THE INVESTIGATION OF THE SAFE BASIN EROSION UNDER THE ACTION OF RANDOM WAVES

Xianglu Huang, Shanghai Jiao Tong University
Shanghai (China)

Abstract

The safe basin eroded by a random wave train was investigated numerically. The stability criteria of a hetro or homo-clinic orbit , the Melnikov function criteria was discussed intuitively. Some conclusions were drawn. The suggestions of the application of the safe basin erosion in random waves in the determination of the probability distribution function of capsize were given.

1. INTRODUCTION

The concept of safe basin is very useful in dealing with the ship capsize in waves. Several papers have been published on this topic in recent years. But most of them are dealing with the ship on regular waves. Some papers [1][2] considering the random waves were published, but by no means the problem is full understood at present. This is a difficult problem and is not easy to solve.

If we look at the figures 2 in [6] of a series of the temporary Probability Distribution Function of the phase trace of a ship rolling motion on a given random wave , it shows that there are no specific appearance appear around the position of hetro- or homo-clinic orbit, which should be the boundary of safe basin (before eroded). But according to the definition of those boundaries, it should have some effect on the Probability Distribution Function. The reason of such inconsistency may be explained as follow. The temporary PDF is not able to reflect the result of the future. In other words, although the phase trace of the system will go to another attractor, we are not able to see such consequence in the temporary PDF. So, in order to evaluate the probability of capsize, the threshold of capsize should be found. The threshold is related to the external excitation. Several discussions about the stability of the hetro- homo clinic orbit under the action of external excitation have been published and they showed that the excitation together with the damping will have effect on the stability of boundary. The stability of the orbit can be judged by the value of so called Melnikov function. This function from physical point of view is the sum of the work external excitation force has done on the orbit and the energy exhausted by the damping. The orbit will stay in stable status if the work done by the excitation is less than the exhaust energy the damping has absorbed. The exhaust energy ordinarily is represented by the angle of extinction of the ship rolling in still water.

For the determination of ship capsize, it is very important to determine the boundary of stability in phase plan, out of such boundary ship capsize will happen. It is appropriate to consider that this boundary is closely related to the safe basin. The more the basin eroded the more the ship capsize likely to happen. This has been investigated in several papers for ship in regular waves. But, for ship on a random wave train, there are several peculiar things .We will show it latter.

2.THEORETICAL CONSIDERATION

We consider the relationship of the energy and work in an oscillation of ship. There are two kinds of mechanical energy: kinetic and potential. These are related to the Hamilton system of the problem. Also there are two kinds of the works which were done by an external excitation force and damping. From the relation of energy and work, the increment of oscillation amplitude due to the work an external excitation has done on the oscillation orbit can be determined by the following calculation. We assume in the calculation that the frequency of the excitation is the same as the natural frequency of the ship rolling.

At first we consider the oscillation of the Hamilton system The solution of such system is the free un-damped oscillation of ship roll. This solution always expressed by the orbit in a phase plan, which is constituted of the axis displacement and velocity. In the phase plane, the coordinates of hetro-clinic orbit will be

$$\theta_{\pm}^{0}(t) = \pm \mathrm{th}\left(\frac{\sqrt{2}}{2} t\right)$$

$$\varphi_{\pm}^{0}(t) = \pm\frac{\sqrt{2}}{2}\sec h^{2}\left(\frac{\sqrt{2}}{2} t\right)$$

in which $\theta_{\pm}^{0}(t)$ is the oscillation displacement, while $\varphi_{\pm}^{0}(t)$ is the rolling velocity. The natural frequency of the Hamilton system is a function of the parameter k of the Jacobian elliptic function depends on the oscillation amplitude. Actually, the free oscillation of the un-damped ship is dependent on the amplitude or its initial conditions, which is characterized by the level of mechanical energy

$$H(\theta,\varphi) = \frac{1}{2}\varphi^{2} + \frac{1}{2}\theta^{2} - \frac{1}{4}\theta^{4} = h$$

