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Performance analysis Of U – Tube Tank For Roll Stabilization

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Abstract:

The passive U – tube tank stabilization remains an effective way of damping the roll motion of Offshore Supply Vessels in stationary condition when they are in the support mission mode. This paper describes the performance of a U-Tube passive tank stabilizer system deployed in an Offshore Supply Vessel. A properly tuned system can result in appreciable roll reduction. Analytical and experimental results are presented and discussed. The suppression of roll motion in the resonance period demonstrates that the system can be effectively designed for a particular vessel with knowledge of specific ship based data such as location of tank, effect of the mass of fluid in tank, and the natural roll period of the tank. The salient conclusions are brought out

1.Introduction

Fins and anti-rolling tanks along with bilge keels are commonly used to reduce roll motion. Fins are not effective when the vessel is operating at low speeds where as anti-rolling tanks are effective even in stationary condition. Anti-rolling tanks are divided into passive and active systems. Active system needs external power to operate. U-tube tanks are commonly used as anti-rolling tanks.

Mathematical modelling of U-tube tank was developed by **Lloyd (1989)** for single degree of roll motion by neglecting nonlinear terms.**Gawad et al. (1999)** made theoretical investigation to study the effect of tank location, tank mass, tank damping on maximum roll RAO using the formulation by **Lloyd(1989**) equations. **Holden et al.** (2010) have done the non-linear mathematical modeling of the U-tube tank using Lagrangian energy method and compared the results with experimental results.Earlier research findings have highlighted the roll response at resonance and also reported the influence of tank parameters on the roll response behavior. An analytical formulation has been used in this paper to obtain roll response results. Comparsions have been made using experimental results. In principle, the tank parameters viz., tank mass, tank location, tank period and tank damping influence the roll response reduction.

2.Methodology

The analysis is carried out using the following equation.

Equation of motion for the tank;

$$a_{\tau\tau}\ddot{\tau} + b_{\tau\tau}\dot{\tau} + c_{\tau\tau}\tau + a_{\tau 4}\ddot{\phi} + c_{\tau 4}\phi = 0 \qquad \text{..........(1)}$$

Equation of motion for the ship;

$$(I_{xx} + A_{44})\ddot{\phi} + B_{44}\dot{\phi} + C_{44}\phi + a_{4\tau}\ddot{\tau} + c_{4\tau}\tau = M_{ex} \qquad \text{..........(2)}$$

where

$$a_{\tau\tau} = Q_t\left(h_r + \frac{w_r}{h_d}\frac{w}{2}\right),$$

$$c_{\tau\tau} = c_{\tau 4} = Q_t g,$$

$$a_{\tau 4} = Q_t(h_r + r_d),$$

$$Q_t = \frac{1}{2}\rho w^2 w_r l$$

Equations (1) and (2) are solved for steady state roll response amplitude (ϕ_0):

$$\phi_0 = \frac{M_0}{\alpha^2+\beta^2}\sqrt{[\alpha(c_{\tau\tau} - \omega_e{}^2 a_{\tau\tau}) - \beta\omega_e b_{\tau\tau}]^2 + [\alpha\omega_e b_{\tau\tau} + \beta(c_{\tau\tau} - \omega_e{}^2 a_{\tau\tau})]^2}$$

where

$$\alpha = (c_{\tau\tau} - {\omega_e}^2 a_{4\tau})^2 + {\omega_e}^2 b_{\tau\tau} B_{44} - \left(C_{44} - {\omega_e}^2 (I_{xx} + A_{44})\right)(c_{\tau\tau} - {\omega_e}^2 a_{\tau\tau})$$

$$\beta = \omega_e b_{\tau\tau}\left(C_{44} - {\omega_e}^2 (I_{xx} + A_{44})\right) + \omega_e B_{44}(c_{\tau\tau} - {\omega_e}^2 a_{\tau\tau})$$

Principal particulars of the vessel (Offshore Supply Vessel) are:

