The 2014 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM14)
Busan, Korea, August 24-28, 2014

Extreme roll motion assessment of ART equipped floating structures by spectral analysis

Kang-Heon Lee[1)], San Kim[1)], and [*]Phill-Seung Lee[1)]

[1)]*Division of Ocean Systems Engineering, Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon, 305-701, Republic of Korea*

**phillseung@kaist.edu*

ABSTRACT

Extreme roll motion assessment of floating structures is vital for the ocean platforms. Especially, the extreme roll motion of floating production units should be less than the design criteria to ensure the safe operating condition in ocean environments. However, the ART (Anti Roll tank) system has been focused on the reduction of roll motion at a natural roll frequency. This design approach could bring out the large roll motion at two coupled natural frequencies near the original natural frequency of floating structures. In the context of spectral analysis, these two new peaks can induce the high energy spectrum for roll motions when one of the two new peak frequencies is close to the peak frequency of the wave spectrum. Therefore, the extreme roll motion should be assessed in conjunction with the conventional ART design approach.

In this study, the extreme roll motion of free surface ART equipped floating structures are predicted by spectral analysis. Initially, the theoretical background of sea-keeping analysis under the steady state monochromic wave is addressed and the roll RAO (Response Amplitude Operator) is evaluated in the wide range of wave frequencies. Then, the overall spectral analysis algorithm is addressed and the extreme values, significant and extreme roll motion amplitudes are defined and calculated. The standard sea spectrums, JONSWAP (Joint North Sea Wave Project) is considered for a numerical example.

1. INTRODUNCTION

The extreme roll motion analysis is discussed for the evaluation of ARTs effect on the ship roll motions in irregular waves. Initially, the usual hydrodynamic analysis in regular waves is addressed. Then, the conventional spectral analysis (Price 1974 and Journée 2001) algorithm is applied to obtain the significant and extreme roll motion of ART

[*] Corresponding Author: Associate Professor, phillseung@kaist.edu

equipped ship. Through a numerical example, the efficiency and effect of ART on the ship roll motion in irregular waves are evaluated.

2. SHIP MOTIONS IN REGULAR WAVES

The six rigid body motion of ship ξ_j in regular water waves are obtained by solving the linear system:

$$\sum_{j=1}^{6}\left[-\omega^2\left(M_{ij}+m_{ij}(\omega)-m_{ij}^S(\omega)\right)+i\omega b_{ij}(\omega)+\left(c_{ij}+c_{ij}^S\right)\right]\xi_j = X_i(\omega)\,,\quad \text{for}\quad i,j=1,2,\ldots,6\,, \tag{1}$$

where, M_{ij} and $m_{ij}(\omega)$ are ship's mass and added mass, $b_{ij}(\omega)$ and c_{ij} are radiation damping and restoring matrix, $X_j(\omega)$ is wave exciting force, and $m_{ij}^s(\omega)$ and c_{ij}^S are added mass and restoring matrices of internal fluid inside the ARTs, respectively.

3. SPECTRAL ANALYSIS

In this section, the methodology of spectral analysis is addressed. For the extreme roll motion assessment, the roll RAO of ship $A(\omega)$ in regular waves should be first found and the wave energy spectrums $S_\varsigma^{(p)}(\omega)$ should be defined. Then, the relation between wave energy spectrum $S_\varsigma^{(p)}(\omega)$ and the energy spectrum of ship motion $S_x^{(p)}(\omega)$ can be defined:

$$S_x^{(p)}(\omega)=\left|A(\omega)\right|^2 S_\varsigma^{(p)}(\omega)\,, \tag{2}$$

where, ς is the wave amplitude and the p means the sea state number.

