Dynamic Stability of Damaged Ship in Random Beam Seas

K. H. Sohn, S. G. Lee and K. S. Choi
Department of Naval Architecture and Ocean Engineering
Korea Maritime University, Pusan 606-791, KOREA

Y. S. KIM
Daeduk R&D Center, Shipbuilding & Plant Research Institute
Samsung Heavy Industries Co., Ltd., Taejeon 305-600, KOREA

ABSTRACT

This paper presents a brief outline of dynamic stability of damaged ship at final stage of flooding in rough, beam wind and waves. First of all, we evaluate the static, residual stability of damaged ship. Then we also evaluate the dynamic stability of damaged ship in terms of capsizing probability based on energy balance in roll and risk analysis, the method of which was firstly proposed by Umeda et al.(1993) to high speed craft in intact condition. The one degree-of-freedom roll equation is adopted with effects of damage fluid and external forces due to wind and waves, but without effect of sloshing. As a result, we can express the dynamic stability of damaged ship in probabilistic manner according to sea state, operating condition and damage situation.

1. INTRODUCTION

Capsizing of damaged ship may happen due to deficiency of pure static, residual stability, but also more frequently due to deficiency of dynamic stability in rough weather. For safety against capsizing of intact ship due to deficiency of dynamic stability in beam seas, Resolution A.562, weather criterion, was recommended by IMO(1985). The criterion was based on energy balance in roll motion with experientially determinded safety factor. So it can hardly be justifiable to apply the criterion directly to damaged ship. Recently Umeda et al.(1993) have pointed out that IMO Resolution A.562 has several problems from the viewpoint of modern naval architecture, then have suggested risk analysis method for assessment of dynamic stability of intact ship in beam seas.

In this paper, we establish dynamic stability assessment of damaged ship at final stage of flooding in rough, beam wind and waves. The degree of dynamic stability of damaged ship is expressed quantitatively in terms of capsizing probability that is calculated on the basis of the theory of ship dynamics with the effect of sea state, operating condition and damage situation. These probabilistic method was firstly applied by Umeda et al.(1993) to high speed crafts in intact condition. Before application of the probabilistic method to the assessment of dynamic stability of damaged ship, we also establish residual static stability of damaged ship on the basis of lost buoyancy method and added weight method(Lewis(1988)). The present study was carried out as a part of rescue technique of damaged ship.

2. METHOD

2.1 Residual static stability

Fig. 1 shows that the ship initially at waterline WL, comes to float at waterline WL_2 because of sinkage and trim due to flooding of one or more of its compartments. According to lost buoyancy method(Lewis(1988)), we can evaluate the equilibrium draft after flooding as follows.

$$\begin{aligned} df &= df_0 + S - (0.5 - LCF_1'/L)\,t \\ da &= da_0 + S + (0.5 + LCF_1'/L)\,t \end{aligned} \tag{1}$$

where L denotes ship length, df and da fore and aft drafts at waterline WL_2, df_0 and da_0 those at waterline WL, S and t parallel sinkage and change in trim due to damage fluid, and LCF_1' the center of flotation of remaining area of impaired waterplane WL_1 from amidships. According to added weight method(Lewis(1988)), we can also evaluate the metacentric height GM_2 at waterline WL_2. Using the numerical calculation method suggested by Hamamoto(1993), we calculate the static righting arm GZ_2 for the metacentric height GM_2 at waterline WL_2.

Then the effective righting arm corresponding to waterline WL, denoted as GZ', can be expressed as follows.

$$GZ' = GZ_2 \times W_2 / W \tag{2}$$

where W denotes displacement before flooding, and W_2 that after flooding, which containing damage fluid.

Fig. 2 shows heeling moment and heel angle due to unsymmetrical flooding. For final stage of flooding, the residual static righting arm GZ will be evaluated as follows.

$$GZ = GZ' - \delta v' (tcg - TCG) \cos\phi / W \tag{3}$$

where δ denotes specific weight of damage fluid, v' net volume of damage fluid below waterline WL, ϕ heel angle, and tcg and TCG transverse center of gravity of v' from amidships and that of net added buoyancy from amidships respectively.