- Length Over all : 65.47m
- Length between perpendiculars : 60.40m
- Length at waterline : 63.34m
- Breadth : 14.60m
- Depth : 6m
- Draft : 4.2m
- Displacement : 2891t
- Design speed : 12 knots
- Block coefficient : 0.76
- Longitudinal prismatic coefficient : 0.82
- Midship section coefficient : 0.93
- VCG : 4.1m
- Roll radius of gyration : 5.11m
- Pitch radius of gyration : 17.06m
- Yaw radius of gyration : 17.06m

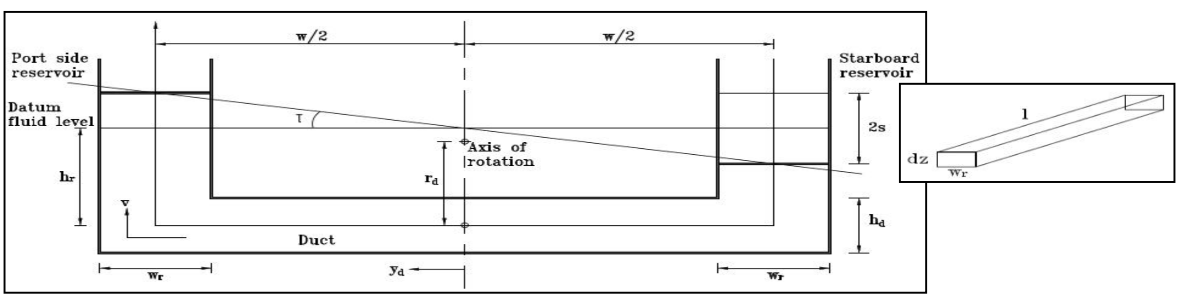

Figure1: Typical cross section of U - tube tank

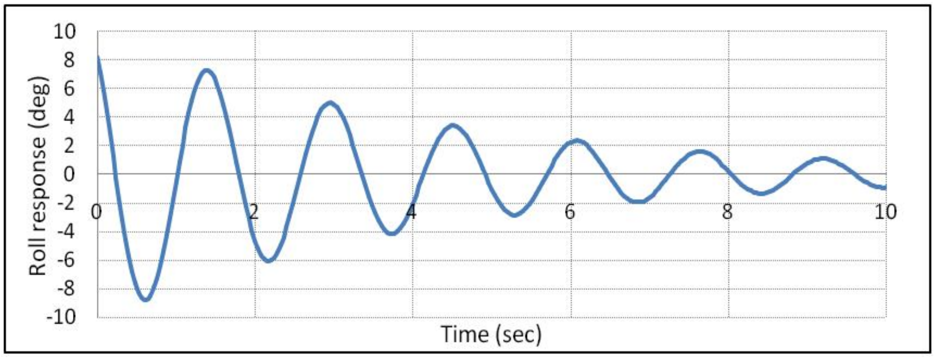

Figure 2: Decay test - Hull without bilge keel

Natural period = $1.57 \times \sqrt{17}$ = 6.48 sec

Damping ratio , $\xi = \dfrac{\ln\left(\dfrac{\phi_0}{\phi_n}\right)}{2\,\pi\,n} = \dfrac{\ln\left(\dfrac{7.32}{2.32}\right)}{2\,\pi\,\times\,3} = 0.061$

Viscous damping = $\xi \times 2\sqrt{A_{44} \times C_{44}} - (\text{Radiation damping at wave period, 6.48 sec})$

$$= 0.061 \times 2 \times \sqrt{1.04 \times 10^{8} \times 9.52 \times 10^{7}} - (7.6 \times 10^{6}) = 4.54 \times 10^{6}\ \text{N-s}$$

