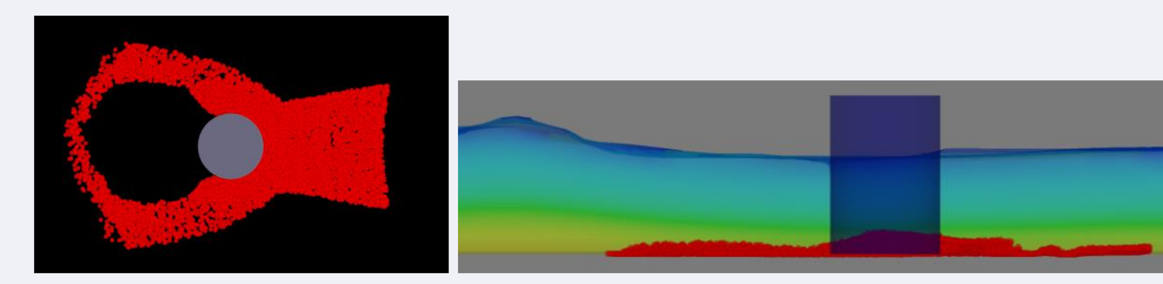


Fig.5 Plan and side view of the bed morphology after exposure to waves for 80s (simple monopile)

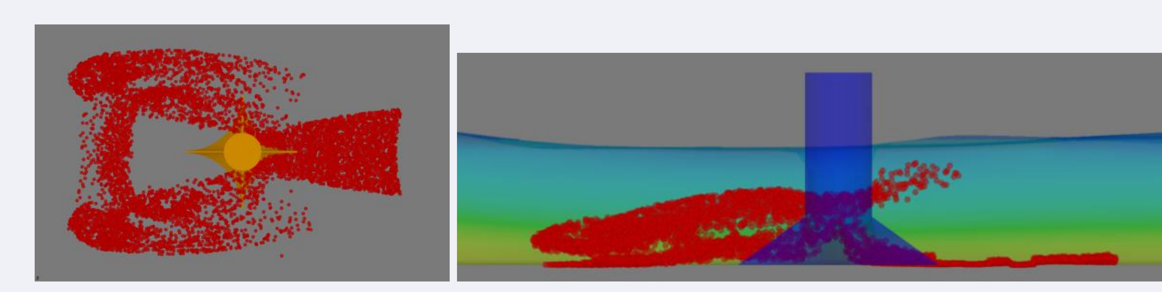


Fig. 6 Plan and side view of the bed morphology after exposure to waves for 80s (quattro-pod monopile)

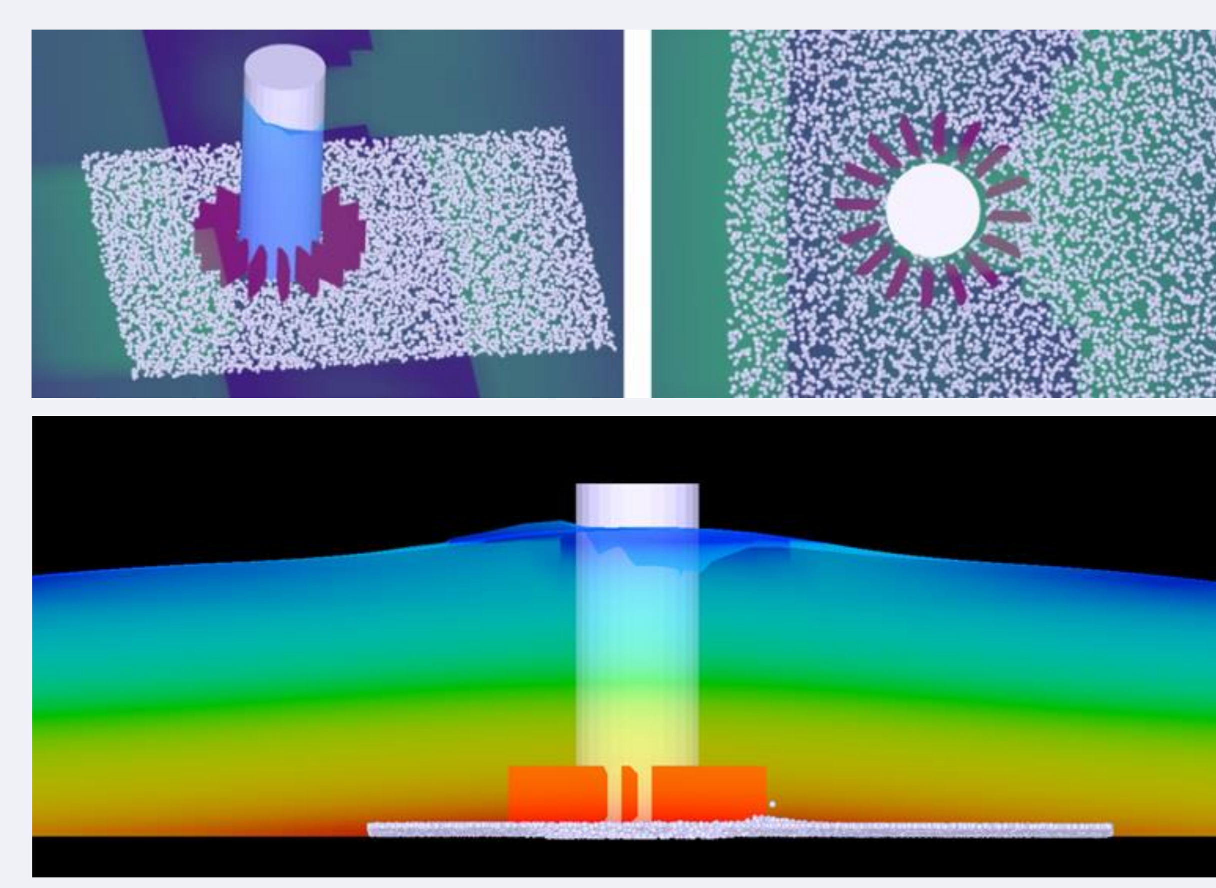


Fig. 7 Plan and side view of the bed morphology after exposure to waves for 80s (hybrid monopile)

- ✓ Considering the fact that a significant portion of the initially deployed silts still keep in touch with the bed, the scouring reduction effects of a hybrid monopile were somewhat verified.

Conclusions

- ✓ In order to verify the scouring control effects of the hybrid monopile proposed in this study, we first numerically simulated the wave propagation via a simple monopile. Then, we moved on to the cases of a quattropod, tripod, three leaves, and hybrid monopiles.
- ✓ The scouring reduction effects of a hybrid monopile are verified by taking into consideration the fact that a significant portion of the initially deployed silts are still in touch with the bed.

References

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2. Nielson, P. [1994] Coastal bottom boundary layers and sediment transport. World Scientific.

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