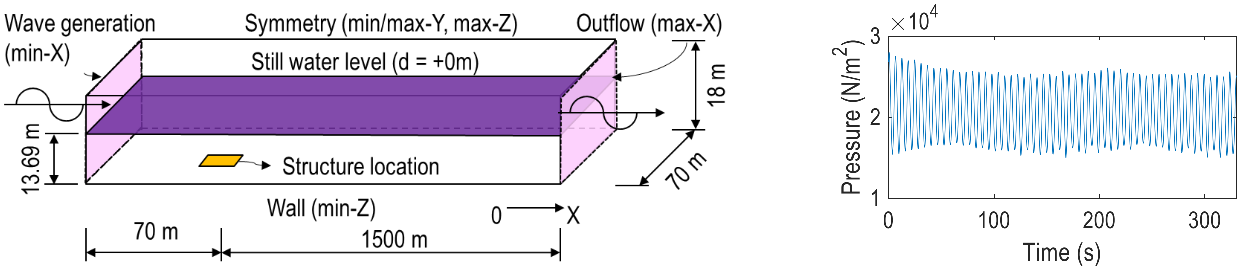
Table 2 Wave properties at 32^0N-127^0E near Jeju Island, Korea

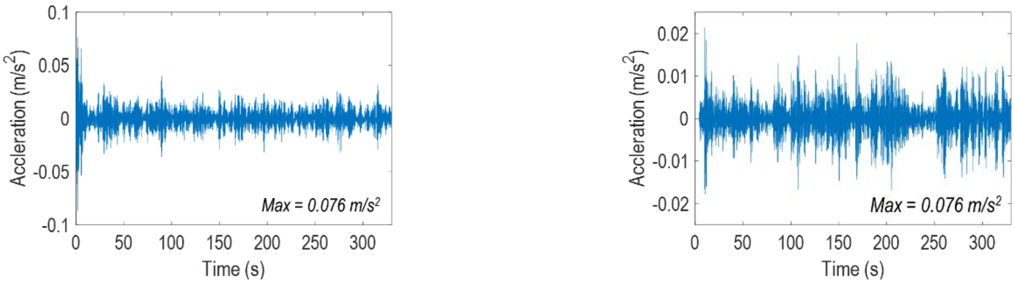
Cases	Observation time	Type	Wave Height (m)	Wave Period (s)
Wave 1	1st Jan 2017	Significant	0.5	6
Wave 2	3rd quarter of 2017	Significant	1.34	6.1
Wave 3	5th Jan 2017	Max	2.8	5.5
Wave 4	9th Jan 2017	Max	4.6	6.5



(a) Geometry and boundary (a) Wave pressure

Fig. 2 Simulation of wave field

The vibration response of the target structure is recorded from 11 sensors, which are equally distributed on the wind turbine tower. The measuring period and sampling rate are 330 s and 50 Hz, respectively. The acceleration signals at sensor 7 under wave 2 are illustrated as examples. The max value of acceleration signal along-wave direction at sensor 7 is 0.076 m/s^2 within 5 s from the time when wave approaches the caisson foundation as shown in Fig. 3 (a). Meanwhile, the maximum value of acceleration signal across-wave direction at sensor 7 is only 0.021 m/s^2 within first 10 s as shown in Fig. 3 (b).

