An Investigation Into The Coupling of Sloshing Effect Due to Translation Force of FLNG Motions

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***Abstract*—The motion of FPSO fluid inside gas carrier is normally restricted by loading condition of the vessel, whether the vessel is operated at near empty condition or under 30 % from fully loaded condition. In this way, resonance or sloshing effects of the fluid on the FPSO's hull are limited. However, nowadays the FPSO carriers are considered to be operated at intermediate loading condition and also during the production. In this condition, the FPSO is more likely to be induced into resonance due to wave action and FPSO motion. This resonance or sloshing behavior of the FPSO leads to high impact pressure on hull storage construction. A theory based on gas dynamics for shock wave in a gas flow has been used to describe the motion of the fluid. Then, a linier potential theory as used in strip theory ship motion. The current paper describes a study model experiment in Maneuvering & Ocean Engineering Basin (M.O.B) at the Indonesian Hydrodynamic Laboratorium. It uses a wooden barge at scale of 1 : 70, together with various wave heading, amplitude and period. Using high speed video camera, the wave front formed by the bore of the FPSO in resonance is observed and the impact to the tank hull is measured.**

Keywords—**non- linier hydrodynamic, sloshing, impact, motion**

Abstrak*— *Gerakan FPSO cairan di dalam pembawa gas LNG biasanya dibatasi oleh kondisi pemuatan kapal, apakah kapal tersebut dioperasikan pada kondisi muatan mendekati kosong atau di bawah 30 % dari kondisi muatan penuh. Dengan cara ini, resonansi atau efek permukaan bebas cairan di konstruksi lambung FPSO terbatas. Namun, pada penelitian saat ini FPSO di operasikan pada kondisi pembebanan menengah. Dalam kondisi ini , FPSO adalah lebih mungkin diinduksi ke resonansi dari akibat karena gelombang menerpa lambung kapal dan gerakan FPSO itu sendiri. Resonansi ini atau pengaruh permukaan bebas muatan gas atau cairan di ruang muat menyebabkan dampak tekanan yang tinggi pada konstruksi lambung kapal FPSO. Sebuah teori yang didasarkan pada dinamika gas untuk gelombang kejut dalam aliran gas dapat digunakan untuk menggambarkan gerakan fluida. Kemudian, potensi teori linier seperti yang digunakan dalam teori olah gerak kapal. Pada penelitian ini menjelaskan percobaan uji model FPSO yang dilaksanakan pada kolam uji maneuvering (MOB) di Laboratorium Hidrodinamika Indonesia. Ini menggunakan model tongkang kayu di skala 1 : 70 , dengan berbagai variasi gelombang, amplitudo dan periode. Menggunakan kamera video berkecepatan tinggi , gerakan fluida yang terjadi pada ruang muat diamati dan direkam dengan menempatkan sebuah kamera pada bagian depan ruang muat fluida FPSO.

Kata Kunci— ***hidrodinamika non-linier, sloshing, tekanan, olah gerak***

I. Introduction

This study considers the motion responses of a FLNG in waves, coupled with sloshing in cargo. When a floating body with liquid cargo is under excitation in ocean wave, its FLNG motion is affected by both external wave excitation and internal sloshing-induced forces, moment and impact load on FLNG cargo structures. The former is an important task in the design of internal cargo structure. In particular, this is an essential element in the design of membrane-type liquefied natural gas (FLNG) carriers or FLNG platforms. The latter has been of interest for the prediction of translation dynamic forces behavior of ship motion. Meanwhile the design load of the main hull structure is governed by the external wave load and internal load due to ship motion, the sloshing impact load due to liquid motion inside the tank governs the design load for the FLNG containment system and surrounding bulkheads.

