The Studies for the Resonance of Hwa-Lian Harbour Agitated by Typhoon Waves

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Abstract

Hwa-Lian Harbour is located at the north-eastern coast of Taiwan, where is relatively exposed to the threat of typhoon waves from the Pacific Ocean. In the summer season, harbour resonance caused by typhoon waves which generated at the eastern ocean of the Philippine. In order to obtain a better understanding of the existing problem and find out a feasible solution to improve harbour instability. Typhoon waves measurement, wave characteristics analysis, down-time evaluation for harbour operation, hydraulic model tests are carried out in this program.

Under the action of typhoon waves, the wave spectra show that inside the harbors short period energy component has been damped by breakwater, but the long period energy increased by resonance hundred times. The hydraulic model test can reproduce the prototype phenomena successfully. The result of model tests indicate that by constructing a jetty at the harbour entrance or building a short groin at the corner of terminal #25, the long period wave height amplification agitated by typhoon waves can be eliminated about 50%. The width of harbour basin 800m is about one half of wave length in the basin for period 140sec which occurs the maximum wave amplification.

I. Introduction

Hwa-Lian Harbour is an artificial harbour built on a steep and narrow east coast of Taiwan. More than 4000m long breakwater was constructed to protect the harbour basin against incident waves from the Pacific Ocean. Figure 1 shows the location and layout of the harbour, which has 25 wharves after the fourth stage expansion. In the summer season, harbour resonance may be agitated by typhoon waves which generated at the east of the Philippine. Harbour resonance, may cause down time for harbour operation, or even break the ship mooring lines.

Institute of Harbour Marine Technology(IHMT) No. 83, Lin-Hai Rd., Wuchi, Taichung District, Taiwan, Fax. No: 886 04 6571329, E-mail ckcihmt@ms6.hinet.net Field investigation has been carried out since 1989, a waverider has been deployed at the outside of the harbour. In 21 June 1990, Typhoon Ofelia formed at the eastern ocean of the Philippine, and moved toward Taiwan in NNW direction. Finally made landfall with the eye of typhoon striking at 17km south of Hwa-Lian Harbour. One hour before landfall, the maximum wave height 20.5m, period 16.0sec was recorded; The corresponding significant wave height and period were 13.9m and 14.1 sec respectively. Time series of wave height and period are plotted as shown in figure 2. Four commercial vessels were berthed at the terminal, two of them escaped for survival when significant wave hight was greater than 4m; the mooring lines of two other ships were broken and the harbour facilities were damaged while wave height increased rapidly.

In November 1992, there were three typhoons Elise, Hunt and Gay. The center of those typhoons were located at SE direction and more than thousand kilometers away from Hwa-Lian. But, the harbour basin was agitated by swells generated by typhoon and berthed ships were forced to leave the harbour for survival.

In order to get a better understanding of the harbour hydraulic environment during the threat of typhoon, an intensive research program had been carried out by the Institute of Harbour and Marine Technology (IHMT) since March 1993. Field investigation, hydraulic model test and numerical computation are included in this research project. This paper present field investigation wave characteristics, down time of harbour operation, model test for different amendment layouts.



Figure1 Layout of Hwa-Lian Harbour and Location of Instruments

Figure 2 Time Series of Wave Height and Period for Ofelia Typhoon

II. Field Investigation

Figure 1 shows the location of wave stations. The permanent station, St.2 locates at outside of the harbour, a directional wave-rider and current meter have been installed since 1989. At the harbour entrance, St.5 and terminal stations located at water front of terminal #8, #10, #22, four pressure type wave gauges were installed prior to typhoon wave attacked Hwa-Lian Harbour. At the offshore station, St.2 offshore incident waves were recorded 20 min every two hours with sampling rate 1.28Hz. At the harbour basin and entrance stations waves were recorded 34min every hour with 1 Hz sampling rate.

III. Wave Characteristics

The paths of six typhoons which occurred in the summer of 1994 are plotted as shown in figure 3. IHMT had succeeded to obtain wave data inside and outside of the harbour synchronously during Typhoon Tim, Fred and Gladys moved toward Hwa-Lian Harbour. Figure 4 shows time series of wave height variation for the offshore station St.2, the harbour entrance station St.5 and terminal stations #22,#8,#10. The sheltering coefficient is defined as the ratio of wave height between the terminal station or the harbour entrance station and the offshore station. The sheltering coefficient and corresponding incident wave direction recorded at St.2 are plotted as shown in the upper and middle diagrams of figure 4. For a specific time, the location of typhoon center, the incident wave height, wave direction and sheltering coefficients at the harbour entrance station St.5, terminal stations #22, #8, #10 are tabulated in table 1.