If $h = h(k)$ $0 < k < 1$ then the phase orbit determined by the parameter k is

$$\theta_{k} = \frac{\sqrt{2}k}{\sqrt{1+k^{2}}} sn\left(\frac{t}{\sqrt{1+k^{2}}}, k\right)$$

$$\varphi_{k} = \frac{\sqrt{2}k}{1+k^{2}} cn\left(\frac{t}{\sqrt{1+k}}, k\right) dn\left(\frac{t}{\sqrt{1+k^{2}}}, k\right)$$

In which $sn(u), cn(u), dn(u)$ are Jacobian elliptic functions with mode k, $0 < k < 1$, $h(k) = k^{2}/(1+k^{2})^{2}$. The period of oscillation corresponds to the orbit is $T_{k} = 4\sqrt{1+k^{2}}K(k)$, $K(k)$ is the complete elliptic integral of first kind

For the hetro-clinic orbit, the work external forces acted on the orbit or the Melnikov function is[3]

$$M_{\pm}(\delta, k_{d}, f) = \int_{-\infty}^{\infty}[-k_{d}\varphi_{\pm}^{0}(t) + f\cos\omega(t+\delta)]\varphi_{\pm}^{0}(t)dt$$

$$= -k_{d}I_{1} \pm fI_{2}\cos\omega\delta$$

Provided the excitation has the form

$$F = f\cos\omega(t+\delta)$$

in which $\omega\delta$ is the phase angle of oscillation.

$$I_{1} = \frac{2\sqrt{2}}{3}, \quad I_{2} = \sqrt{2}\pi\omega\csc h\left(\frac{\sqrt{2}}{2}\pi\omega\right)$$

If the oscillation is on an orbit which has a period differ from the period of hetro-clinic orbit. We can calculate the work external excitation has done on such sub-harmonic oscillation as follows.

For any given energy level h or orbit amplitude, exists uniquely k satisfy

$$T_{k} = 4\sqrt{1+k}K(k) = \frac{2\pi}{\omega}.$$

The Melnikov function defined on such orbit is

$$M(\delta,k_d,f)=\int_0^T[-k_d\varphi_k(t)+f\cos\omega(t+\delta)]\varphi_k(t)dt$$

$$=-k_dJ_1(\omega,k)+fJ_2(\omega,k)\cos\omega\delta$$

In which:

$$J_1(\omega,k)=\frac{8}{3(1+k^2)^{3/2}}[(k^2-1)K(k)+(1+k^2)E(k)]$$

$$J_2(\omega,k)=2\sqrt{2}\pi\omega\csc h\frac{\pi K'(k)}{2K(k)}$$

$K'(k)=K(k')=K(\sqrt{1-k^2})$, $E(k)$ are the complete elliptic integral of second kind.

It is clearly if the energy of external excitation force is excess than the damping energy, the oscillation amplitude will increase. That is

$$fJ_2(\omega,k)>k_dJ_1(\omega,k)$$

$$f\cdot 2\sqrt{2}\pi\omega\csc h\frac{\pi K'(k)}{2K(k)}>k_d\frac{8}{3(1+k^2)^{3/2}}[(k^2-1)$$

$$K(k)+(1+k^2)E(k)]$$

or the excess energy will be

$$\Delta E=f\cdot 2\sqrt{2}\pi\omega\csc h\frac{\pi K'(k)}{2K(k)}-k_d\frac{8}{3(1+k^2)^{3/2}}[(k^2-1)$$

$$K(k)+(1+k^2)E(k)]$$

In the above derivation, the equation has been normalized with respected to it parameters. So all of the quantities should be multiple a factor related to the real equation. The time scale is $\sqrt{M/C}$, in which M is the inertial coefficient while C is the linear restoring coefficient. The amplitude has the factor as $\sqrt{C_3}$, C_3 is the coefficient of the third order restoring term.