Many studies on the ship sloshing problem were carried out in 1970's and early 1980's for the design of FLNG carriers. Recently, the demand of sloshing analysis is rising again for the design of larger FLNG carriers and LNG Floating-Production-Storage-Offloading (FPSO) vessels. Many numerical studies on sloshing flows have been reported during last two decades. Some representative works have been introduced by [1-6]. Despite numerous studies, not many methods are applicable for actual engineering use such as the simulation of violent flows and the prediction of impact loads. However, recent experimental and numerical study shows that even at the milder sea states, the sloshing load at the filling level near the 30% of tank height can be as high as the sloshing load at the high filling level at the North Atlantic [7-9]. This study aims to observed on the physical phenomena involved in violent sloshing flows, and the development of proper numerical models for practical use. Both the experimental observation and numerical computations were carried out [10-12]. The model experiment was studied presented on simplified model of heave and pitch motion of an FLNG due to sloshing effect and comparison some experiment results. This study aim to observed coupling effect from pitching and heaving to

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global of motion. The dynamic motion of an FLNG consist of rotation and translation called 6 degree of motion [13,14].

II. METHOD

A. Model Set-Up and Its Particular

The FLNG model was produced according to a scale 1 : 70 .The model consists of hull body (barge shape structure) completed with cargo tank, normal bilge tank. The FLNG model was made from wood and steel frame which is required strengthen the hull body with principle particular as set on Table 1. The model should be statically and dynamically balanced to adjust the position centre of gravity and radii gyration see Figures 1- 2. The Cargo tank is made of acrylic transparent glass 1 cm wall thickness. In the following lines plan and table of principal dimension of FLNG with scale factor.

The model test were carried out in regular and random waves. The random waves were adjusted to represent Pierson-Moskowitz wave spectrum. The waves in basin were generated by means of a wave generator.

B. Notation & Procedure of Calibration

The notation of the motion and force components was taken in relation to their directions with respect to the model system of axes. The following notations and sign conventions are applicable in Table 3.

C. Procedure Calibration

All from the recorded decay curves of the various motion decay or free extinction tests natural periods have been derived to used for evaluated. The damping coefficients were derived from the decrease of motion amplitude for two successive oscillations as follows: (See Figure 3), and for calibration factor (see Figure 4).

$\phi(t)$ = time trace of motion ϕ

ϕn = motion amplitude of n-th oscillation

$T\phi$ = natural period of motion ϕ.

The logarithmic decrement Δ can be determined:

$\Delta = \ln (\phi n_1/\phi n_2)$ (1)

The dimensionless damping coefficient or damping ratio to critical damping is expressed by:

$k = b/b_{critical}$ (2)

Which can be calculated from the logarithmic decrement by:

$k = \Delta / (4\pi^2+ \Delta^2)^{1/2}$ (3)

Linear (Equivalent) Damping

When the system behaviors is almost linear (equivalent) damping can be derived as follows:

The linear motion x(t) during a free extinction test can be described by, assuming a linear system:

$$(m+1).\frac{d^2x}{dt^2} + B_{x.}\frac{dx}{dt} + C.x = 0 \quad (4)$$

$$(I + I_A).\frac{d^2\phi}{dt^2} + B_\phi.\frac{d\phi}{dt} + C_\phi.\phi = 0 \quad (5)$$

Where:

m = vessel mass

I = vessel inertia for rotation

A = added mass

I_A = added inertia for rotation

B_x = linear damping coefficient

B_ϕ = angular damping coefficient

C_x = linear spring coefficient

C_ϕ = angular spring coefficient

The spring coefficients are a combination of the hydrostatic spring and the stiffness of the mooring system.

The non-damped natural period of this system can be calculated as:

$$T_\phi = 2\pi\sqrt{\frac{I + I_A}{C_\phi}} \quad (6)$$

$$T_x = 2\pi\sqrt{\frac{m + A}{C_x}} \quad (7)$$

For such a system the critical damping B_{crit} is defined as:

$$B_{x_{crit}} = 2\sqrt{(m + A).C_x} \quad (8)$$

$$B_{\phi_{crit}} = 2\sqrt{(I + I_A).C_x} \quad (9)$$

If the damping is equal to, or larger than, the critical damping, no overshoot of dynamic amplification occurs in the system. To determine the degree of damping in a system, the damping is sometimes expressed as a ratio B_β of the linear damping coefficient B and the critical damping B_{crit}:

$$B_\beta = \frac{B}{B_{crit}} \quad (10)$$

III. RESULT AND ANALYSIS

The prediction of responses structure of an FLNG is generally made in regular wave. In currently work various heading angle (90,135) degree, wave height 2 m and filling of the storage tank 30 %, period (see Table 2 test with regular wave) and for simplicity analysis purpose using mark point “ ” and “ ” (for heading angle 90 deg and for heading angle 135 deg). In this model test sort term response calculation of linier non linier are given natural Response Amplitude Operator (RAO) of FLNG (see Table 3). Based on linier theory it is assumed that for each wave period the relation between input wave amplitude and motion always the same. From the test were carried out rotation moment and translation forces .Specially for rotation moment was discussed in [14]. The translation forces at heading seas 90 degrees and 135 degrees (See Figures 5, 6 and 7). The result are for RAO of Surge many different specially for wave frequency 0.35 rad/sec, for RAO of Sway motion at heading seas 135 degree and heading seas 90 degree, there is significant wave amplitude at frequency 0.35 rad/ sec and for heading 90 degree mostly RAO trend curve is attributed (See Figure 6) and for RAO of heaving heading seas 90 degree was much higher then heading seas 135 degree because of the damping show a tendency increase (See Figure 7). When the wave spectrum is coming to hull construction of FLNG with wave direction are beam seas position as seen on Figure 8 is according to test program has set on Table 2, so that model has motion acculamutive with sloshing. The wave breaking and splashes are typeal phenomena observed in traslation dynamic forces caused to sloshing flow. Figure (9 a,b,c) shows three of snapshots of sloshing flow at 30

% storage tank filling. A typical process of impact at 30 % filling condition is (1) formation of strongly non linier free surface flow, (2) impact on side wall, and (3) wave run-up along wall and splashes generation. It is doubt that splashes provide a significant contribution to impact or global motion. Our experiment observation shows that splashes provide contribution impact occurrence of about P = 5 Kg on Figure 9a.

III. Conclusion

In the present study, the physical and technical issues of sloshing flows in FLNG ship are described. The physical phenomena in violent sloshing flows have been carefully observed in experiments, which was carried out at IHL Surabaya. Based on the present study, the following conclusions are drawn:

1. The coupled motion rotation moment and translation forces problem is well predicted by the linear theory based on the impulsive response function must be continued with mathematical modeling to validated and solve the instrumentation error. Specially for motion induced by sloshing dynamic.
2. There are several physical issues which should be considered in sloshing analysis. These issues include the effects of cushioning due to air pocket, local wave breaking, splashes and pressure to hull construction. .To understand their effects is critical to develop numerical models for sloshing analysis is need to study more detail.
3. The nonlinearity of sloshing flow plays a critical role in the ship motion coupled with sloshing. The sloshing-induced translation force is not linearly proportional to excitation amplitude. Therefore, the ship motion coupled with sloshing does not vary in a linear manner with respect to wave amplitude.