Figure 4 Time Series of Wave Height Characteristics for Stations Inside and Outside of the Harbour

Table 1 indicates that the sheltering coefficients of harbour entrance and terminal stations depend on the incident wave direction and sheltering environment. The incident wave direction have good relationship with the location of the typhoon center. For example, the center of Typhoon Tim was 600km in SE of Hwa-Lian, incident wave came from 125°, wave height coefficient reduced from 0.6 at the harbour entrance to 0.1 at the inner basin terminal #10; the center of Typhoon Fred located at 100km in ESE and moved toward Hwa-Lian in WNW direction, wave height increased from 2.6m to 4.9m, incident wave direction decreased from 115° to 95°, the sheltering coefficient decreased accordingly. But, when the center of typhoon approached Hwa-Lain, the incident wave direction and sheltering coefficients were changed rapidly by local wind field.

	TIME	CENTER	WAVE	INCIDENT WAVE Hs	SHELTERING				(TYPHOON	
TYPHOON					OEFFICIENT				CENTER)	
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1	1	(KM)	(0)	(m)						
TIM	07/09/	SE	125	2.0	0.65	0.33	0.17	0.1	MOVED NW	
	18:00	(600)								
	1						{			
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1	16:00	(140)					i i		LANDFALL	
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FRED	08/19/	ESE	115	2.6	0.52	0.30		0.1	MOVED	
	00:00	(1000)							WNW	
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1	18:40	(200)	1						NNE	
	08/21/	ENE	75	2.9	0.45	0.38	•	0.11	MOVED	
	02:00	(250)							NNE	
GLADYS	08/31/	ESE	115	1.2	0.45	0.1	· ·		MOVED	
ļ	08:00	(700)	}			j	ļ	}	WNW	
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1	09/01/10:0	E	80	4.4	0.36	0.18	1 .	0.13	BEFORE	
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TABLE 1 SUMMARY OF INCIDENT WAVES AND WAVE HITH COEFFICIENT

Energy spectra for waves recorded at the permanent station St.2 and terminal stations #22, #8 and #10 are plotted as shown in figure 5. After the sheltering of the breakwater, the short period wave energy measured at terminal stations were reduced tremendously. The degree of energy density reduction depends on the sheltering condition. At the outer basin the energy density ratio between terminal #22 and incident wave is about 1/10; at the inner basin the ratio between #8 or #10 and incident wave decreases further to 1/100. On the other hand, long period waves from 140sec to 160sec recorded in the harbour basin, the energy density were amplified hundred folds. The detail time series water surface for various wave stations are plotted in figure 6, which shows water surface recorded at harbour stations have rather long periodic motion in comparison with that of incoming wave recorded at St.2.



IV Down-time Evaluation

According to the berthing records of Hwa-Lian Harbour indicate that in the summer season, down time for harbour operation due to the action of typhoon wave has occurred at least once every year since 1985. Based on the status of berthing conditions provided by Hwa-Lian Harbour Bureau from 1990 and the corresponding paths of the typhoon, as shown in figure 7, issued by the Central Weather Bureau, table 2 shows the summary of typhoon generated swells that made harbour instability and caused down time for harbour operation.

Based on the advance typhoon path, the leaving location which listed in column 4 of table 2, is defined as the location of typhoon, while berthing ship commences to leave the harbour due to agitation of swells. By assuming the propagation velocity of swill is 50 km/hr, the initial time and location were estimated as shown in column 5 of table 2. The initial time and location are defined as the time and location that typhoon generated swells which might arrive the harbour and force ships to leave the harbour for safety. The analysis results of initial and leaving locations are plotted as shown in figure 8. The swell generated at the initial location arrives the harbour and causes ships to leave the harbour for survival, while the center of typhoon moves from initial location to leaving location.



