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RESEARCH ARTICLE

Response control of buoyant leg storage and regasification platform using magnetorheological dampers

Supplementary Files

S1. Sampling frequency and phase-lag calculation

S1.1. To find the highest structural frequency

The platform's dominant heave-related time periods lie in 8.15–15.00 s under moderate to very high sea states. Therefore, the highest structural excitation frequency is calculated as follows:

$$f_{\max} = \frac{1}{T_{\min}} = \frac{1}{8.15} = 0.123\ Hz$$

in angular frequency,

$$\omega_{\max} = \frac{2\pi}{T_{\min}} = 0.771\ rad/s$$

S1.2. To find the sampling frequency

Consider a sampling frequency, f_sample, of 50 Hz, hence sampling interval $T_{sample} = \frac{1}{50} = 0.02s$. The ratio between sampling and the highest excitation frequency is:

$$\frac{f_{sample}}{f_{\max}} = \frac{50}{0.123} = 406.5 \gg 2$$

which is well above the Nyquist requirement and sufficient for real-time semi-active control.

That is, as per the Nyquist–Shannon Sampling Theorem, to accurately convert a continuous signal into digital form, the sampling frequency must be at least twice the highest frequency present in the signal.

S1.3. To find the phase lag due to the digital delay

Assuming a conservative one-sample delay, $T_{delay} = T_s = 0.02s$, the additional phase lag is:

$$\phi_{delays} = \omega_{max} T_s = 0.771 \times 0.02 = 0.01542$$
$$\text{rad.} = 0.883$$

Thus, the digital delay introduces less than 1° of phase lag, which is negligible for a slow-moving offshore platform.

S2. Sea and environmental conditions

S2.1. Sea conditions

The sea conditions selected for this study are representative of realistic and critical environmental conditions that can be encountered by an offshore platform.[1] Three sea states—moderate, high, and very high—are characterized by significant wave heights (H_s), zero-crossing wave periods (T_z), and wind speed, as shown in Table S2.

A moderate sea state represents normal operating conditions during routine liquefied natural gas transfer and regasification, ensuring reliable platform performance. A high sea state corresponds to severe weather in which cargo operations may stop, but the platform must continue regasification and safety functions. A very high sea state denotes extreme or survival conditions, such as cyclones or hurricanes, where the primary objective is to maintain structural integrity and ensure the overall survivability of the platform.

S2.2. Approach angle

The selected wave approach angles of 0° and 90° are essential for assessing platform dynamics under critical loading directions. At 0°, waves travel along the axis connecting buoyant legs (BLs) BL2 and BL3, aligned with the global surge direction; in this configuration, waves meet BL2 and BL3 at 30° and BL1 perpendicularly at 90°. At 90°, waves directly impact BL1, which is oriented parallel to the global sway direction, making this case important for evaluating heave–pitch and heave–roll coupling. These two orientations represent the most severe design directions recommended by Det Norske Veritas Germanischer Lloyd Recommended Practice-C205.[2] Considering both ensures a complete understanding of

Table S1. Sea conditions

Sea state	**Moderate**	**High**	**Very high**
Significant wave height, $H_s(m)$	6.5	10	15
Zero-crossing wave period, $T_z(s)$	8.15	10	15
Wind speed at 10m height, $V_{10}(m/s)$	15	35	45