2.2 Sea states

We assume that wind velocity changes with time around average velocity U_T according to wind spectrum suggested by Davenport(1957). Futher it is also assumed that the wind generates long crested irregular waves on sea surface with significant wave height $\overline{H}_{1/3}$ and mean wave period $\overline{T}$ as given in Table 1 for corresponding valves of Beaufort scale. Standard spectrum recommended by ITTC(1978) for fully developed waves, is determinded to be used here.

2.3 Roll equation and response spectrum

The roll motion of damaged ship drifting in beam wind and waves is considered. Firstly the static heel angle, ϕ_s, caused by aerodynamic lateral force, F_A, is obtained by the following equation of equilibrium(cf. Fig. 3).

$$F_A(h_A + h_H) - WGZ(\phi_s) = 0 \tag{4}$$

where h_A and h_H denote the distances from waterline to the center of projected area in air and to that of drifting force in water respectively, and GZ the residual static righting arm of damaged ship. F_A is given as follows

$$F_A = \frac{1}{2} \rho_A A_A C_{DA} U_T^2 \tag{5}$$

where ρ_A denotes air density, A_A projected area of damaged ship in air, C_{DA} aerodynamic drag coefficient. For the roll motion of damaged ship in inclined condition due to static heel angle, refering to papers by Shin(1981), Tasai(1969) and Kat(1996), we adopt one degree-of-freedom roll equation with the effects of damage fluid and external forces, but without sloshing effect as follows.

$$(I_{xx}+J_{xx})\ddot{\phi}_r + B_e\dot{\phi}_r + WGM_s\phi_r = WGM_s\gamma\Theta_w(t) + \tilde{K}_A(t) \tag{6}$$

where $(I_{xx}+J_{xx})$ denotes virtual moment of inertia in roll, B_e equivalent linear damping coefficient, ϕ_r relative roll angle measured from ϕ_s, namely $\phi_r = \phi - \phi_s$, GM_s the slope of residual GZ curve of damaged ship at static heel angle ϕ_s, namely $GM_s = [dGZ/d\phi]_{\phi=\phi_s}$, γ effective wave slope coefficient, $\Theta_w(t)$ instantaneous slope of surface waves, and $\tilde{K}_A(t)$ instantaneous roll moment due to fluctuating wind velocity, denoted as $u(t)$, which is assumed as $|u(t)| \ll U_T$. $\tilde{K}_A(t)$ is given as follows.

$$\tilde{K}_A(t) = \rho_A A_A C_{DA} h_{AG} U_T u(t) \tag{7}$$

where h_{AG} is the distance of center of the wind force from center of gravity of damaged ship. The eq. (6) may be replaced by another form as follows.

$$\ddot{\phi}_r + b_e\dot{\phi}_r + \omega_s^2\phi_r = \omega_s^2\gamma\Theta_w(t) + k_A u(t) \tag{8}$$

where

$$\omega_s^2 = WGM_s / (I_{xx}+J_{xx}) \tag{9}$$

$$k_A = \rho_A A_A C_{DA} h_{AG} U_T / (I_{xx}+J_{xx}) \tag{10}$$

원문누락

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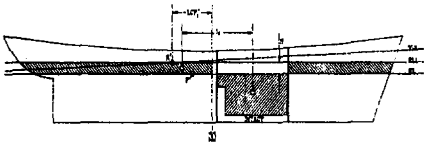