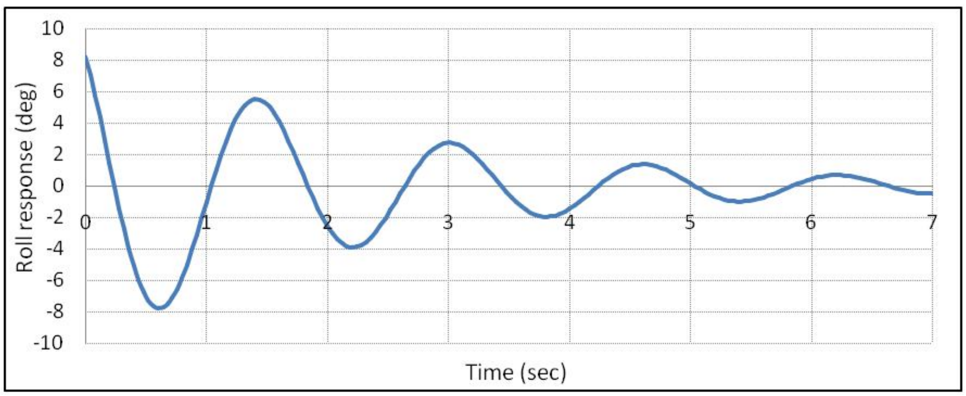

Figure 3: Decay test - Hull with bilge keel

Natural period = $1.6 \times \sqrt{17}$ = 6.6 sec

Damping ratio, $\xi = \dfrac{\ln\left(\dfrac{\phi_0}{\phi_n}\right)}{2\,\pi\,n} = \dfrac{\ln\left(\dfrac{5.47}{1.37}\right)}{2\,\pi\,\times\,2} = 0.11$

Viscous damping = $\xi \times 2\sqrt{A_{44} \times C_{44}} - (\text{Radiation damping at wave period, 6.48 sec})$

$$= 0.11 \times 2 \times \sqrt{1.04 \times 10^{8} \times 9.52 \times 10^{7}} - (7.6 \times 10^{6}) = 14.32 \times 10^{6}\ \text{N-s}$$

4.Results & Discussions

4.1.Analytical Results

A basic rectangular U-tube cross section is designed so that its natural period of roll matches with the ship's natural period of roll, with the following dimensions

w_r= Reservoir width =2.21m

w = Duct width =11.39m

h_d = Height of the duct =1.53m

h_r=Reservoir level =2.55m

Natural period of tank = $2\pi\sqrt{\frac{a_{\tau\tau}}{c_{\tau\tau}}} = 2\pi\sqrt{\frac{h_r+\left(\frac{w_r}{h_d}\cdot\frac{w}{2}\right)}{g}}$ = 6.58 sec

and roll response was found by varying tank parameters.

4.1.1.<u>Effect Of Tank Damping</u>

Roll response is found by varying the tank damping by keeping other parameters constant viz., liquid mass in tank = 3.2% ship mass, tank location is such that duct centre line is at the water plane.Tank period = Roll natural period = 6.58s

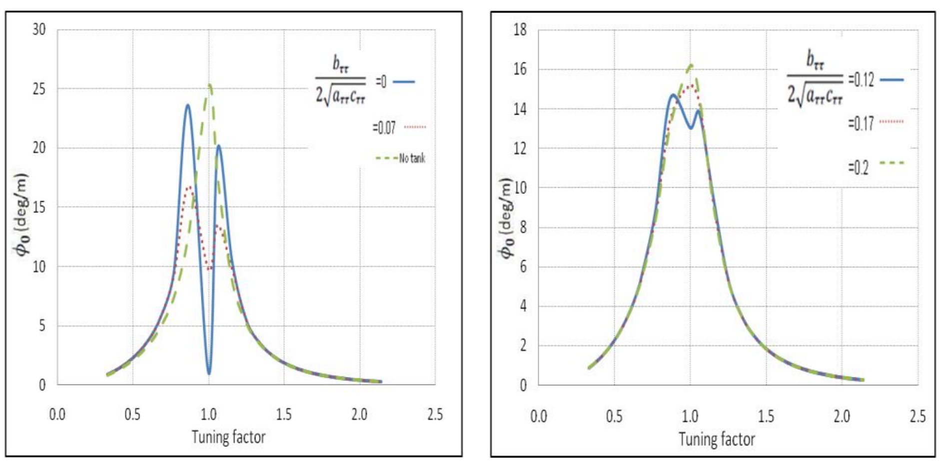

Figure 4 and Figure 5: Roll response vsTuning factor for various tank damping condition