Then, the significant roll motion amplitude ($A_{sig}^{(p)}$) is defined:

$$A_{sig}^{(p)}=2\sqrt{m_0^{(p)}}\,, \tag{3}$$

in which the zero order moment $m_0^{(p)}$ is calculated:

$$m_0^{(p)}=\int_0^\infty S_x^{(p)}(\omega)d\omega\,. \tag{4}$$

Finally, the extreme roll motion amplitude $A_{ext}^{(p)}$ can be obtained:

$$A_{ext}^{(p)} = \sqrt{2m_0^{(p)} \log_e N}\ , \tag{5}$$

where, N is the number of observations and given as

$$N = \frac{1}{2\pi}\sqrt{\frac{m_2^{(p)}}{m_0^{(p)}}}\ , \tag{6}$$

in which the second order moment $m_2^{(p)}$ is obtained:

$$m_2^{(p)} = \int_0^\infty \omega^2 S_x^{(p)}(\omega) d\omega\,. \tag{7}$$

4. NUMERICAL EXAMPLE

The box barge and three free surface ARTs depicted in Fig. 1 are considered and dimensions and analysis condition are summarized in table 1. The roll natural frequency of barge is 0.487 rad/sec and the tuned water depth of ARTs is the 4.105 m.

As mentioned, the RAO should be obtained in prior to the spectral analysis and that is obtained through the Eq. (1) and showed in Fig. 2. The hydrodynamic analysis code PADO (Kim 2013 and Lee 2014) was used for RAO computation.

Table 1. Dimension of 3D box barge and 3 ARTs (filling ratio = 0.0 %) and analysis condition.

3D box barge			
L_x (m)	300	$I_{xx}\,(kg\cdot m^2)$	7.60735E10
L_y (m)	50	$I_{yy}\,(kg\cdot m^2)$	1.28255E12
L_z (m)	30	$I_{zz}\,(kg\cdot m^2)$	1.32865E12
d (m)	10	LCG, TCG (m)	0
Displacement (ton)	150000	VCG (m)	-0.91538
3 ARTs		Sea spectrum	JONSWAP
L_{t_x} (m)	4	Water depth (m) : h_E	infinite
L_{t_y} (m)	40	Direction $(\deg)$: θ	90
L_{t_z} (m)	10	Frequency $(rad/\sec)$: ω	0.2~1.2