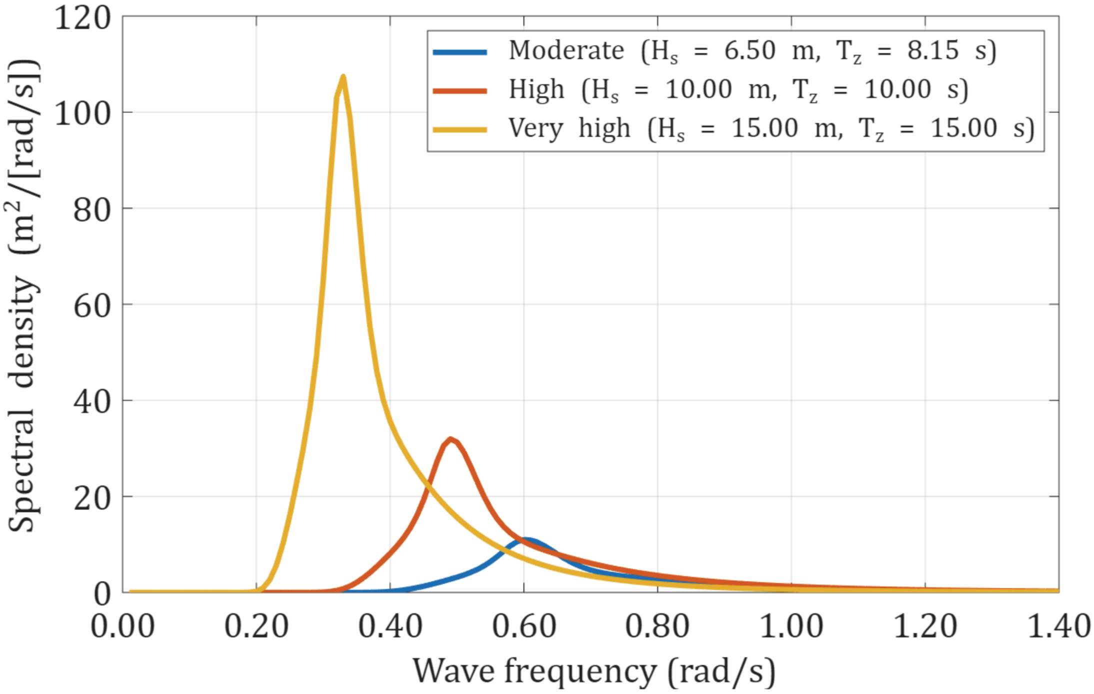

Figure S1. Joint North Sea Wave Project wave spectra

platform stability and limits excessive motions that may increase BOG generation and safety risks.

S2.3. Environmental loads

To simulate realistic offshore conditions, this study incorporates the combined effects of irregular waves, current, and wind loads. These environmental inputs are modeled in accordance with international offshore design standards to accurately represent both operational and extreme sea states. Irregular waves are generated using the Joint North Sea Wave Project spectrum, which provides a realistic distribution of ocean-wave energy and captures nonlinear features and sharp energy concentration near the peak frequency—making it well suited for evaluating the dynamic response of floating platforms.[3] Wave parameters, such as significant wave height (H_s) and zero-crossing period (T_z), are selected for moderate, high, and very high sea states to cover the full range of expected loading. **Figure S1** shows the corresponding spectral density variation, where higher sea states exhibit increased energy and a shift toward lower peak frequencies, reflecting the dominance of long-period waves. This modeling framework enables time-domain simulations that capture the stochastic nature of wave-induced heave motion.

The current profile used in this study (Figure S2) follows a three-point wind-driven model representative of deep-water Gulf of Mexico conditions. Current velocity is highest near the surface and decreases with depth, with a marked reduction between 60 and 90 m, before becoming nearly uniform below 200 m—consistent with observed offshore trends. This stepped profile, as recommended in the literature, is widely used in hydrodynamic simulations to capture realistic vertical current variations. Current loading contributes to drag forces and influences the restoring behavior of the buoyant legs, making it an important component of BLSRP dynamics. Wave–current interaction is accounted for through a Doppler shift in the wave period, which modifies incoming wave energy and affects passive response control performance under severe conditions.

The evaluation of wind loads is a critical aspect of offshore platform design and analysis.[4] In this study, wind loading is modeled using the guidelines provided in Det Norske Veritas Germanischer Lloyd Recommended Practice-C205.[2]

