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Nonlinear destructive interaction between the wind and wave load acting the offshore wind energy converter

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Abstracts

- ✓ Despite its great engineering value, the nonlinear destructive interaction between wind and wave loads acting on the offshore wind energy converter has been maltreated due to our lack of efforts to incorporate the new achievements in the study of modern fluid mechanics
- ✓ We numerically simulate the structural behavior of a 5 MW offshore wind energy converter subject to wind and random waves using the structural dynamic model that was developed to quantitatively estimate the nonlinear destructive interaction.
- ✓ Numerical results shows that the randomly fluctuating water surface as the wind blows would restrict the deflection of the substructure of the offshore wind energy converter.
- ✓ The wavy motions at the water surface makes the atmospheric boundary layer grow non uniformly, which leads to the development of a large eddy swirling in the direction opposite to incoming wind near the atmospheric boundary layer out of a series of hairpin vortex.
- ✓ As a result, the vertical distribution of the longitudinal wind velocity is modified, the accompanying energy loss drastically weakens the wind velocity which consequently leads to the smaller deflection of the substructure of the offshore wind energy converter.

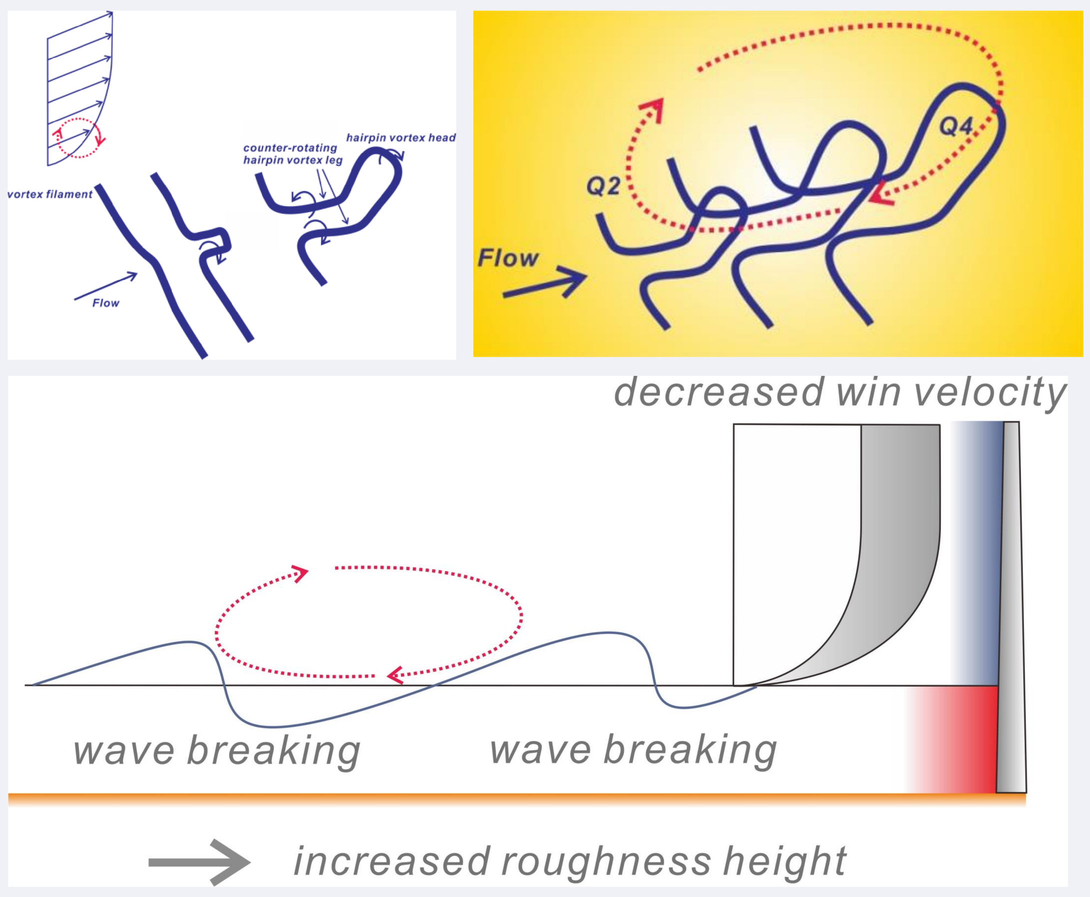
Objectives

- ✓ Despite its unlimited potential for growth, the offshore wind energy industry still suffers from problems such as the excessive initial capital investments.