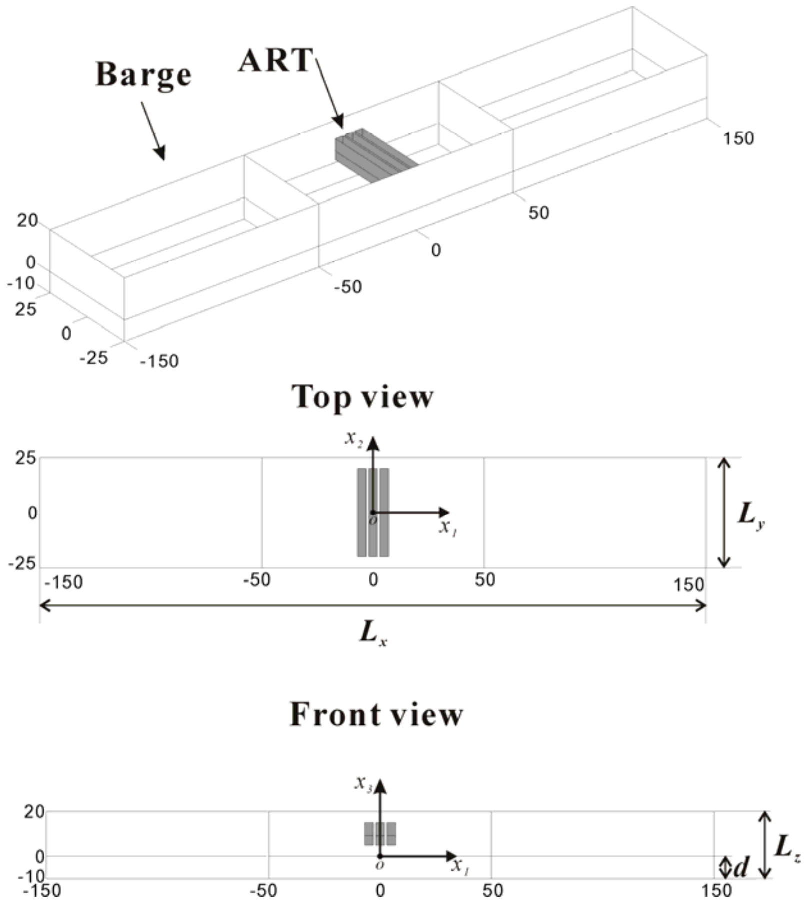

Fig. 1 Box barge and ARTs

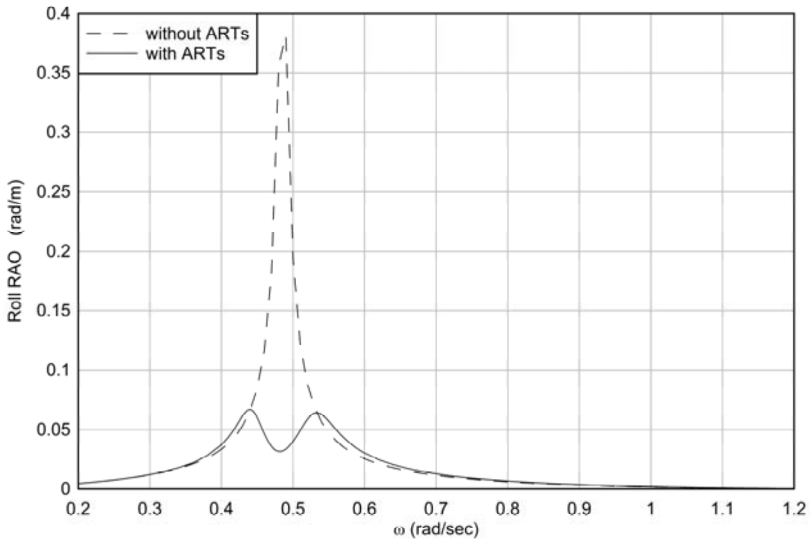

Fig. 2 Roll RAO of box barge

For the extreme roll motion assessment, the JONSWAP spectrum is generated by using the beaufort wind scale data. Then, the significant roll motion and the extreme roll motion are obtained through the Eq. (3) and Eq. (5) and the results are summarized in table 2.

Table 2. Significant and extreme roll motion of barge

Sea state (p)	$H_{1/3}$ (m)	T_1(s)	$A_{sig}^{(p)}$ (deg)		$A_{ext}^{(p)}$ (deg)	
			Without ART	With ART	Without ART	With ART
3	0.80	4.20	0.222479	0.06749	0.44253	0.14234
4	1.10	4.60	0.609727	0.19324	0.99132	0.43423
5	1.65	5.10	1.995230	0.65507	4.38213	1.63442
6	2.50	5.70	6.366367	2.02212	13.33142	4.92314

5. CONCLUSIONS

In this study, the extreme roll motion analysis was performed for the evaluation of ART effect on ship roll motion in irregular waves. The spectral analysis is quite conventional method in ship industry and therefore the evaluation is very straightforward. In the numerical results, the significant roll motion is about reduced by 70% and the extreme roll motion is suppressed by 65%. In particular, as the peak frequency of sea spectrum and the ship roll natural frequency getting closed, the increment of extreme values is getting larger and larger. Therefore, the deep consideration is required on the design of ARTs in irregular waves.

REFERENCES

Price, W.G. and Bishop, R.E.D. (1974), "Probabilistic Theory of Ship Dynamics", Chapman & Hall Ltd, London.
Journée, J.M.J. and Massie, W.W. (2001), "Offshore Hydrodynamics", Delft University of Technology, Delft.
K.T. Kim, P.S. Lee, K.C. Park, (2013), A direct coupling method for 3D hydroelastic analysis of floating structures, Int. J. Numer. Meth. Eng. **96**, 842-866.
K. H. Lee, K. T. Kim, J. G. Kim, P. S. Lee, (2014) A direct-coupled FEM-BEM formulation for hydroelastic analysis of floating liquid storage structures, Marine Structures, Submitted.