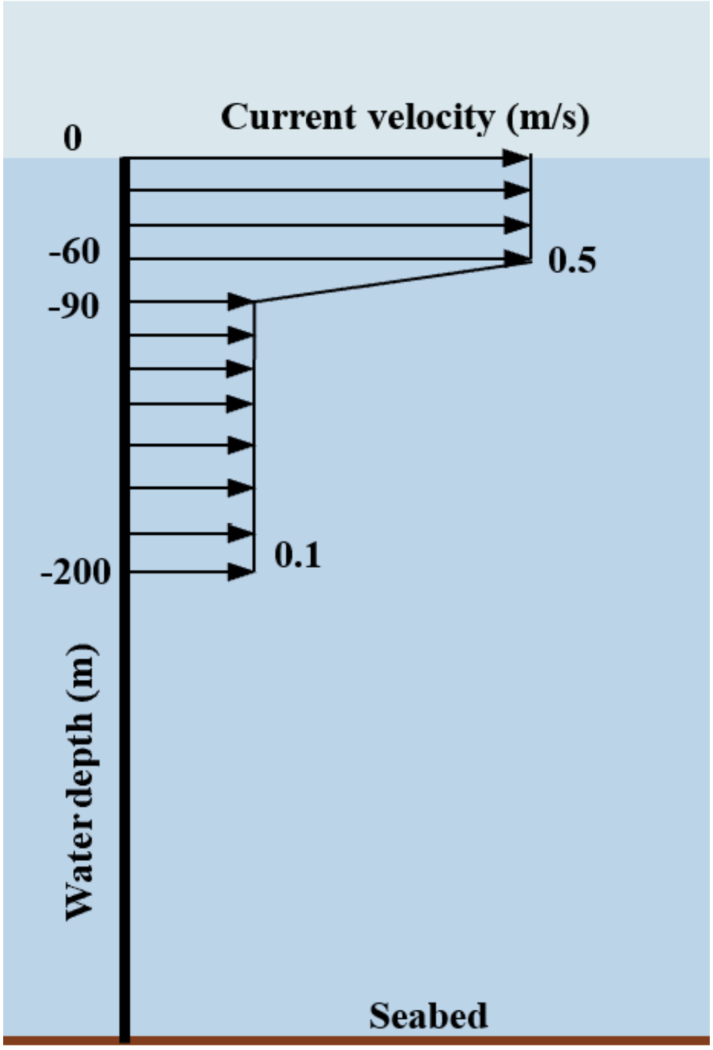

Figure S2. Current profile

Table S2. Summary of sea states and environmental conditions considered

Case index	Environmental condition	Approach angle	RCM status	Sea condition
C1	Case 1: wave alone	0° and 90°	With and without RCM	Moderate, high, and very high
C2	Case 2: wave + current			
C3	Case 3: wave + current + wind			

Abbreviation: RCM: response control mechanism

The wind velocity at the standard reference height of 10 m above mean sea level is determined for each sea state using Equation (1). To account for the vertical variation of wind speed, a 1/7th power-law profile—commonly applied in offshore and open-sea environments with low surface roughness—is adopted:

$$V_z = V_{10}\left(\frac{z}{10}\right)^{\frac{1}{7}} \tag{1}$$

where V_{10} is the wind speed at 10 m elevation (m/s), z is the elevation above sea level (m), and V_z is the mean wind speed at height z (m/s). Short-duration wind gusts can significantly influence the dynamic response of offshore structures. The gust velocity is therefore estimated using a gust factor F_g (1.35–1.45), as expressed in Equation (2):

$$V = F_g V_s \tag{2}$$

where V is the gust wind velocity (m/s), V_s is the sustained (mean) wind speed (m/s), and F_g is the gust factor. The dynamic wind pressure acting on the platform is then calculated using Equation (3):

$$P_w = \frac{1}{2}\rho_a C_w V^2 \tag{3}$$

where P_w is the wind pressure (N/m2), $\pi_a = 1.25$ kg/m3 is air density, and $C_w = 0.7$ is the wind pressure coefficient. The total wind force on a structural component is obtained by integrating the pressure over its projected area using Equation (4):

$$F_w = P_w A \tag{4}$$

Wind forces may generate significant overturning moments, especially when combined with wave and current loads. Table S2 summarizes all environmental conditions assessed in this study for two wave-approach angles (0° and 90°) and three sea states—moderate, high, and very high—to evaluate platform performance with and without the response control mechanism.

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