Fig. 1 Sinkage and change in trim caused by lost buoyancy

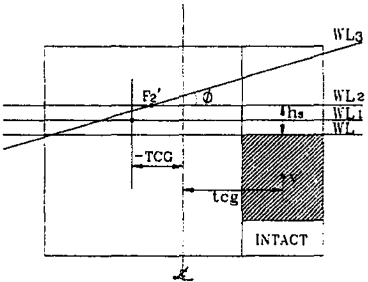

Fig. 2 Unsymmetrical flooding and heel

Table 1 Sea states

Beaufort	U_T (m/sec)	$\overline{H}_{1/3}$ (m)	$\overline{T}$(sec)
1	0.95	0.1	1.2
2	2.50	0.2	1.7
3	4.45	0.6	3.0
4	6.75	1.0	3.9
5	9.40	2.0	5.5
6	12.35	3.0	6.7
7	15.55	4.0	7.7
8	19.00	5.5	9.1
9	22.65	7.0	10.2
10	26.50	9.0	11.6
11	30.60	11.5	13.1
12	34.85	14.0	14.4

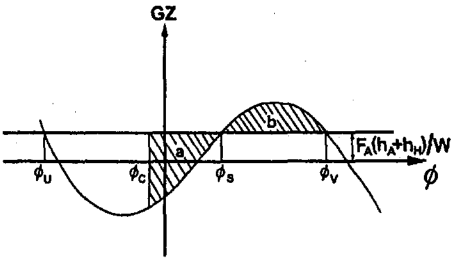

Fig. 3 Energy balance in roll

Table 2 Principal dimensions of ship and model

Items		Ship	Model
Length between perpendiculars	L (m)	167.0	2.385
Breadth	B (m)	22.6	0.323
Depth	D (m)	13.4	0.191
Mean draft(designed)	d (m)	9.0	0.1287
Displacement volume	V (m^3)	26186.0	0.0763
Block coeff.	C_b	0.77	0.770
Prismatic coeff.	C_p	0.778	0.778
Waterplane coeff.	C_w	0.849	0.849
Model scale			1/70

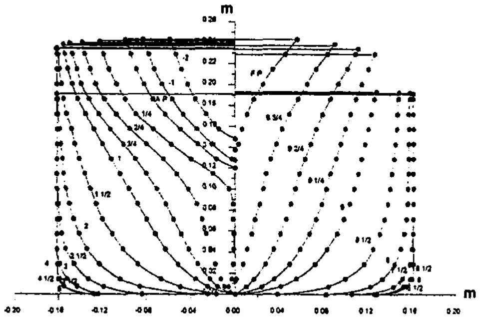

Fig. 4 Body plan (numerical value is expressed in model size)

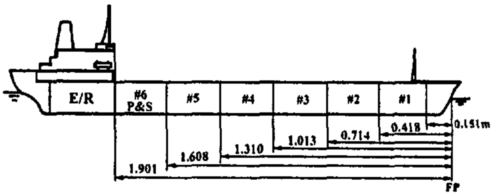

Fig. 5 Profile and tank arrangement (numerical value is expressed in model size)

Table 3 Definition of damage number

Damage No.	Damaged tank
-1	#6 port
1	#6 star.
2	#5
3	#4
4	#3
5	#2
6	#1
7	#6 port & star.
8	#6 port & #5
9	#6 star. & #5
10	#5 & #4
11	#4 & #3
12	#3 & #2
13	#2 & #1

Table 4 Intact condition of full ship

Ballast condition		
Draft fore	df	3.71 *m*
aft	da	4.41 *m*
Metacentric height	GM	3.1, 2.5, 2.0 *m*
Permeability	μ	0.95
	μ_s	0.97
Half load condition		
Draft fore	df	6.0 *m*
aft	da	7.0 *m*
Metacentric height	GM	1.0, 0.7 *m*
Permeability	μ	0.5
	μ_s	0.5

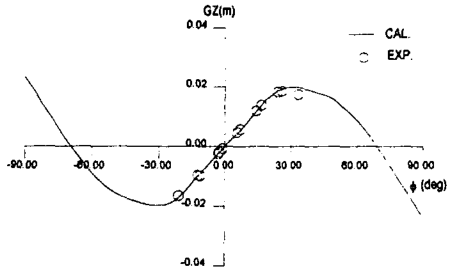

Fig. 6 Righting arm at intact condition(ballast condition, $GM = 3.1\,m$ in full size)