- ✓ Extra costs incurred by conservative design for offshore wind energy converter can be easily addressed at the design stage by taking into account the nonlinear destructive interaction between wind and wave loads such as the stabilizing effect of water waves on the deflection of the converter.

Nonlinear Destructive Interaction

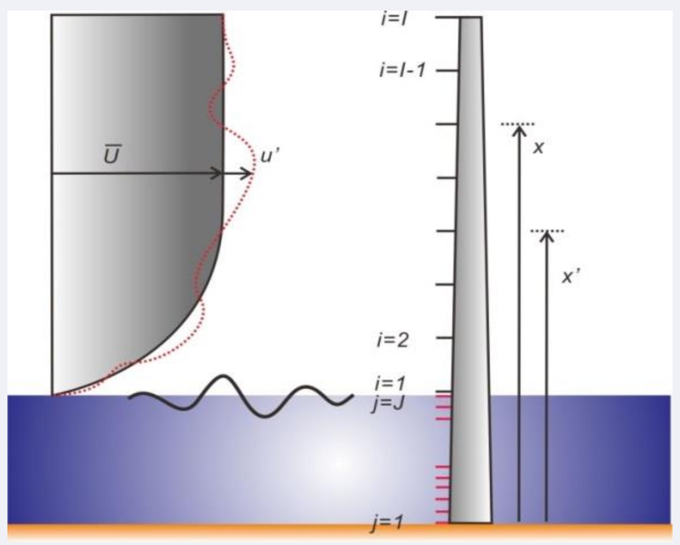
Large Eddy

- ✓ The bumpy water surface due to the presence of waves as the wind blows, which first give a birth to a series of hairpin vortex, and later the solenoidal effects of each hairpin vortex adds up to the formation of a large eddy circulating in the direction opposite to incoming wind near the atmospheric boundary layer (Adrian,2007)



Environmental Load

Wind with gusts



Random wind velocities are given by (Deodatis, 1996A)

$$\begin{bmatrix} u_1' \\ u_2' \\ u_3' \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ u_I' \end{bmatrix} = \begin{bmatrix} \int S_{11}^{1/2} & \int S_{12}^{1/2} & \int S_{13}^{1/2} & \cdots & \int S_{1I}^{1/2} \\ \int S_{21}^{1/2} & \int S_{22}^{1/2} & \int S_{23}^{1/2} & \cdots & \int S_{2I}^{1/2} \\ \int S_{31}^{1/2} & \int S_{32}^{1/2} & \int S_{33}^{1/2} & \cdots & \int S_{3I}^{1/2} \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \int S_{I1}^{1/2} & \int S_{I2}^{1/2} & \int S_{I3}^{1/2} & \cdots & \int S_{II}^{1/2} \end{bmatrix} \begin{bmatrix} e^{i\omega t} d\omega \\ e^{i\omega t} d\omega \\ e^{i\omega t} d\omega \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ e^{i\omega t} d\omega \end{bmatrix}$$