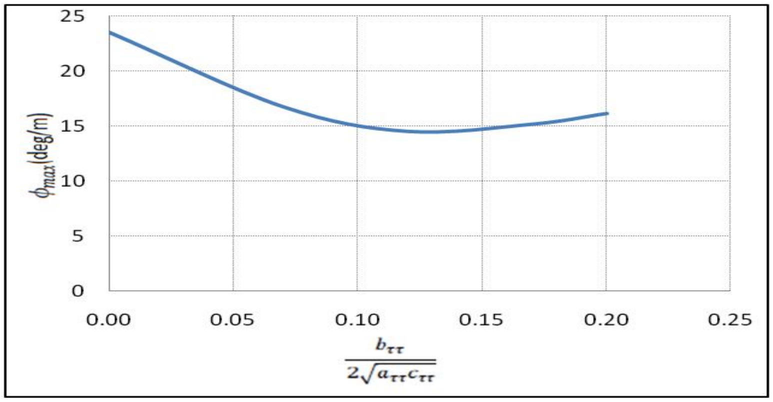

Figure 6: Effect of tank damping - Max.roll response vs Tank damping

For very low damping, the roll RAO is reduced at resonance but at the cost of increase in other regions. As damping increases, maximum roll response is decreases till the minimum value and starts increasing again. Hence, the optimum damping ratio range is found to be 0.12 to 0.14.

5.Optimum Tank Parameters

The favorable tank dimensions and characteristics are as follows;

Reservoir width, w_r=2.21m, Duct width, w=11.39m,

Height of the duct, h_d=1.53m, Reservoir level, h_r =2.81m,

Tank mass m_t= 3%∇= 86.73t,

Tank damping $b_{\tau\tau} = 0.12 \times 2\sqrt{a_{\tau\tau}.\, c_{\tau\tau}}$, Tank length, $l = \dfrac{m_t}{\rho(2\, h_r\, w_r + w\, h_d)} = 3\text{m}$

Natural period of tank = $2\pi\sqrt{\dfrac{a_{\tau\tau}}{c_{\tau\tau}}} = 2\pi\sqrt{\dfrac{h_r + \left(\dfrac{w_r}{h_d}\cdot\dfrac{w}{2}\right)}{g}}$ = 6.66 sec.

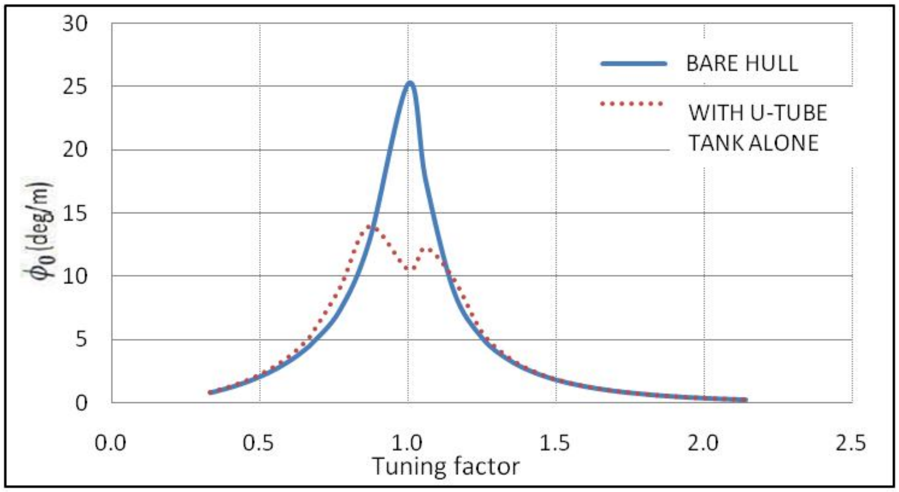

Figure7: Roll response - Comparison of Bare hull and hull with U - tube tank of optimum parameters

In comparison with the natural roll response of the bare ship (i.e. without bilge keel),there is a clear 44% reduction of roll when the U - tube tank is provided.

