I-174

DYNAMIC BEHAVIOUR OF THE SHIP AND THE BERTHING STRUCTURE AFTER IMPACT.

SADAO KOMATSU & ABDEL HAMID SALMAN.
Osaka University, Members of JSCE.

INTRODUCTION.

As size of ships, particulary tankers, increases inthe recent years, the design of off-shore berthing structures has become ever important. In design of the berthing structure, the engineers face the problem of evaluation of the part of kinetic energy of the berthing ship, that the marine structure should absorb during berthing, which is quite difficult to be determined theoretically. Imperical formula is being used for design purposes. This paper describes a method of analysis for determining the part of energy to be absorbed by each of the structure and fender, and the part dissipated in swinging and rolling of the ship after impact. The combined dynamic response of the system is considered. In the analysis, this affords a considerable help to design the economic structure and the suitable fender to meet any given mode of berthing.

KINETIC ENERGY OF THE BERTHING SHIP:

The general formula for determining the kinetic energy ofthe berthing ship is :

$$E_o = \tfrac{1}{2}M \cdot V_o^2 + \tfrac{1}{2}I \cdot \omega^2 \qquad (a)$$

In practice the angular rotation of the ship 'ω' is small compared to its velocity of translation 'V_o', and may be neglected, thus equation (a) becomes:

$$E_o = \tfrac{1}{2}M \cdot V_o^2$$

where M is the virtual mass.

The velocity 'V' depends on many factors, such as; ship size, currents, winds and mode of the berthing operation. The virtual mass 'M' is a function of the ship hull shape, the velocity magnitude and direction and the water depth uner the ship.

During berthing the kinetic energy of the ship may be dissipated in sevral ways among which, are the followings ;

i- Elastic deformation of the structure and fender.

ii- Swinging and heeling of the ship.

iii- Elastic deformatin of the ship hull.

iv- Piling of the water enclosed between the hull and the structure(this may occur in the case of closed structures)

Marine structure designers are interested in the part of energy that transmitted to the structure and the fender. Most designers use an imperical formula for determining this effective energy, in the following form;

$$E_{effective} = C \cdot Eo$$

where C denotes the energy dispersion factor. Its value varies on a wide range(o.2-1.0) depending on various factors such as the berthing mode, the fender system stiffness... etc.

The problem of determining the effective energy has been treated analatically by some invistigators. Michalos has treated the problem as a single-degree-of-freedom dynamic motion,i.e. the sway motion of the ship was only considered. Vasco Costa has derived a dynamic equation, for estimating the effective energy, based on the sway and yawing motion of the ship. The influence of the fender system stiffness was disregarded in the given equation. Hayashi and Shirai have dealt with the problem as a three-degree-of-freedom dynamic motion; sway, yawing and rolling motion were included. Fenders with linear spring constants were only considered, besides the relative stiffness of the structure and fender was overlooked.

In the view of the aforementioned informations, the Authors present a method to analyise the dynamic response of the ship and the fender system comprises;

- The sway, yawing, and rolling motion of the ship.
- Fenders of either linear or non-linear spring constants.

MOTION EQUATIONS :

After impact fig.(I), the center gravity of ship and the point of contact move to 'G1' and 'X21' respectively due to sway motion of the ship. Then 'G1' moves to 'G2' due to yawing and finally to 'G3' due to rolling. Motion of 'X2' due to rolling is neglegted. At any time 't' the following dynamic equations hold :

N.B. For notations see the solved example.

i - Ship

Sway motion $\ddot{X}_G = - P\,(t) \,/\, M2$

Yawing motion $\ddot{\theta} = P\,(t) \cdot R \cdot \cos\,(\,\theta 2 - \theta\,) \,/\, I_{2-2}$

Rolling motion $\ddot{\phi} = (\,P\,(t) \cdot H - W \cdot H1 \cdot \phi\,) \,/\, I_{1-1}$

ii - Fender

$$\ddot{X}2 = (- R \cdot \ddot{\theta} - H1 \cdot \ddot{\phi} - P\,(t)\,) \,/\, M2$$

iii-Structure

$$\ddot{X}1 = (\,P(t) - K1 \cdot X1\,) \,/\, M1$$

where $P(t) = F2\,(\,X2 - X1\,)$

F_2 denotes the spring constant which is function of (X2 - X1).