If in resonance condition, the oscillation became stationary, then the excess energy should be zero. When the oscillation reaches an orbit, the work done by the external excitation on such orbit is larger than the energy exhausted by the damping the orbit may become instability. For the hetro-clinic orbit, it corresponds to the condition of capsize. But if the parameter $k<1$. the orbit is corresponding to the orbits inside the hetro-clininc orbit. In these cases the amplitude of oscillation at first will increase due to the work excess to the energy exhausted by the damping. Then it reaches an stable orbit. The capsize will happen if the amplitude continue to increase and became larger than the stability vanishing angle. The energy excess to the balance condition can be considered as an angle or amplitude, which has the same potential energy. Such angle actually is the position at which the instability will happen. In this way we are able to find the boundary of the instability due to the action of external forces, or in other words safe basin erosion. The amplitude of the oscillation represents the potential energy of the motion, which is related to the energy by the restoring curves. In our case the energy of which is

$$E(\theta)=C(\theta-C_3\theta^3)$$

$$E(\theta)=\int_0^{\theta_1}C(\theta-C_3\theta^3)d\theta=\frac{C}{2}\theta_1^2-\frac{CC_3}{4}\theta_1^4$$

If the amplitude increase to some angle $\theta_m+\Delta\theta_m$,then the potential energy increment in our normalized equation(in which C and C_3 will be unit) is

$$E(\theta+\Delta\theta)=\frac{1}{2}(\theta_1+\Delta\theta_1)^2-\frac{1}{4}(\theta_1+\Delta\theta_1)^4$$

The amplitude increase due to the excess energy can be determined by the following relation [4]

$$\Delta E=f\cdot 2\sqrt{2}\pi\omega\mathrm{csch}\frac{\pi K'(k)}{2K(k)}-k_d\frac{8}{3(1+k^2)^{3/2}}[(k^2-1)K(k)$$

$$+(1+k^2)E(k)]$$

$$=\frac{1}{2}(\theta_1+\Delta\theta_1)^2-\frac{1}{4}(\theta_1+\Delta\theta_1)^4-\frac{1}{2}\theta_1^2+\frac{1}{4}\theta_1^4$$

$$=\left[\theta_1\Delta\theta_1+\frac{1}{2}\Delta\theta_1^2-\frac{1}{4}(4\theta_1^3\Delta\theta+6\theta_1^2\Delta\theta_1^2+4\theta_1\Delta\theta_1^3+\Delta\theta_1^4)\right]$$

$$=\left[\theta_1\Delta\theta_1+\frac{}{2}\Delta\theta_1^2-\ \theta_1^3\Delta\theta-\frac{6}{4}\theta_1^2\Delta\theta_1^2-\ \theta_1\Delta\theta_1^3-\frac{1}{4}\Delta\theta_1^4\right]$$

$$=\left[\theta_1(1-\theta_1^2)\Delta\theta+\frac{1}{2}(1-3\theta_1^2)\Delta\theta_1^2-\theta_1\Delta\theta_1^3-\frac{1}{4}\Delta\theta_1^4\right]$$

The angle $\Delta\theta$ can be determined by solving the above equation. Ordinarily, this equation is not easy to be solved. But we can solve it numerically.

3.THE SAFE BASIN EROSION

By using the method mentioned in the previous section, we can determine the boundary inside the orbit at which the capsize will happen. But it is only available for the resonance cases. That is to those excitations, their frequency is approaches to the natural frequency for the corresponding orbit. As an example, we calculate the excess angle of a ship with following parameters under the given initial condition and excitations. The parameters and results are listed in the table.

Table 1: Parameters of the ship

Inertial coeffi.	D	N	C	C3
990ton	480KN	40	1m	-0.7

The amplitude of which the capsize will happen at given external excitation was calculated by the above method. In the calculation only resonance condition that is the frequency of external excitation is the same as the natural frequency of the system were considered. Of course such natural frequency depends on the amplitude of oscillation.