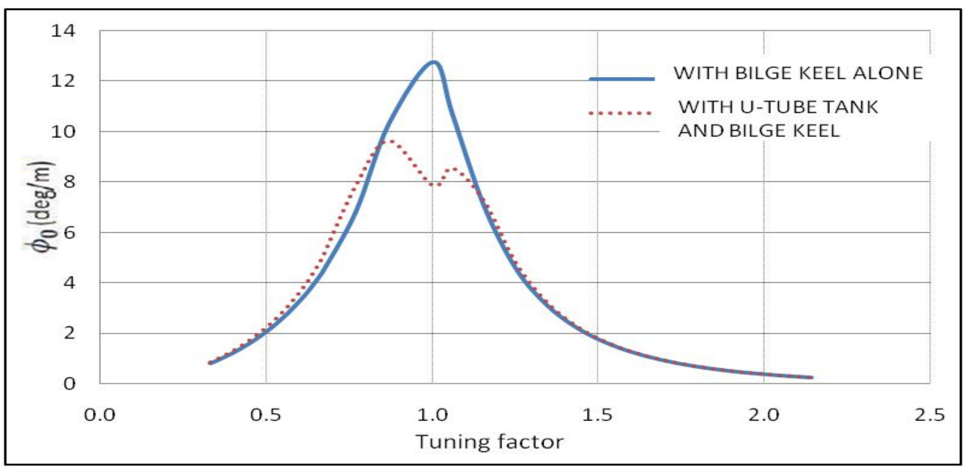

Figure 8: Roll response - Comparison of hull with bilge keel alone and hull with U - tube tank and bilge keel

The presence of the bilge keel has already reduced the roll motion response to nearly 45%. Now, with the presence of U-tube tank along with bilge keel, the peak roll reduction is nearly 60% when compared to the roll response of bare hull.

6.Experimental Validation

The model of the Offshore Supply Vessel was built to a scale of 1 : 17 in fiber glass material. The model was prepared for geometric, as well as mass and mass distribution based similarity so as to achieve dynamic similarity. The experimental studies were conducted in the Wave basin at IIT Madras (30m x30m x3m). Tests were conducted in stationary condition in regular waves. The measurement system consisted of conductivity type wave probes for wave measurements (Danish Hydraulics, Denmark) and Motion Reference Unit for roll motion measurement (ORE Systems, USA).