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Figure 1. Model of FLNGL

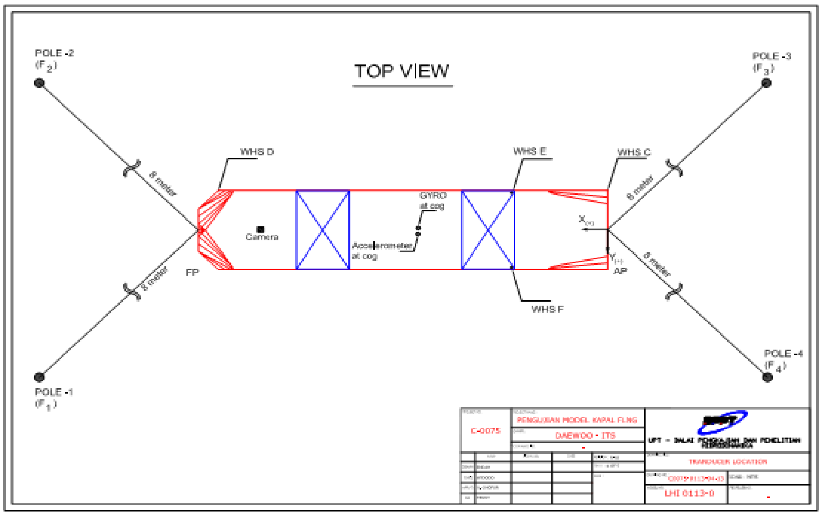

Figure 2. Set up position of model FLNG in model basin

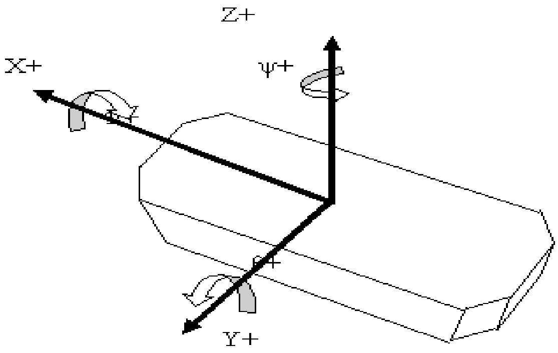

Figure 3. Model-fixed system of axes [14]

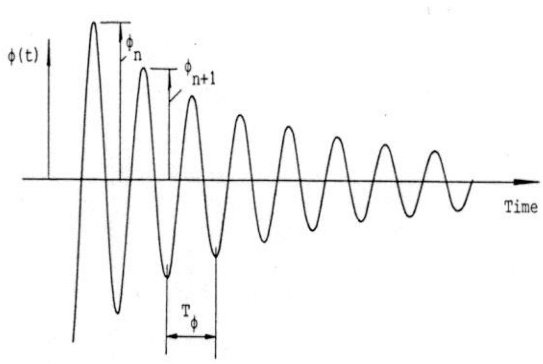

Figure 4. Decay test [15]