Table 2 : Estimated amplitude at which the instability may happen

$\alpha = 0.1$	$\alpha = 0.2$	$\alpha = 0.3$
$\theta_m = 1.076$	$\theta_m = 0.956$	$\theta_m = 0.598$
$T = 17.2642$sec	$T = 14.3173$sec	$T = 10.2468$

To show the erosion of safe basin intuitively some of the pictures of safe basin were given below.

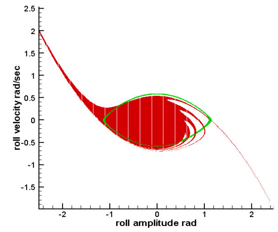

Fig 1 $T = 9.024\,\text{sec}$ $\delta = .05$ $\alpha = .3$

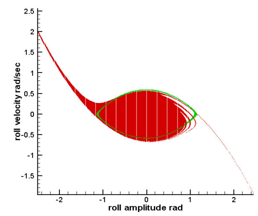

Fig 2 $T = 10\,\text{sec}$ $\delta = .05$ $\alpha = .2$

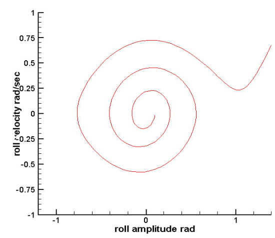

Fig3. The phase trajectory of a capsizing oscillation

The values listed in the table are obtained under the resonance condition. So it can not be used as a judgement for the safe basin erosion. But, it can give us some illuminations. At least, it shows the basic trend is the same as we can see in the examples of safe basin erosion. It is interesting to look at a sample trajectory of roll oscillation Fig3, which lead to capsize. The trajectory goes out like a spiral with expanding amplitude.

In order to quantify the safe basin erosion, the area of the eroded basin was calculated according to the number of grids at which the capsize was not happen. The total grids number in the calculation is 400*400. The increment of displacement is .01 rad while the increment of velocity is .005 rad/sec. The percentage of safe basin erosion was defined as

$$PS = \frac{N_{notcapsize}}{160000}$$

The value of PS for a series of regular waves with different frequency and wave slopes are listed in following tables

From the calculated PS value of safe basin, it can be seen that the variation of the safe basin has an uniform manner with respect to both the level (wave slope) and frequency of external excitation. In general it will decrease with the increase of level, and the calculation are reproductive.

As to the influence of frequency on the erosion of safe basin, it shows that the rate of reducing PS is increasing with the increasing of period. This is not difficult to be explained by the theory because the natural frequency is lower in large amplitude oscillation. Low frequency excitation will lead to the resonance of roll in large amplitude cases.

α	T=8.2sec	T=9.024sec	T=10sec	T=12sec
0.1	7.300156E-02	7.274532E-02	7.246406E-02	7.217344E-02
0.2	7.066093E-02	6.910625E-02	6.543594E-02	3.187656E-02
0.3	6.541719E-02	5.922500E-02	3.227187E-02	5.659375E-03
0.4	5.735938E-02	4.063594E-02	1.670937E-02	4.796875E-04
0.5	4.763125E-02	2.451250E-02	9.968750E-03	1.234375E-04
0.6	3.706563E-02	1.387187E-02	4.707812E-03	0.000000E-01
0.7	2.547031E-02	1.366875E-02	4.468750E-04	0.000000E-01
0.8	1.995938E-02	5.085938E-03	7.640625E-04	0.000000E-01

