VI International Conference on Computational Methods in Marine Engineering
MARINE 2015
F. Salvatore, R. Broglia and R. Muscari (Eds)

HYDROELASTIC BEHAVIOUR OF PNEUMATICALLY SUPPORTED FLOATING STRUCTURES IN REGULAR WAVES

SANGHYUN HONG [†], **HUSEOK LEE** [††], **WOONGIK HWANG** [†††] **AND JONG SEH LEE** [*]

Department of Civil and Environmental Engineering
Hanyang University
Ansan, Gyeonggi-do, 426-791, Korea
[†] e-mail: jerom1st@hanyang.ac.kr
[††] e-mail: bznglay@hanyang.ac.kr
[†††] e-mail: nakta83@hanyang.ac.kr
[*] e-mail: jonglee@hanyang.ac.kr

Key words: Hydroelastic Response, Aircushion, Floating Jetty, LNG Terminal, Pipeline

Abstract. Hydroelastic response of floating structures is of interest as they have various fields of application including waterfront infrastructure, off-shore wind farms, LNG terminals, etc. This paper presents a numerical approach to examine the hydroelastic responses of the pneumatically supported floating structures for potential applications in floating jetties for LNG terminals. For the hydroelastic analysis, the fluid is modeled as a 2D semi-infinite strip of seawater whereas the floating structure is modeled as a beam. A direct coupled model is then constructed by using the boundary integral formulation for the fluid and FEM for the structure and by incorporating a pneumatic factor at the fluid-structure interface to consider the compressibility of air. For case studies of the pneumatic support effect, hydroelastic responses of the pneumatically supported type are compared to those of the pontoon type. It is shown that, in general, the pneumatic supports contribute to the reduction of the hydroelastic responses and the response reduction can be enhanced when some pneumatic support conditions are met.

1 INTRODUCTION

For locations with sufficient deep water, LNG access terminals may consist of jetty structures where tankers can be moored and offloading can take place. Some LNG facilities have the jetty terminal connected to an onshore facility by a short trestle structure, which supports the LNG and utility piping, and may in some cases support vehicular access to the loading terminal as shown in Fig. 1.

Costs of a typical trestle structure are dependent upon many factors including the length, the water depth, the soil condition, the number and sizes of trestle piping, etc. [1]. Subsea pipelines can be used instead, thereby eliminating the need and cost for a connecting trestle as shown in Fig. 2 [1]. As an alternative to these two pipeline configurations, a floating jetty for supporting the pipeline may be utilized.

To that end, the hydroelastic response of a floating jetty, viz., the pneumatically supported floating structure (PSFS), is considered in this paper. The PSFS utilizes aircushions below the bottom of the structure for possible reduction of excessive hydroelastic responses and costs of the conventional floating structure type such as pontoons [2, 3].

For the hydroelastic analysis, the floating structure is modeled as a beam, whereas the fluid pressure applied to the structure is determined through the boundary integral formulation of the velocity potential. Then fully coupled analysis within the frequency domain is carried out. To investigate the effect of the pneumatic support, the hydroelastic responses of the PSFS are compared to those of the pontoon type for various support conditions and wavelengths of the regular incident wave.

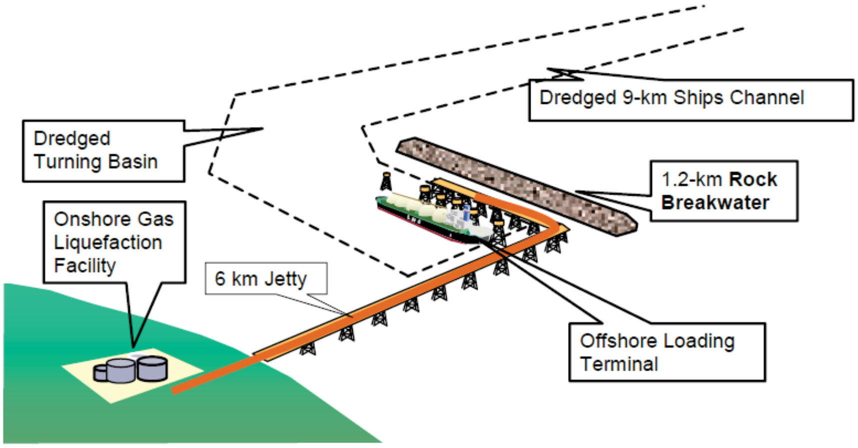

Figure 1: LNG Loading jetty with breakwater [1]