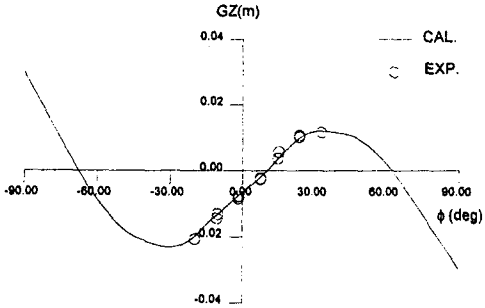

Fig. 7 Residual righting arm for damage No. 1 (ballast condition, initial $GM = 3.1\,m$ in full size)

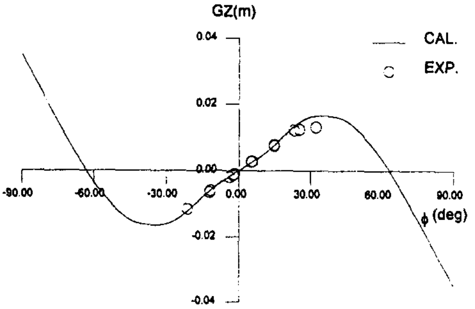

Fig. 8 Residual righting arm for damage No. 2 (ballast condition, initial $GM = 3.1\,m$ in full size)

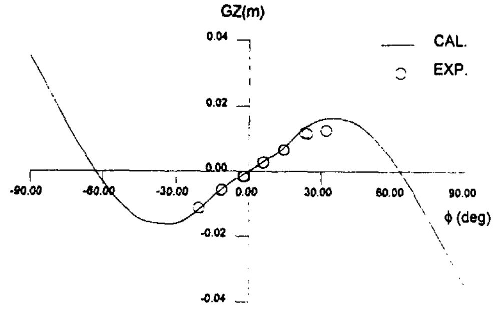

Fig. 9 Residual righting arm for damage No. 4 (ballast condition, initial $GM = 3.1\,m$ in full size)

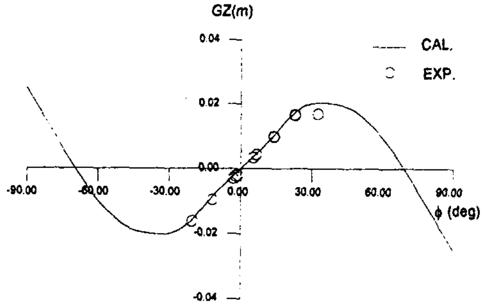

Fig. 10 Residual righting arm for damage No. 6 (ballast condition, initial $GM = 3.1\,m$ in full size)

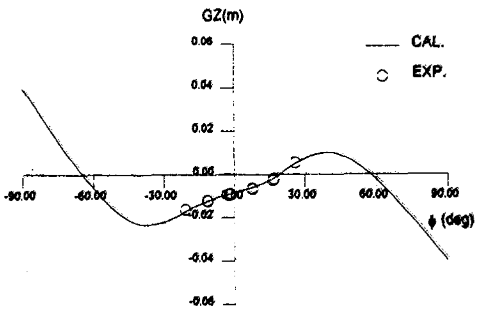

Fig. 11 Residual righting arm for damage No. 9 (ballast condition, initial $GM = 3.1\,m$ in full size)