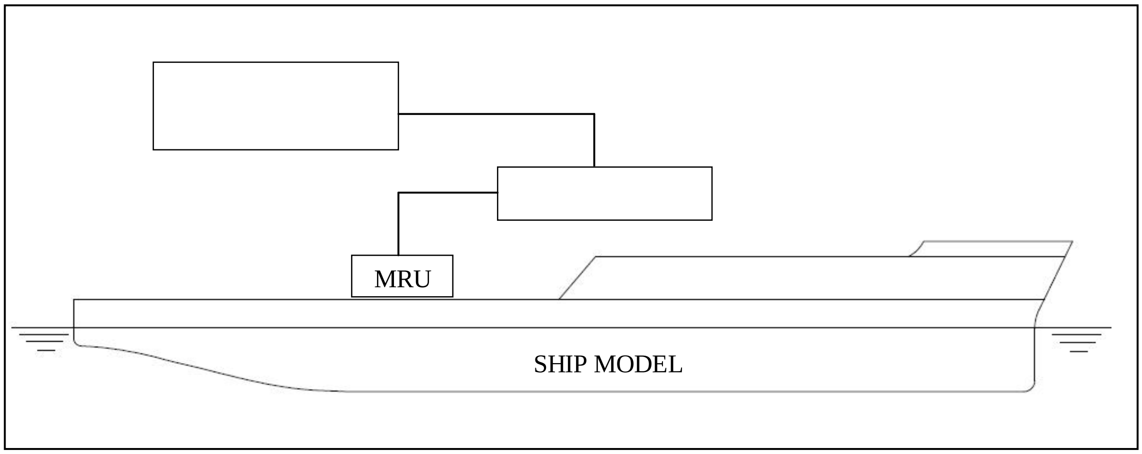

Figure 9: Schematic diagram showing the experimental setup

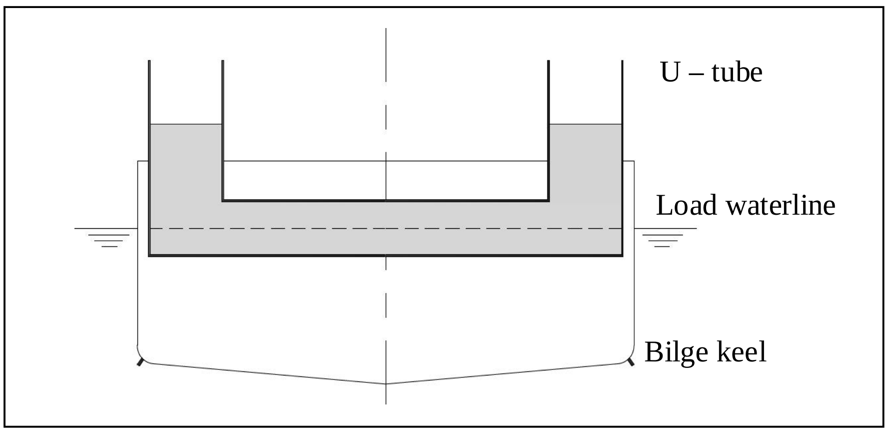

Figure 10: Side view of model with U - tube tank and bilge keel.

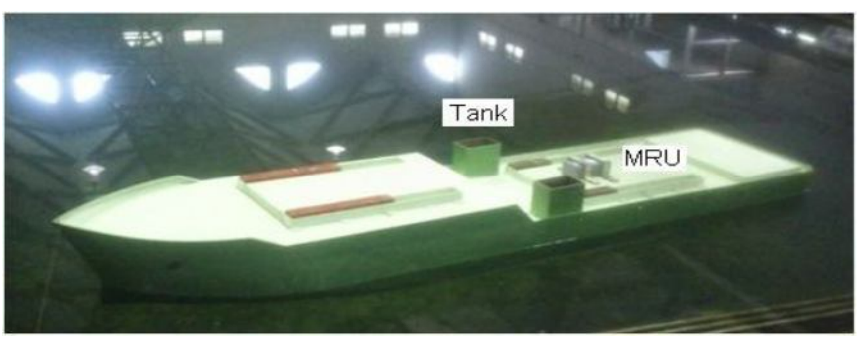

Figure 11:Experimental setup for Seakeeping test in Wave basin

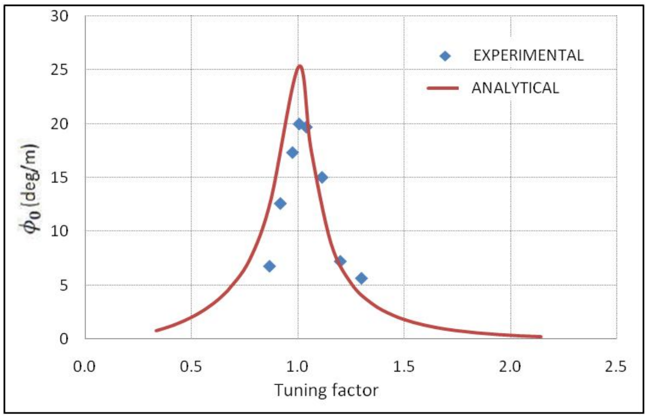

Figure 12:Roll response - Comparison of experimental and analytical results for bare hull.

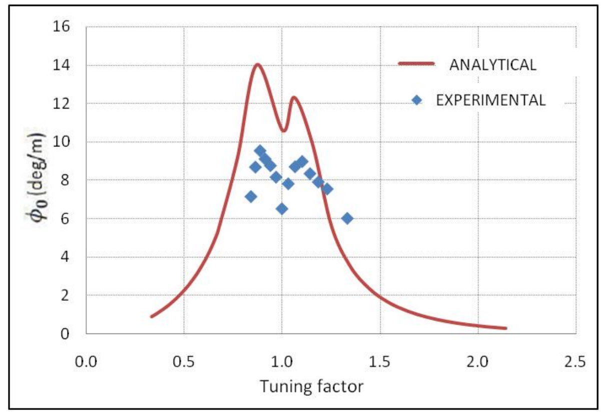

Figure 13: Roll response - Comparison of experimental and analytical results for hull with U - tube alone.