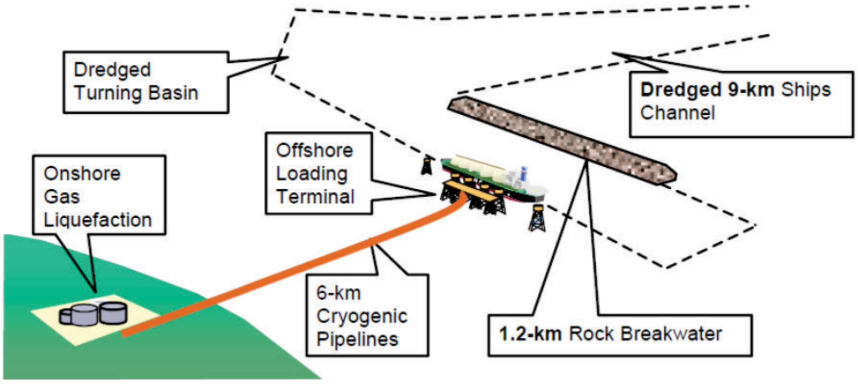

Figure 2: Subsea LNG pipeline with loading jetty [1]

2 SCHEMEMATICS OF FLOATING JETTY USING PNEUMATIC SUPPORTS

Figure 3 shows schematically the LNG terminal with PSFS-type jetty segment and flexible joints at both ends.

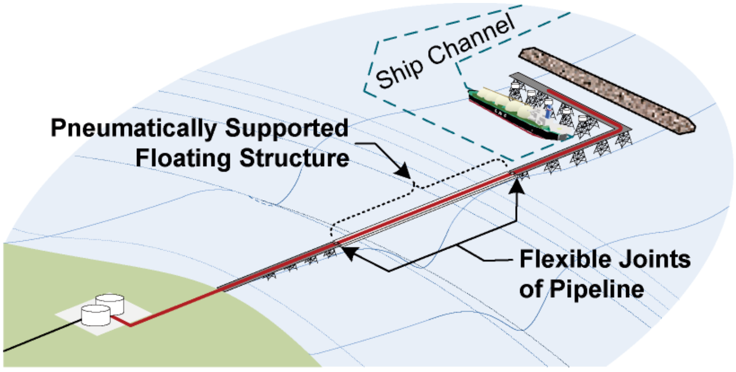

Figure 3: Schematics of the floating jetty for supporting the pipeline

The PSFS is supported by an array of pneumatic modules as shown in Fig. 4. The bottom of each pneumatic module is divided into the plate-covered domain (Σ_1) and the pneumatically supported domain (Σ_2).

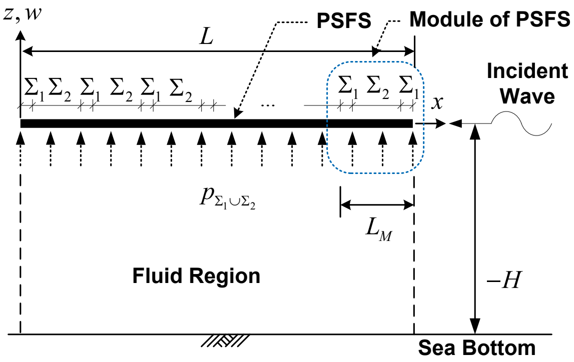

Figure 4: Geometry of pneumatically supported floating structure

The hydrostatic equilibrium of a single pneumatic module is schematically shown in Fig. 5. The whole structure may also be divided into two domains in a similar manner. In Fig. 5, P_c is the absolute internal pressure, P_a is the atmospheric pressure, ζ is the elevation of the internal free surface.