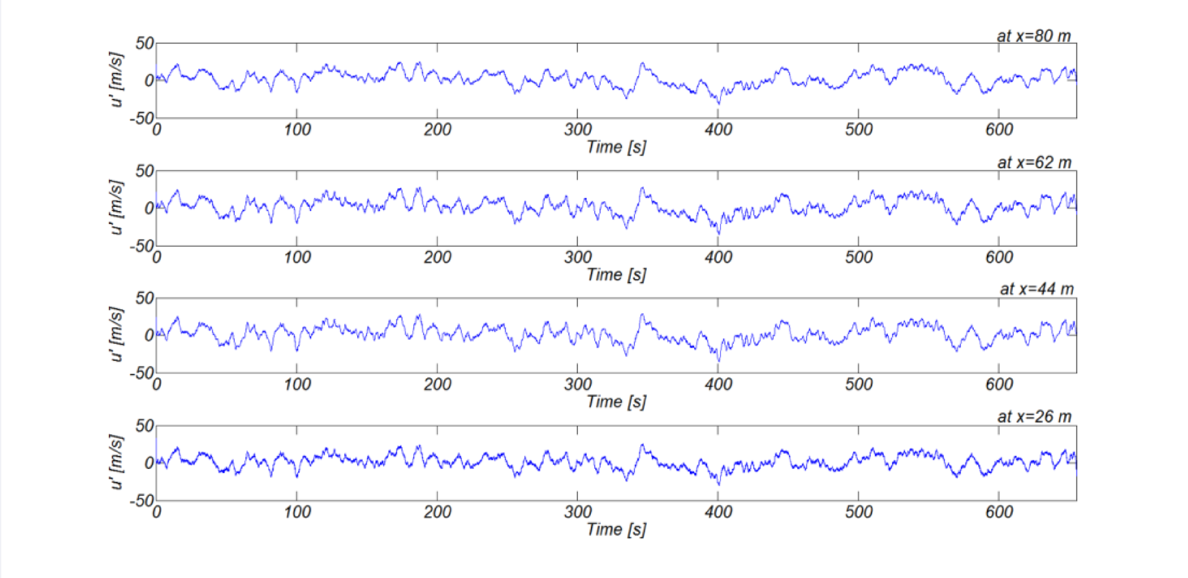


Fig.1 Time series of numerically simulated wind velocities [rough sea]

Random Waves

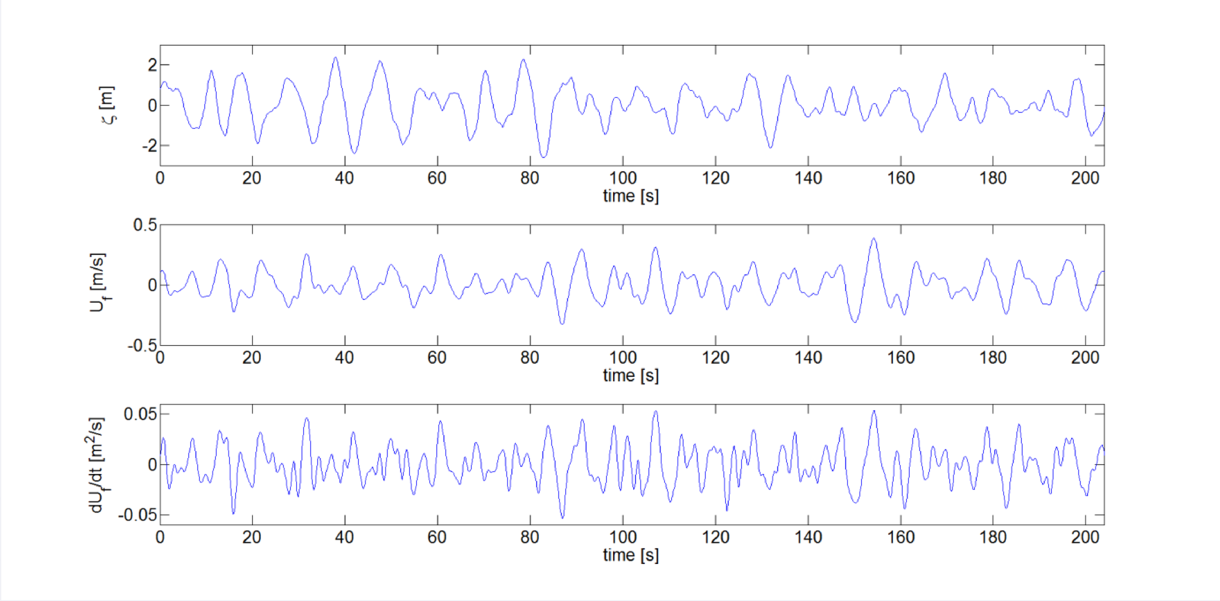


Fig.2 Numerically simulated Surface elevation, Velocity and Acceleration at x=19.0 m for H_s=5m, T_p=10s