Table 3. The PS value of different wave period and wave slope angle

Spectra type: P.M.Spectra		
T=9.024sec	T=10.0sec	T=12.0sec
H=1.0PS= 7.359375E-02	H=1.0PS= 7.359062E-02	H=1.0m PS= 7.361406E-02
H=2.0PS= 7.329062E-02	H=4.0 PS= 7.351719E-02	H=3.0m PS= 7.337032E-02
H=3.0PS= 7.353906E-02	H=5.0 PS= 7.342344E-02	H=4.0m PS= 7.322500E-02
H=4.0PS= 7.350000E-02	H=6.0 PS= 5.275312E-02	H=5.0m PS= 7.308906E-02
H=5.0PS= 7.115938E-02	H=6.1 PS= 4.521250E-02	H=6.0m PS= 7.287187E-02
H=5.1PS= 7.347031E-02	H=6.2 PS= 7.074219E-02	H=7.0m PS= 7.262500E-02
H=5.2PS= 6.971406E-02	H=6.3 PS= 0.000000E+00	H=8.0m PS= 7.349063E-02
H=5.3PS= 6.137813E-02	H=7.0 PS= 0.000000E+00	H=8.5m PS= 7.354531E-02
H=5.4PS= 7.361250E-02	H=9.0 PS= 7.359219E-02	H=9.0m PS= 7.291719E-02
H=5.5PS= 5.062187E-02		H=9.5m PS= 7.085782E-02
		H=9.6m PS= 5.952812E-02

Table 4

4.THE SAFE BASIN EROSION UNDER RANDOM WAVES

In order to investigate the behavior of safe basin under the random waves, we calculate the save basin under irregular wave train. For this purpose, the random wave train has to be generated at first. We generate the random wave train by using the model of Longuet-Higgins. The model is well known

$$\varsigma(t) = \sum_{i=1}^{N} a_i \sin(\omega_i t + \delta_i)$$

in which: $\varsigma(t)$ -- generated wave time history,
a_i -- amplitude of i th component
ω_i --frequency of i th component
δ_i --the random phase angle.

The random phase angle attributed to the i th wave component. The PDF of such random phase is uniformly distributed in the range $(-\pi,\pi)$ with the PDF $\frac{1}{2\pi}$. The inclusion of such random terms, make this wave model random. Ordinary the amplitude of the component waves were determined by some predetermined wave spectra. That is

$$\frac{1}{2} a_i^2 = S(\omega_i) d\omega_i$$

or

$$a_i = \sqrt{2S(\omega_i) d\omega_i}$$

Two kinds of the wave spectra were used in the calculation . One is the ordinary PM type spectra. The form of such spectra is

$$S(\omega) = \frac{A}{\omega^5} e^{-\frac{B}{\omega^2}}$$

It should be noticed that the wave train generated will have a maximum length which is inversely proportion to the step length of frequency used in the wave generation . Out of such length the wave train will re-appear. In our case, the frequency resolution is .002 rad/sec and the length of the wave train generated is 3600sec.

Another series of the wave spectra are designed to fulfil the requirement of the investigation of the influence of the band width of the spectra on the safe basin erosion . The spectra are designed to have a uniform spectra density in a given frequency range. The frequency range of the spectra has a value as 2 or 3.rad., and the mid-point of the frequency of the spectra were given accordingly as a parameter to specify the spectra.

Spectra type: P.M.Spectra		
T=9.024sec	T=10.0sec	T=12.0sec
H=1.0PS= 7.359375E-02 H=2.0PS= 7.329062E-02 H=3.0PS= 7.353906E-02 H=4.0PS= 7.350000E-02 H=5.0PS= 7.115938E-02 H=5.1PS= 7.347031E-02 H=5.2PS= 6.971406E-02 H=5.3PS= 6.137813E-02 H=5.4PS= 7.361250E-02 H=5.5PS= 5.062187E-02	H=1.0PS= 7.359062E-02 H=4.0 PS= 7.351719E-02 H=5.0 PS= 7.342344E-02 H=6.0 PS= 5.275312E-02 H=6.1 PS= 4.521250E-02 H=6.2 PS= 7.074219E-02 H=6.3 PS= 0.000000E+00 H=7.0 PS= 0.000000E+00 H=9.0 PS= 7.359219E-02	H=1.0m PS= 7.361406E-02 H=3.0m PS= 7.337032E-02 H=4.0m PS= 7.322500E-02 H=5.0m PS= 7.308906E-02 H=6.0m PS= 7.287187E-02 H=7.0m PS= 7.262500E-02 H=8.0m PS= 7.349063E-02 H=8.5m PS= 7.354531E-02 H=9.0m PS= 7.291719E-02 H=9.5m PS= 7.085782E-02 H=9.6m PS= 5.952812E-02