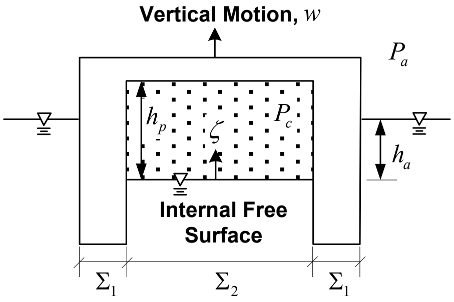

Figure 5: A single module in hydrostatic equilibrium

3 MATHMATICAL FORMULATIONS

The floating structure, based on the concept as shown in Figs. 4 and 5, can be modeled as a beam. The equation of motion of the beam subjected to the fluid pressures is described in the frequency domain as:

$$-\omega^2 \rho_s h w + \frac{EI}{B}\frac{\partial^4 w}{\partial x^4} = p\big|_{\Sigma_1} + \gamma p\big|_{\Sigma_2} \tag{1}$$

The fluid is assumed to be inviscid and incompressible, and the motion of the fluid is irrotational and simple harmonic. Then, the boundary integral equation of the fluid pressure applied to the PSFS is expressed as:

$$2\pi\left(\frac{ig}{\omega}w + \frac{i}{\omega\rho_w}p\right) - 2\pi\phi^{Inc} = \frac{i\omega}{\rho_w g}\int_{\Sigma_1} pGdx + \gamma\frac{i\omega}{\rho_w g}\int_{\Sigma_2} pGdx \tag{2}$$

where G is the Green's function of the free surface.

The pneumatic support effect is applied through the pneumatic factor which may be expressed as:

$$\gamma = \frac{\kappa\left(h_a + \beta\right)}{h_p + \kappa\left(h_a + \beta\right)} \tag{3}$$

where $\beta = P_a / \rho_w g$ is the atmospheric pressure head, h_a is the draft of the internal free surface, h_p is the height of the trapped air, and the polytropic index κ is equal to 1.4 for the air.

For an approximate solution of the coupled hydroelastic problem, the fluid pressure is computed by using the boundary element method, whereas the equation of motion is solved using the finite element method. Resulting fully coupled algebraic equation of Eqs. (1) and (2) is obtained as follows:

$$\begin{bmatrix} \gamma^{-1}\left(\mathbf{M_S} - \mathbf{K_S}\right) & \mathbf{C} \\ \mathbf{C^T} & \mathbf{K_F} - \gamma\mathbf{M_F} \end{bmatrix}\begin{bmatrix} \mathbf{U} \\ \mathbf{P} \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ \mathbf{F_{Inc}} \end{bmatrix} \tag{4}$$

The maximum response of a floating structure to a regular wave is presented using the following response amplitude operator (RAO):

$$|w| = \sqrt{\mathrm{Re}\left(w\right)^2 + \mathrm{Im}\left(w\right)^2} \tag{5}$$

In addition, the reduction effect of the PSFS is evaluated by using the mean concept of the overall responses of the floating structure as follows:

$$U = \frac{1}{aL}\int_0^L \left|w\left(x\right)\right| dx \tag{6}$$

4 HYDROELASTIC RESPONSES OF PSFS

4.1 Numerical models

As a numerical example, the experimental model (1/100 scale) used by Utsunomiya *et al.*

[4] is considered. The experimental model is a pontoon type floating structure with the length of 10 m, width 0.5 m, thickness 0.038 m and draft 0.00836 m. The beam has the bending stiffness of 235 Nm^2. To examine the pneumatic support effect, the typical variables of the PSFS are set to the support type, the number of modules, the pneumatic area ratio, $L_r = L_{\Sigma_2} / L_{\Sigma_1 \cup \Sigma_2}$, the pneumatic factor, and the relative wavelength of the incident wave. The combinations of the variables for the case studies are listed in Table 1. The hydroelastic response analysis is performed at a water depth of 1.1 m subjected to an incident wave which has the height of 0.01 m.

Table 1: Cases for the elvauation of pneumatic support effects

Type	Pontoon	Multiple Pneumatic Module		
Case Index	Case I	Case II-N1	Case II-N10	Case II-N20
No. of Modules	1	1	10	20
Pneumatic Area Ratio	0	1	0.8	
Pneumatic Factor	1	0.2–0.95	Factor A: 0.441 (h_p=28.5 m, h_a=6.0 m) Factor B: 0.746 (h_p=6.1 m, h_a=2.74 m)	
Relative Wavelength	0.1, 0.2, 0.3, 0.4			

The pneumatic factor for the pneumatic support effect is introduced by Eq. (3). The pneumatic factor γ has a range from 0 to 1 as shown in Fig. 6.