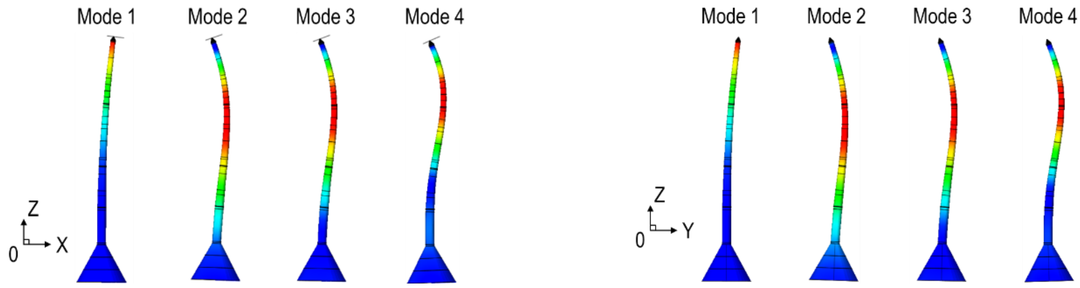


(a) Along wave direction (b) Across wave direction

Fig. 3 Acceleration signals at sensor 7 under wave 2

4. VIBRATION CHARACTERISTICS OF OFFSHORE WIND TURBINE TOWER WITH CAISSON FOUNDATION

In the eigenvalue analysis, regarding along-wave bending modes, the first four natural frequencies are 0.2830 Hz, 1.5619 Hz, 1.8495 Hz and 2.4006 Hz respectively. In the first mode, the most rigorous vibration area is in the top of wind turbine tower as shown in Fig. 4(a). Meanwhile the area in two-third elevation of wind turbine tower has the largest modal amplitude among other three modes. It is noted that the first two modes of wind turbine tower have the distinct mode shapes while the remaining ones are similar to the second mode. This can be due to the effect of foundation vibration. Regarding across-wave bending modes, the first four natural frequencies are 0.2840 Hz, 1.5897 Hz, 1.8820 Hz and 2.4576 Hz respectively. It is also noteworthy that the natural frequency from across-wave direction in each mode is always higher than that from along-wave direction. The first four mode shapes of target structure are similar to those from previous direction as shown in Fig. 4.



(a) Along wave direction (b) Across wave direction

Fig. 4 Bending modes in eigenvalue analysis

In the wave-induced vibration analysis, the vibration characteristics of target structure are identified via the FDD and SSI method. Regarding along-wave bending modes, the first four natural frequency along wave direction are 0.2933 Hz, 1.5606 Hz, 1.8368 Hz and 2.4069 Hz. These extracted natural frequencies match those from the eigenvalue analysis under 4%. It is obtained that the gap between natural frequencies from the eigenvalue and vibration analysis differs largest in the first mode.

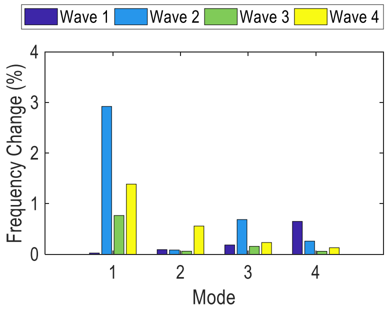
(a) Along wave direction (b) Across wave direction

Fig. 5 Bending modes in wave-induced vibration analysis

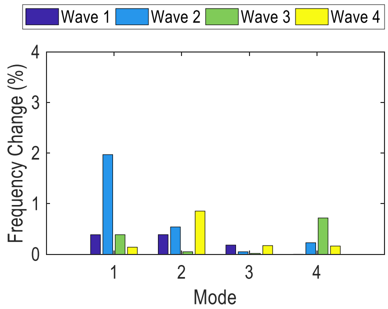
Regarding across-wave bending modes, the first four natural frequencies across wave are 0.2784 Hz, 1.5983 Hz, 1.8829 Hz and 2.4632 Hz. These extracted natural frequencies match those from the eigenvalue analysis under 3%. It is obtained that the gap between natural frequencies from the eigenvalue and vibration analysis differs largest in the first mode. As shown in Fig. 5, the corresponding mode shapes in both direction are similar to those from the eigenvalue analysis.

All waves in Table 2 are employed for the vibration analysis to examine the influence of wave condition on modal parameters. The relative variation between natural frequencies from the eigenvalue and wave-induced vibration analysis are calculated.

As shown in Fig. 6, the first natural frequency varies largely compared to others because the frequencies of incident waves are similar to the first natural frequency. Therefore, if the frequency wave is near the structural natural frequency, it has influence on the modal parameters of that mode. This leads to a situation that structural damages can be hidden from the variation of coming wave in field practices.



(a) Bending modes along wave



(b) Bending modes cross wave

Fig. 6 Comparison of natural frequencies: eigenvalue analysis and wave-induced vibration analyses

5. CONCLUSION

In this paper, the vibration characteristics of offshore wind turbine tower with caisson foundation are numerically analyzed under wave excitation. To achieve the objective, the following approaches were conducted. Firstly, the frequency domain decomposition and stochastic subspace identification methods were presented to identify modal parameters of the target structure. Secondly, the numerical example of the target structure was simulated in the structural analysis program, Midas FEA. The wave field was simulated in the Flow 3D program to measure wave pressures acting on the caisson foundation. Finally, dynamic characteristics of the target structure from the eigenvalue analysis and the several wave-induced vibration analyses were investigated. The following observations are concluded. Firstly, the vibration of foundation bed has influence on the mode shape of target structure. Secondly, if the frequency of incident waves is similar to the fundamental frequency of the offshore wind turbine tower with caisson foundation, the damage-induced frequency variation can be overshadowed by the wave-induced frequency variation.

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