Table 4

In order to investigate the ship capsize in a random beam waves, we calculated the safe basin of the ship under the action of a given random beam waves which is generated by using the above model with a given spectra. The PS values obtained in the calculation of correspond waves are listed in the following tables. It should be noted here that all the values of the PS obtained in random wave cases are random variables, because it depends on the random phase used in the generation of random wave train. In following tables, the PS listed must be considered as a sample of the random outcome. So it only gives us a prediction of the results

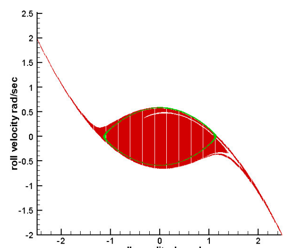

Fig 4. P.M spectra T=9.024 sec H=5.3m

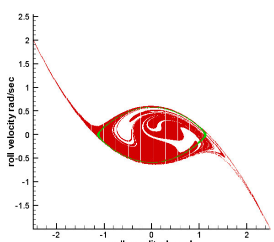

Fig 5 P.M.Spectra T=9.024sec H=5.5m (0.27rad)

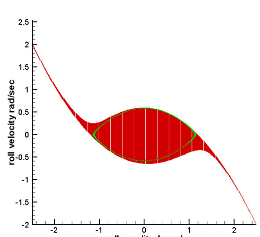

Fig .6 P.M.spectra T=10sec H=5.0m (0.20rad)

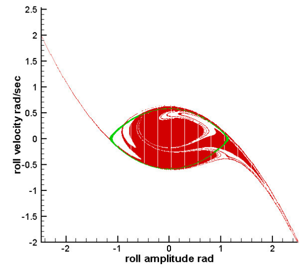

Fig.7 P.M.Spectra T=10secH=6.0m (0.24rad)

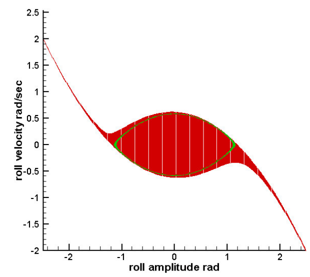

Fig 8 P.M.spectra T=12sec H=8.7m

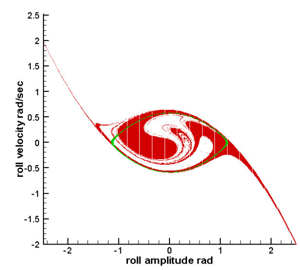

Fig 9 P.M.spectra T=12sec H=8.8m

From all of the pictures of the safe basin, it can be seen that the most of the forms of the basin have very slight fractal character. Only appear at some narrow intervals of waveheight.

In order to investigate the influence of the spectra form such as the band width on the erosion of safe basin. We calculated the safe basin on different spectra of specified band width. Following are the calculated results.

Table 5

Spectra type=uniform Central period=9.024sec	
Band width=3.0rad/sec	band width: 2.0 rad/sec
H=1.0m PS= 7.365000E-02	H=3.0m PS= 7.190312E-02
H=2.0m PS= 7.144687E-02	H=4.0m PS= 6.793437E-02
H=3.0m PS= 7.182813E-02	H=4.5m PS= 6.551719E-02
H=4.0m PS= 6.916562E-02	H=4.6m PS= 5.250781E-02
H=4.5m PS= 5.547656E-02	H=4.7m PS= 6.868906E-02
H=4.7m PS= 6.939062E-02	H=4.8m PS= 5.981406E-02
H=4.8m PS= 7.161250E-02	H=5.0m PS= 6.600937E-02
	H=5.2m PS= 0.000000E-00