(X2 - X1) represent the contraction of fender.

If the information about the spring constant of the ship hull at point of contact is available, then the elastic deformation of the ship hull due impact can be evaluated. Let the hull deformation is denoted by 'X3' and the spring constant by 'K3', then the equation of motion holds will be :

$$\ddot{X}3 = (p(t) - K3 \cdot X3) / M2$$

where $$P(t) = F_2 (X2 - X1 + X3)$$

However the part of energy dissipated in elastic deformation of ship hull is about 10 % ,which can be left for safety.

Besides, from the practical point , the designers are interestedin the frist peak point of response of the vibrated sytem, At this point the damping effect is not so great that can be neglegted and this will be on the safe side.

ENERGY EQUATIONS :

At any time 't' the energy equations hold are :

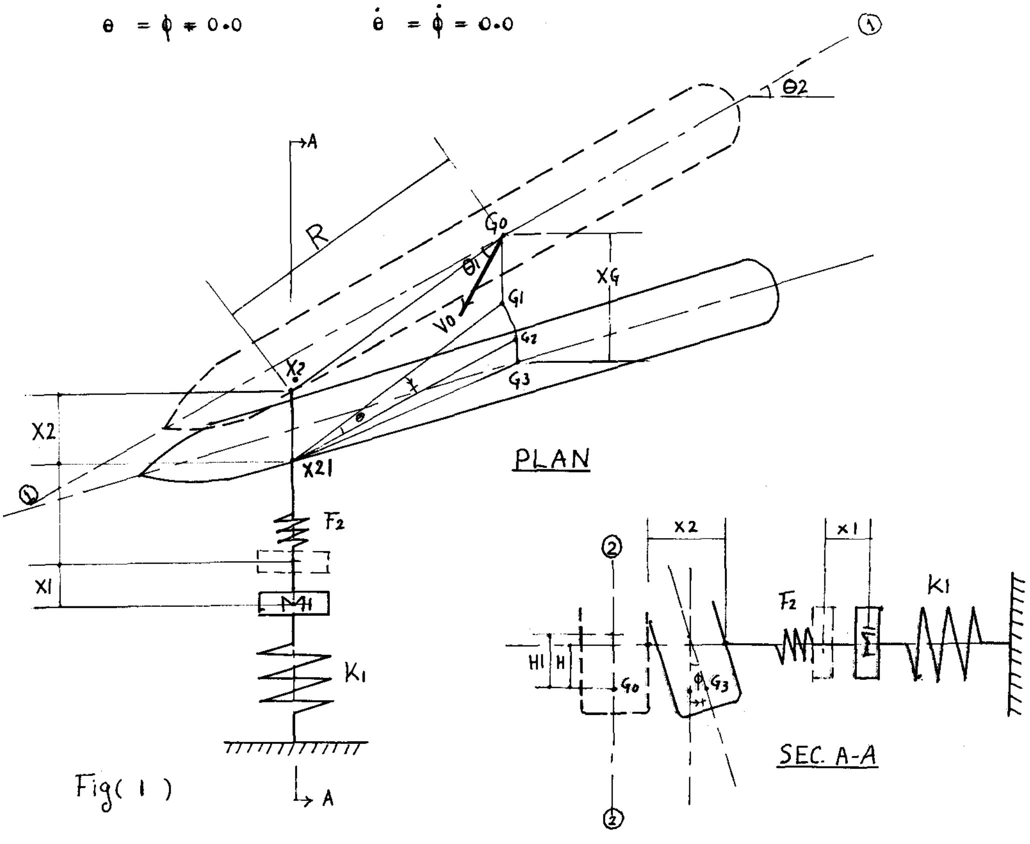
Energy stored by structure	$= \int_0^t P(t)\, dX1$
" " " Fender	$= \int_0^t P(t)\, d(X2 - X1)$
" " " ship hull	$= \int_0^t P(t)\, dX3$
Energy dissipated in swinging	$= \int_0^t R \cdot P(t)\, d\theta$
" " " rolling	$= \int_0^t H \cdot P(t)\, d\theta$

The initial condtions of motion are :

$X1 = 0.0$ $\qquad \dot{X}1 = 0.0$

$X2 = 0.0$ $\qquad \dot{X}2 = Vo \cdot \sin(\theta 1 + \theta 2)$

$\theta = \phi = 0.0$ $\qquad \dot{\theta} = \dot{\phi} = 0.0$



Fig(1)

APPLICATION.