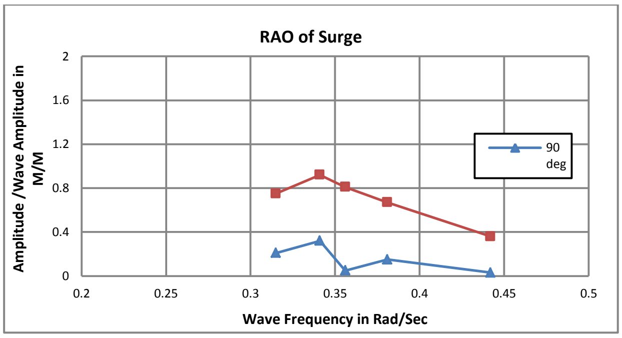

Figure 5. RAO of surge at 90 deg and 135 deg

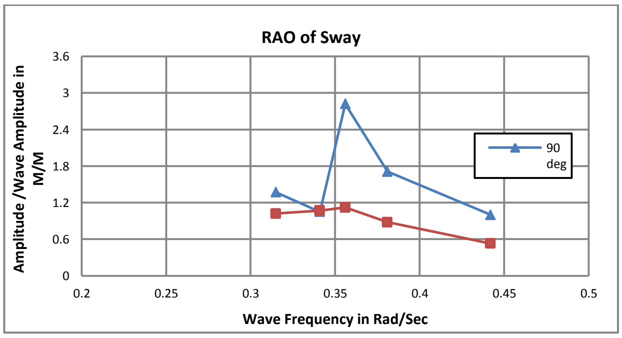

Figure 6. RAO of sway at 90 deg and 135 deg

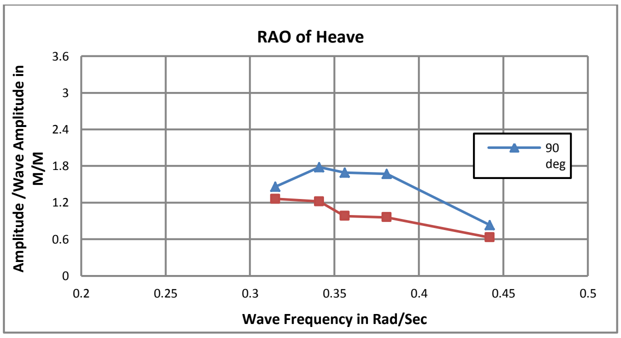

Figure 7. RAO of heave at 90 deg and 135 deg

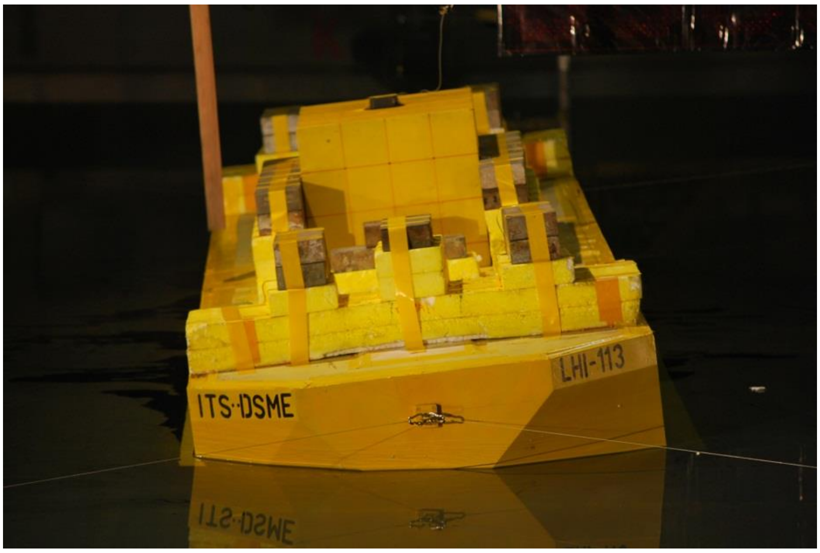

Figure 8. Motion of the model FLNG

(a) (b) (c)

Figure 9. Splashes after side impact occurrence at model 30 % storage filling tank

TABLE 1.
PRINCIPAL PARTICULAR

Description	Symbol	Full Scale		Model of Scale	
Length Overall	LOA	350	m	500	cm
Length Between Perpendiculars	LPP	330	m	442	cm
breadth mid ship section	B	66	m	92,86	cm
Depth	D	27.30	m	39,66	cm
Draft	T	13.200	m	19,71	cm
Displacement	Displ	71.260.600	Kg	77156	Kg
Length Centre of Grafity from AP	LCG	150583	m	215,32	cm
Centre of Gravity from Keel	LCG	21.800	m	31,14	cm
Length Centre of Bouyancy from AP	LCB	180.585	m	215,12	cm
Vertical Centre of Bouyancy	KB	6.999	m	10,00	cm
BM Trans	BMv	26.745	m	36,78	cm
BM Long	BM1	571.173	m	81,596	cm
Roll Radius of Gyration	Kxx	24.850	m	34,36	cm
Pitch Radius of Gyration	Kyy	74.400	m	106,29	cm
Keel to Meta Centric	Km	32.745	m	46,76	cm
Transverse GM	GMt	10.945	m	15,64	cm
Calculation Roll Natural Period	Troll	17.300	m	2,07	cm

TABLE 2.
TESTS WITH REGULAR WAVE

No	Filling of Level (%)	Bilge Keel Type	Heading (deg)	AMPLITUDE (m)	Period (s)	NUM of Ocillation
1	30	Normal	90	2	14.5	15
2	30	Normal	90	2	16.3	15
3	30	Normal	90	2	17.3	15
4	30	Normal	90	2	18.3	15
5	30	Normal	90	2	19.0	15
6	30	Normal	135	2	14.5	15
7	30	Normal	135	2	16.3	15
8	30	Normal	135	2	17.3	15
9	30	Normal	135	2	18.3	15
10	30	Normal	135	2	19.0	15

TABLE 3.
NOTIFICATION

Translation	Rotation

x	: surge in x-direction,		ϕ	:	roll about x-axis,
y	: sway in y-direction,		θ	:	pitch about y-axis,
z	: heave in z-direction		ψ	:	yaw about z-axis

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