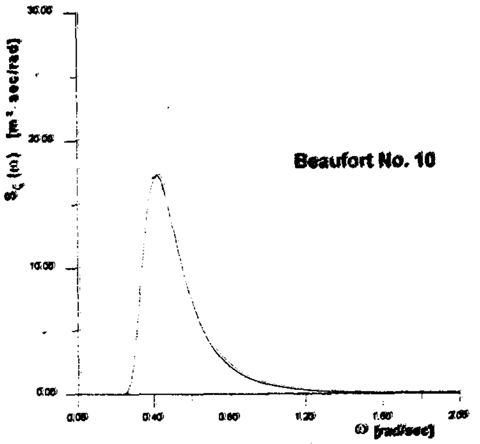

Fig. 12 ITTC(1978) wave spectrum

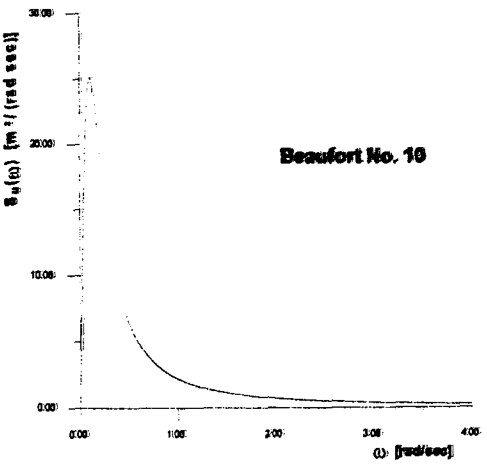

Fig. 13 Davenport wind spectrum

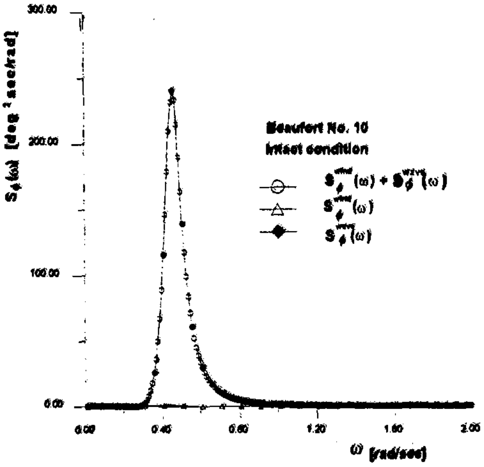

Fig. 14 Roll response spectrum(ballast condition, initial $GM = 2.0\,m$)

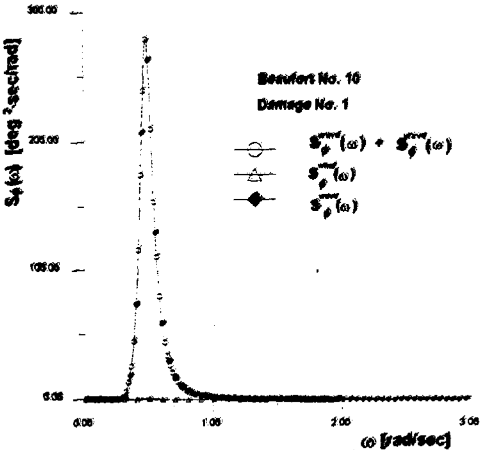

Fig. 15 Roll response spectrum(ballast condition, initial $GM = 2.0\,m$)

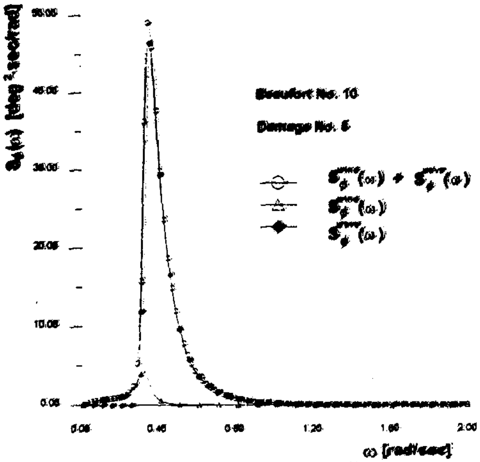

Fig. 16 Roll response spectrum(ballast condition, initial $GM = 2.0\,m$)