Equation of Motion

$$M\ddot{z} + C\dot{z} + Kz = P$$

where

$$M = \int_0^L m\psi^2(x)dx + \int_0^L C_m \rho V \psi^2 dx$$

$$C = \int_0^L c\psi^2 dx + \int_h^L C_D \rho_{air} A\left[U_{air} + \frac{1}{2}U'\right]\psi^2 dx + \int_0^L C_d \rho A U_f \psi^2 dx$$

$$K = \int_0^L EI\Psi^2(x)dx$$

$$P = \int_0^L \frac{1}{2}C_D \rho_{air} A U_{\infty}^2 \Psi dx + \int_0^L \frac{1}{2}C_D \rho_{air} A U_{air} U' \Psi dx + \int_0^h \frac{1}{2}C_d \rho A U_f |U_f| \Psi(x)dx + \int_0^h C_m \rho V \dot{U}_f \Psi(x)dx$$

Numerical Results

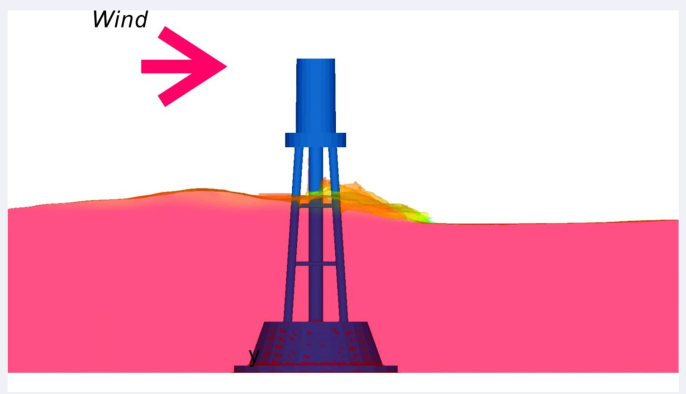


Fig.3 Snapshots of numerically simulated Waves

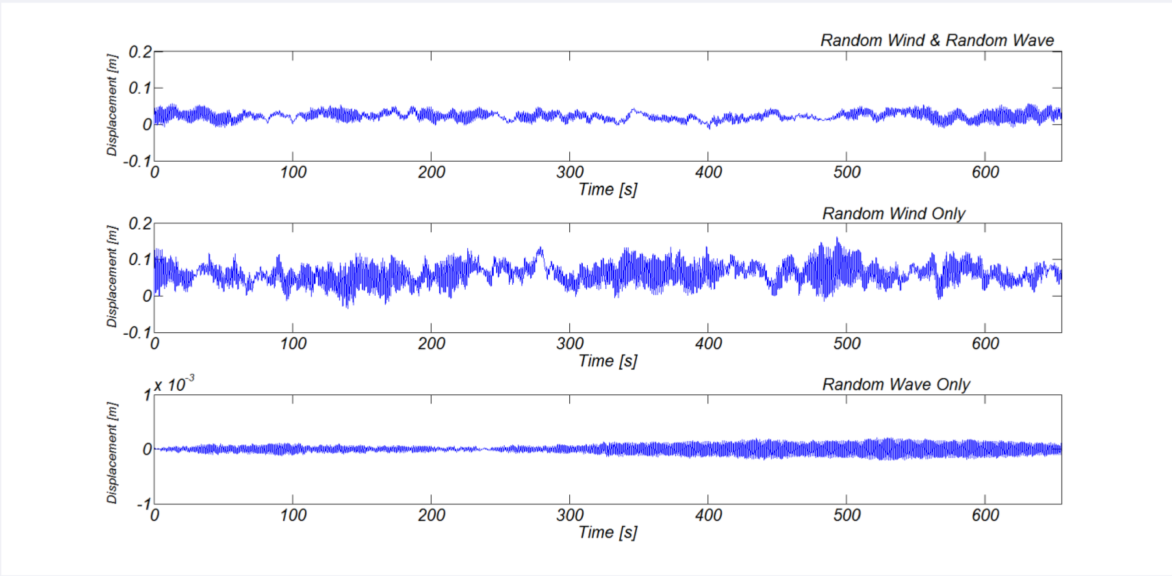


Fig.4 Numerically simulated response of offshore wind turbine substructure against the different combinations of external forces