Table 6

Spectra type=uniform Central period=10sec	
Band width=2.0 rad/sec	Band Width=3.0rad/sec
H=1.0m PS= 7.293437E-02	H=1.0 PS= 7.362968E-02
H=2.0m PS= 7.332031E-02	H=2.0 PS= 7.174218E-02
H=3.0m PS= 6.587187E-02	H=3.0 PS= 6.843282E-02
H=3.2m PS= 6.854063E-02	H=4.0 PS= 6.510156E-02
H=3.3m PS= 7.329062E-02	H=4.2 PS= 6.977969E-02
H=3.4m PS= 6.692969E-02	H=4.3 PS= 6.379063E-02
H=3.5m PS= 6.473281E-02	H=4.4 PS= 6.864218E-02
H=3.6m PS= 7.139687E-02	H=4.5 PS= 6.742813E-02
H=3.7m PS= 7.037344E-02	H=4.6 PS= 6.603906E-02
H=3.8m PS= 6.100000E-02	H=5.0 PS= 0.000000E+00

Table 7

Spectra type:uniform Central period:12sec	
Band width: 2.0rad/sec	band width 3.0 rad/sec
H=1.0m PS= 7.360937E-02	H=1.0m PS= 7.346562E-02
H=1.5m PS= 7.357813E-02	H=1.5m PS= 7.346094E-02
H=2.0m PS= 7.267969E-02	H=2.0m PS= 7.347813E-02
H=2.1m PS= 7.320781E-02	H=2.3m PS= 7.311406E-02
H=2.2m PS= 7.345469E-02	H=2.5m PS= 7.137344E-02
H=2.3m PS= 7.289688E-02	H=2.8m PS= 7.253125E-02
H=2.4m PS= 7.287969E-02	H=3.0m PS= 7.149375E-02
H=2.5m PS= 7.280312E-02	H=3.2m PS= 7.258594E-02
H=2.6m PS= 6.688281E-02	H=3.5m PS= 7.335938E-02
H=2.7m PS= 7.240625E-02	H=3.7m PS= 7.278750E-02
H=2.8m PS= 6.642500E-02	H=4.0m PS= 0.000000E+00

5.SAFE BASIN EROSION IN RANDOM WAVES FROM STATISTICAL POINT OF VIEW

It should be noticed the PS value calculated in random wave cases has strong random behavior, it means the PS value not only depends on the spectra form but also closely related to the random phase series we used in generating the random wave trace. The values we included in the table are some of the samples we obtained occasionally. In order to investigate such problem repeated calculations are performed on some of the waves. Following table is an example of the repeated calculation results. That means we keep the wave spectra form unaltered but generate the wave train by changing the random phase series arbitrarily. The results clearly show that the PS outcome has random manner. Considering that the meaning of safe basin is the influence of initial conditions on the stability of oscillation under external excitation. So, those conditions can be considered as the factors of the possibility of capsize. In regular wave case, the conditions of oscillation are specified by the initial condition and wave, and the wave is specified by amplitude and frequency. But in random cases not only the initial condition and wave specification are required, but also the random phase series should be taken into consideration, which make the safe basin itself a random variable.

Considering that the PS value of the eroded safe basin has reflected the possibility of the capsize of ship on a given waves, it may be appropriate to use such quantity to quantify the probability of capsize on random waves. But the PS value is a random variable. It should be defined in statistical sense. We suggested that the average of all the outcomes we have obtained for several wave trains with the same spectra to be the value representing the PS value in such random waves. This average value of PS can be considered as an indication of the capsize probability of the ship on such random waves. The last two rows in table.8 are average value and standard deviation of all the values in the same column (or the same wave spectra).