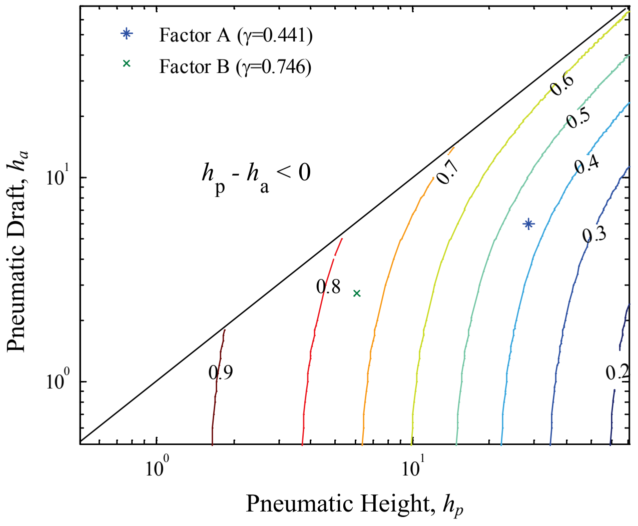

Figure 6: Pneumatic factors

4.2 Numerical results

Numerical results for the pneumatic support effect are presented in this section. The fundamental behaviors (RAO) of the pontoon type (Case I) for different relative wavelengths are shown first in Fig. 7. When the incident wave is relatively short, the response of the central part of the floating structure is quite small.

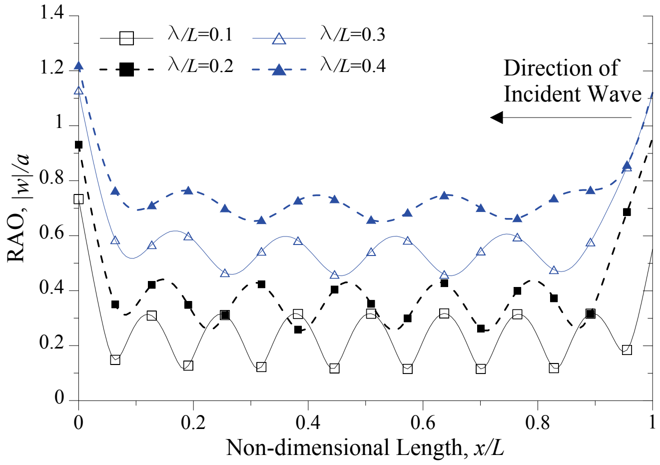

Figure 7: RAOs of Case I

In order to investigate the response reduction effect as a function of the pneumatic factor, the overall displacements of Case II-N1 are compared to those of Case I. Figure 8 shows the relative overall displacements of Case II-N1, i.e., U/U_{CaseI}. The response of Case II-N1 grows smaller monotonically as the pneumatic factor becomes smaller for most incident wavelengths except for $\lambda/L = 0.1$. As for the effect of the incident wavelength, the smaller the incident wavelength, the more significant reduction of the response for the range of the pneumatic factors considered. In the case when $\lambda/L = 0.1$, the reduction effect becomes much stronger throughout the range of pneumatic factors.

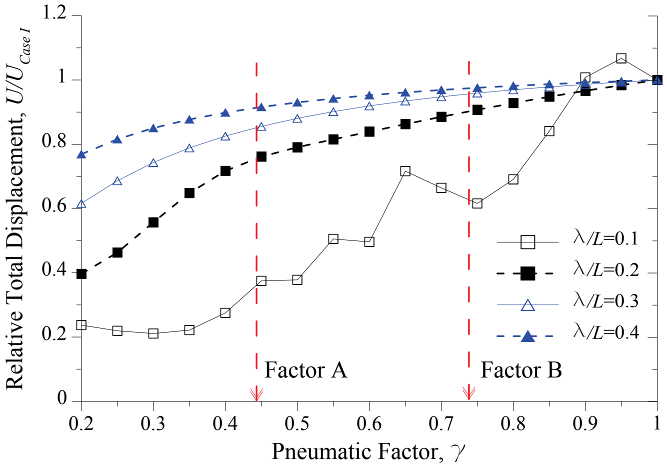

Figure 8: Relative overall displacements of Case II-N1 as a function of the pneumatic factor

As for the effect of the number of pneumatic modules, Figs. 9 and 10 show the response of the PSFS with the pneumatic area ratio of 0.8 and $\lambda / L = 0.1$ for the two pneumatic factors A and B, respectively. Figure 9 shows that the displacement performance of N20-A is noticeably better than that of N10-A. In the case of pneumatic factors B, the response reduction performance is more dependent on the pneumatic factor than the number of pneumatic modules as shown in Fig. 10.