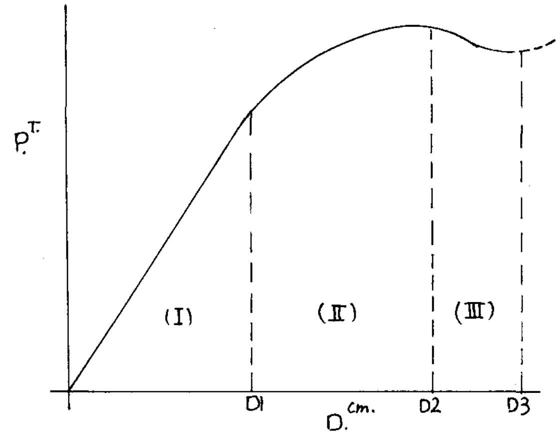
A ship of 58,000 tons displacement weight, approaching a berthing structre provided with a fender, with velocity of approach equals to 10.0 cm./sec. The part of the kinetic energy of the ship that is transmitted to each of the fender and structure and that part dissipated in swinging and rolling of the ship, is to be invistigated in the different cases of berthing stated in table (1).

M_2	= virtual mass of ship	=	130.0 ton.sec^2/cm.
I_{1-1}	= mass inertia about longtidunal axis through G	=	6.78×10^7 ton.sec^2.cm
I_{2-2}	= " " " vertical " " G	=	6.37×10^9 " " "
H_1	= vertical distance between G and metacenter	=	360 cm.
M_1	= berthing structure effective mass (given)	=	0.5 ton.sec^2/cm.

Rubber fender having load-deflection relationship as given by sketch are to be used.

TABLE(1)

BERTHING DATA						STORED E.		DISSIPATED E.	
K1 T/cm	F2 T/cm	H cm	R cm	θ1	θ2	STRUCT. T.Cm.	FEND. T.Cm.	YAWING T.Cm.	ROLLING T.Cm.
100	25.5	600	6000	75°	15°	580	3668	1328	1110
100	34.0	"	"	"	"	820	2268	1007	873
100	42.5	"	"	"	"	1055	2134	1012	895
400	25.5	"	"	"	"	246	4078	1452	1226
400	34.0	"	"	"	"	290	2670	953	844
400	42.5	"	"	"	"	374	2688	985	889
800	25.5	"	"	"	"	968	4286	1290	1096
800	34.0	"	"	"	"	565	2656	969	853
800	42.5	"	"	"	"	569	2913	985	891
400	25.5	606	6000	45°	15°	196	2181	798	682
400	34.0	"	"	"	"	222	1997	730	648
400	42.5	"	"	"	"	362	2005	744	672
200 Const.	40 Elast.	" spring	" stiff.	"	"	450	2010	816	729



Load-Deflection Relation.

$D_1=10^{cm.}$ $D_2=20^{cm}$ $D_3=25^{cm.}$

$$P(\mathrm{I})=F_2.D \qquad 0.0< D\leqslant D_1$$

$$P(\mathrm{II})=F_2.D_1\left[-2.62\left(\frac{D}{D_1}\right)^{1.36}+4.30\left(\frac{D}{D_1}\right)-0.68\right] \qquad D_1\leqslant D\leqslant D_2$$

$$P(\mathrm{III})=F_2.D_1\left[0.313\left(\frac{D}{D_1}\right)^{2.5}-0.93\left(\frac{D}{D_1}\right)^{2}+1.52\left(\frac{D}{D_1}\right)+0.27\right] \qquad D_2\leqslant D\leqslant D_3$$

CONCLUSION

From table (1) the following conclusions can be drawn :

1- In all cases, the part of energy dissipated in rolling is less than that dissipated in swinging.

2- For the same structure stiffness, the energy dispersioniin swinging and rolling decreases as the fender stiffness increases.

3- For different structure stiffness, provided with the same fender, and the same ship approx, part of energy dissipated in swinging & rolling is almost constant.

4- As the fender-structure stiffness ratio increases, the energy absorbed by structure increases.