$$\text{Average PS}=\sum_{i=1}^{N}\frac{PS_i}{N}$$

$$\text{S.D.of PS}=\sqrt{\sum_{i=1}^{N}\frac{(PS_i-Av(PS))^2}{N}}$$

Table 8
P.M.Spectrum T=12.0sec

	H=7.0	H=8.0	H=8.5m	H=9.0m	H =9.7m
PS	7.358125E-02	7.278125E-02	5.033438E-02	7.186094E-02	0.000000E+00
PS	7.296094E-02	7.334844E-02	6.701094E-02	6.203750E-02	0.000000E+00
PS	7.362188E-02	4.485156E-02	6.498437E-02	6.370313E-02	6.808594E-02
PS	7.357031E-02	6.382656E-02	0.000000E+00	6.718906E-02	6.806093E-02
PS	7.132656E-02	0.000000E+00	6.001719E-02	7.205468E-02	0.000000E+00
PS	6.455625E-02	6.795000E-02	6.810625E-02	0.000000E+00	0.000000E+00
PS	7.342969E-02	7.144532E-02	7.160156E-02	7.172656E-02	7.195156E-02
PS	5.046719E-02	0.000000E+00	7.316563E-02	0.000000E+00	0.000000E-02
PS	0.000000E-00	6.645312E-02	7.205625E-02	5.758438E-02	3.174531E-02
PS	7.360469E-02	7.267344E-02	7.081250E-02	0.000000E+00	0.000000E+00
Av	6.271188E-02	5.333297E-02	5.980890E-02	4.615625E-02	2.398437E-02
SD	2.203173E-02	2.781658E-02	2.098323E-02	3.083420E-02	3.114527E-02

In which PS_i is the PS value calculated with the ith sample wave train with the same wave spectra. It is interesting to notice that such outcomes have more slight dispersion around its mean value in low wave height than in higher waves. The dispersion increases rapidly after some wave level are reached.

In order to survey the influence of randomness of the wave on the safe basin erosion, the average PS of different wave height in wave period=12sec for both regular and random waves were plotted together in Fig10

In this figure the left curve is PS value on regular waves, while right curve is on random waves. It can be seen that the randomness of the wave has significant influence on the PS value especially when the wave is higher than 4m. The consequence of randomness is it will reduce the erosion of safe basin in low wave height. Only after some threshold of wave height it reduce rapidly. It will be interesting to find out such threshold.

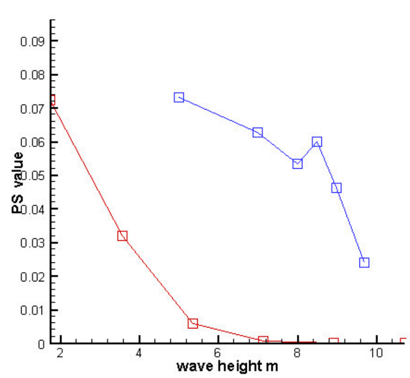

Fig. 10 The variation of PS with respect to wave height for regular and random waves with a period of 12 sec

6.CONCLUDING REMARKS

The above argument can be summarized into several points.

First, the safe basin under the action of regular waves has very regular behavior. The area occupied by the stability initial conditions varied with the increasing of excitation level in an uniform manner. In general it reduced with the increase of the level.

In random wave condition, the situation becomes more complicated. This is due to the randomness of waves, which make the excitation in an uncertain manner. We use the Longuet-Higgins model to generate the wave train. In such approach, the random phase series has to be used, which is the source of the randomness of the wave train. Calculation showed the behavior of safe basin in random wave condition has different characteristics compared with those in regular waves. Due to the random phase the safe basin in a given wave height and period may have very different form and magnitude. Also the variation of the safe basin is not changing smoothly with the variation of wave height. But, in general it still has some trend. It means we have to analyze such safe basin from the stochastic point of view. We suggested that the average and standard deviation to be used in the analysis of the safe basin in random wave case. Some examples show such analysis is appropriate and may used to study further into the investigation of capsize of ship in random sea.

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