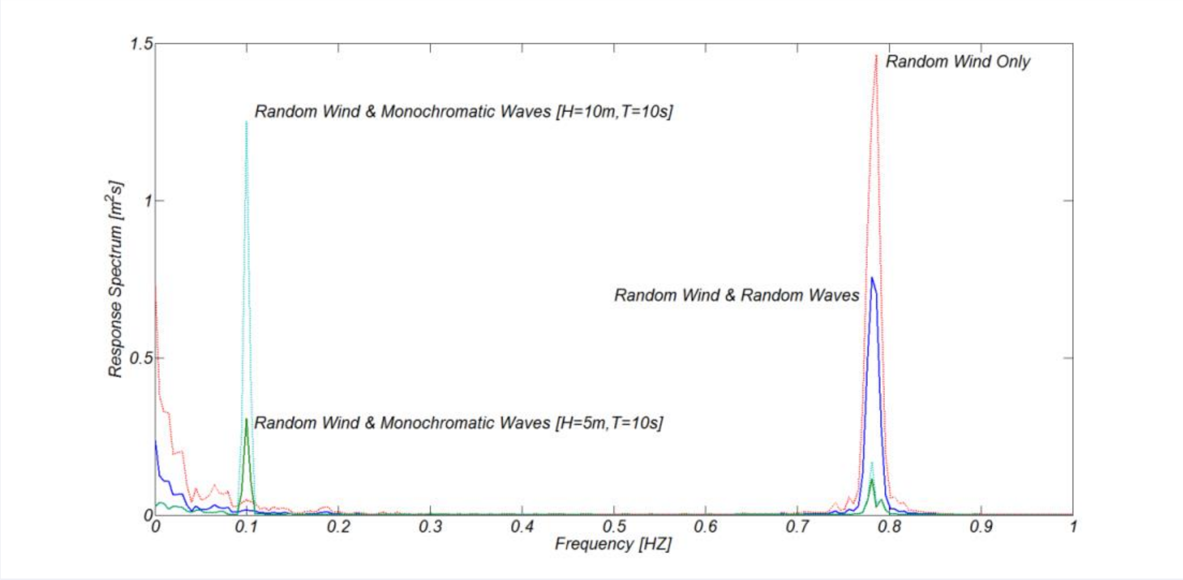


Fig.5 Response spectrum of offshore wind turbine substructure against different combinations of external forces

Conclusions

- ✓ Numerical results show that the main external force on the offshore wind energy converter in the west coast of the Korean Peninsula is a wind with gust because it is built in shallow waters, and hence only 25percent of substructure of offshore wind energy converter is exposed to incoming waves.
- ✓ It was also shown that under stormy weather condition, the mean wind velocity is drastically weakened by the thickened atmospheric boundary layer and its accompanying energy loss (over 30%). In addition, the direction of gust does not always comply with the direction of mean wind field, and during a significant portion of the total simulation period [640 s], the gust moves along the opposite direction of the mean direction of mean wind field, and it has been frequently observed that a gust easily surpasses the mean wind velocity.
- ✓ Therefore, it can be deduced that the main external force on the substructure of offshore wind energy converter is a wind with gust, and the stabilizing effect of waves comes from the increased roughness height when the free water surface fluctuates due to waves, which eventually make the atmospheric boundary layer thickened, and its accompanying energy loss drastically makes the mean wind velocity and gust weaken.

References

1. R. J Adrian, Hairpin vortex organization in wall turbulence, *Phys. Fluids 19, 041301* (2007).
2. G. Deodatis, Simulation of ergodic multi variate stochastic processes, *Journal of engineering mechanics,* **122**(8) (1996A).