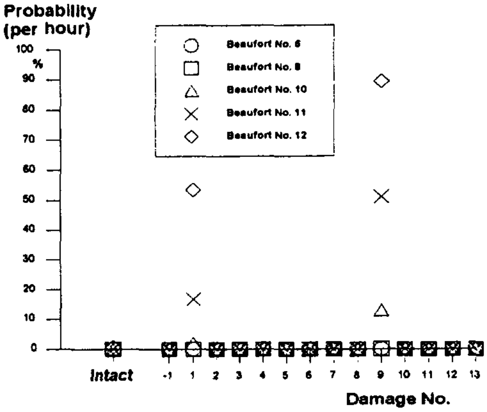

Fig. 17 Capsizing probability per hour(ballast condition, initial $GM = 3.1\,m$)

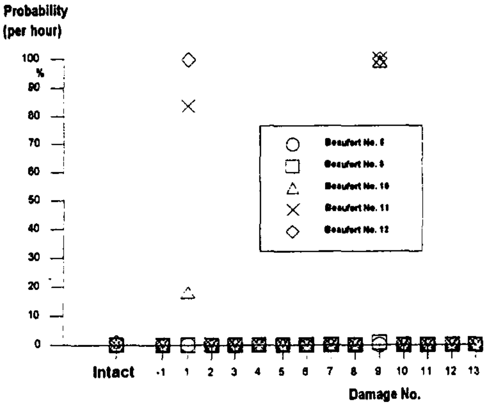

Fig. 18 Capsizing probability per hour(ballast condition, initial $GM = 2.5\,m$)

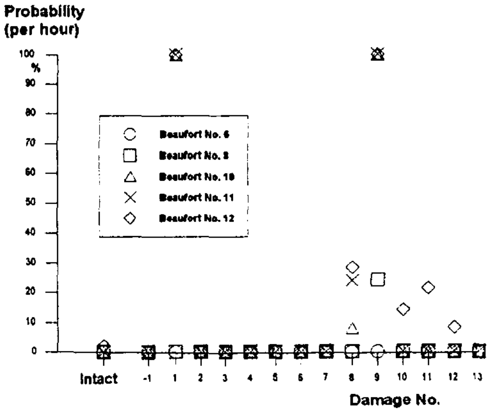

Fig. 19 Capsizing probability per hour(ballast condition, initial $GM = 2.0\,m$)

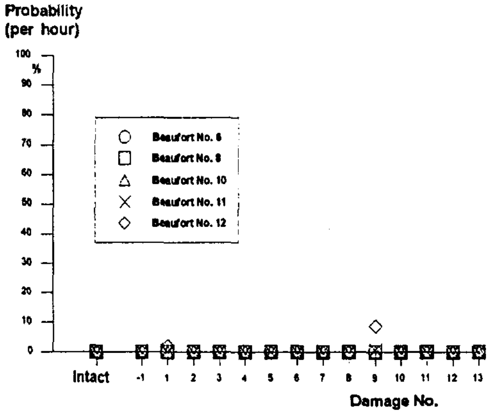

Fig. 20 Capsizing probability per hour(half load condition, initial $GM = 1.0\,m$)

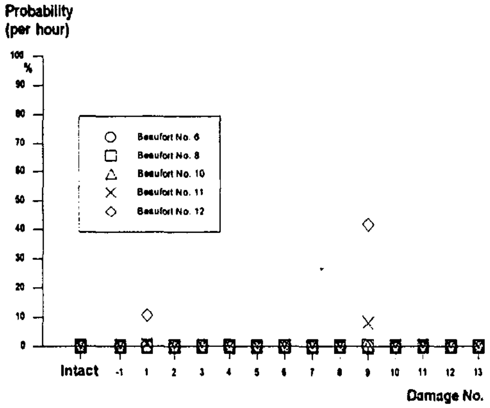

Fig. 21 Capsizing probability per hour(half load condition, initial $GM = 0.7\,m$)