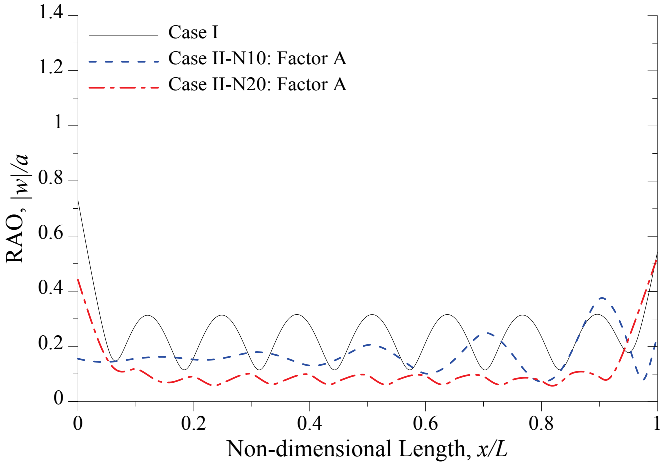

Figure 9: RAOs of Case II-N10 and N20 with Factor A for $\lambda / L = 0.1$

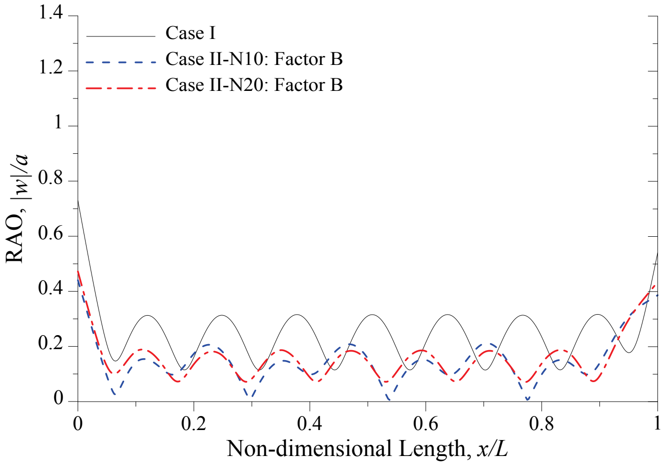

Figure 10: RAOs of Case II-N10 and N20 with Factor B for $\lambda / L = 0.1$

5 CONCLUSIONS

This study aims at potential application of floating jetties for LNG terminals. To that end, an analytical study is carried out to examine the hydroelastic responses of the pneumatically supported floating structure subjected to regular waves. It is shown that the floating structure with an idealized single pneumatic module is most effective when the incident wave is relatively short and the pneumatic factor is relatively small. The response reduction effect of the multiple PSFS is closely related to the number of pneumatic modules according to the pneumatic factor. The large responses of the both ends are significantly reduced when particular conditions of the number of pneumatic modules and the pneumatic factor are met. This study demonstrates that the analytical technique proposed herein can be used to examine the design conditions which are essential for practical applications of the pneumatically supported floating structures.

ACKNOWLEDGEMENT

This research was supported by a grant (13IFIP-B06700801) from the Industrial Facilities & Infrastructure Research Program funded by the Ministry of Land, Infrastructure and Transport of Korean.

REFERENCES

[1] Phalen, T., Prescott, C.N., Zhang, J., and Findlay, T., Update on subsea LNG pipeline technology, *Proc. of the Offshore Technology Conf.* (2007) **OTC 18542**: 1−10.

[2] Wang, C.M., Tay, Z.Y., Takagi, K., and Utsunomiya, T., Literature review of methods for mitigating hydroelastic response of VLFS under wave action, *Applied Mechanics Reviews, ASME* (2010) **63**(3): 1–18.

[3] Seidl, L.H. *Development of an ASP (Air Stabilized Platform)*, Technical Report PB80-221997, U.S. Maritime Administration, University of Hawaii, (1980).

[4] Utsunomiya, T., Watanabe, E., Wu, C., Hayashi, N., Nakai, K., and Seika, K., Wave response analysis of a flexible floating structure by BE-FE combination method, *Proc. of the 5th Int. Offshore and Polar Engng. Conf.* (1995): 400–405.