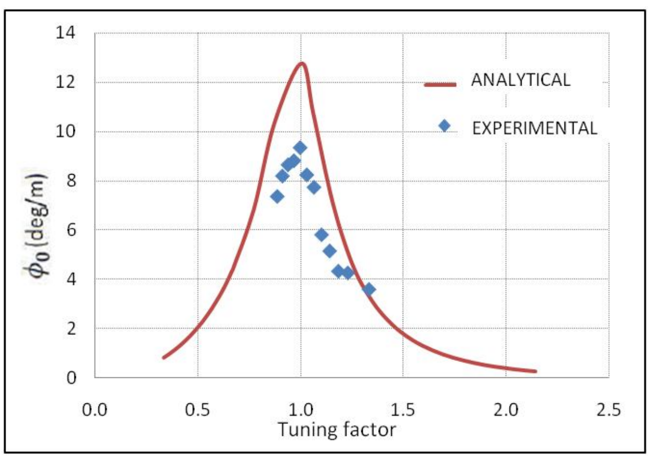

Figure 14:Roll response - Comparison of experimental and analytical results for hull with bilge keel alone.

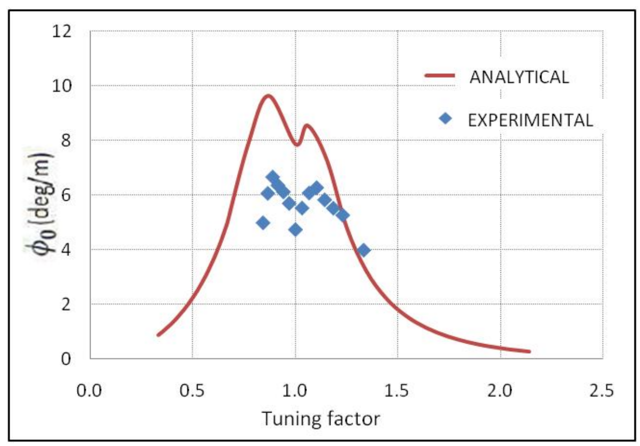

Figure 15: Roll response - Comparison of experimental and analytical results for hull with bilge keel and U - tube tank.

7.Result And Conclusion

- The analytical modeling in principle brings out the influence of many tank based parameters such as tank mass, tank natural period, tank location. Key results alone are presented in this paper.
- Model experiments based results are compared and presented along with analytical results.

Some of the salient conclusions arrived at on the basis of the study are:

- The bilge keel itself substantially reduces roll in the resonance region to the tune of 45%.
- Independent tests carried out to quantify the influence of the U - tube tank alone, show equally large roll reduction. In other words the U-Tube tank alone substantially reduces the roll motion.
- Combined use of bilge keel &U – tube tank, achieves substantially higher roll reduction than by the use of any one of the above systems.

- **Nomenclature**

B= Breadth

D= Depth

L= Lagrangian (K.E-P.E)

O= Centre of rotation/Origin

T= Moulded Draft

a= Wave amplitude

g= Acceleration due to gravity

l = Length of the tank

s= Movement of free surface from mean level

v= Velocity

w= Duct width of U-tube tank

A_{44} = Uncoupled Roll Added Mass Moment of Inertia

B_{44} = Uncoupled Roll damping coefficient

C_{44} = Uncoupled Roll restoring moment Coefficient

I_{xx} = Mass moment of inertia of ship about X-axis

M_{ex} = Wave exciting moment about X-axis

h_d= Duct height of U-tube tank

h_r= Reservoir mean level

m_t= Mass of U-tube tank

r_d= Elevation of centre of rotation from duct centre line

ω_e= Wave encountering frequency

w_r= Reservoir width of U-tube tank

ω_s= Natural frequency of roll for ship

ω_t= Natural frequency of roll for U - tube tank

$L.B.P$= Length between perpendiculars

$a_{4\tau}$= Added mass coefficient in Roll motion due to fluid oscillation

$a_{\tau\tau}$= Added Mass coefficient of tank

$b_{\tau\tau}$= Damping coefficient of tank

$c_{4\tau}$= Restoring moment coefficient in fluid oscillation due to Roll motion

$c_{\tau\tau}$= Restoring moment coefficient of tank

∇ = Mass of the Ship

ϕ= Ship rotation about X-axis (Roll)

τ = Angle subtended by liquid levels in the two limbs of the U-tube.

ρ= Density of water

φ= Phase difference

8.Reference

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