Table2 Summary Of Down Time For Berthing

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V. Model Tests

The main purpose of model test is to find out a feasible amendment layout to eliminate long period wave energy inside the basin amplified by harbour resonance. The optimum layout will be proposed for the improvement of Hwa-Lian Harbour in the future project.

Model tests were conducted in a 62m long and 57m wide wave basin. Regular and irregular wave generator, wave gauges and data acquisition system have been equipped in the laboratory. Hwa-Lian Harbour was built in the basin by using model scale 1:150. Both regular and irregular waves were simulated in the model tests. In the primary stage, 14 layouts were tested by regular wave for qualitative analysis. Prototype incident wave height 0.75m, and wave period ranges from 10sec to 180sec were reproduced in the model tests. The existing and three amended layouts as shown in figure 9 were selected for further tests by irregular waves. The spectra of Tim typhoon waves recorded at offshore of Hwa-Lian Harbour and JONSWAP spectra were simulated in irregular wave tests.





Figure 9 Layout of the Model Tests

Wave data in front of the wave paddle (incident wave), harbour entrance and inside the basin were recorded at 30 locations in the model tests to evaluate wave disturbance of the harbour protected by breakwater. Figure 10 and 11 show wave height ratio versus incident wave period at terminal #22 of the outer basin and terminal #8 of the inner basin for primary 12 layouts. The wave height ratio is defined as the ratio of wave height between a specific location at the basin and offshore incident station. Figure12 and 13 show the detail wave height ratio of terminal #22 and #8 for the existing and three amendment layouts. The results of the existing layout indicate that the short period wave is sheltered by breakwater, the wave height ratio at #22 of the outer basin is about 0.4 and the ratio at #8 of the inner basin in less than 0.15. But for the 140sec long period wave height ratio, the amplification factor is more than 3.4 at #22 and about 2.0 at #8. The short period wave height ratios of outer and inner basins obtained in model tests and measured in field investigation are quite consistence in case of the same direction of incident wave.



Figure 10 Wave Height Ratio of the Terminal #22 for 12 Layouts



Figure 11 Wave Height Ratio of the Terminal #8 for 12 Layouts



Figure 12 The Detail Wave Height Ratio of the Terminal #22 for 4 Layouts



Figure 13 The Detail Wave Height Ratio of the Terminal #8 for 4 Layouts

The amendment layout B, rebuilds the old portion of the eastern breakwater, installs perforated rubble breakwater at the north end. This layout doesn't improve the short period wave height ratio of the outer basin. But, the ratio of the inner basin decreased, because some portion of incident wave energy of inner basin transmits through perforated breakwater. Layout B does not change the geometry of the outer basin, the resonance mechanism of the long period wave is existing. The long period wave height amplification remains the same scale as the existing layout. Layout J, a short groin is constructed at the turning corner of the terminal #25 which located beside the navigation channel. The mode of wave resonance is broken by the interaction of groin and long period wave height in the basin is eliminated by the disturbance of refraction waves. Layout Q, builds a jetty at the harbour entrance and eastern breakwater remains the same as layout B. It is obvious that the jetty and the west breakwater forms as a resonant basin at the harbour entrance, the incident long period wave energy is damped by the transverse waves in the basin. The test results show that the long period wave height amplification due to resonance decreases more than 40%. The short period wave height ratio of terminals #22 and #8 for layout J and O are smaller in comparison with those of layout A and B.

Based on 4096 sampling data recorded at each run of model test (about 205 seconds), wave spectra were analyzed by using FFT method. The wave spectra of four layouts are plotted as shown in figure 14. In order to find out the difference of three wave spectra, which measured at incident location, terminal #22 and terminal #8, were plotted in a figure for the same layout. By simulating waves recorded in Tim typhoon, the spectrum has peak period 1.25sec in model or 15.3sec in prototype and no extraordinary long period wave energy component. The test results indicate that the short period wave energy density at terminal #22 and at terminal #8 is reduced by the sheltering of breakwater. There are not much difference for various layouts in the short period wave.

The spectra show that long period 11.8sec and 5.6sec in model or 144sec and 67sec respectively in prototype, the energy density at the inner and outer basins are enlarged by harbour resonance. Long wave period 144sec is quite consistency with regular wave period 140sec that caused the maximum wave amplification. Low frequency energy density at terminal #22 and #8 amplifies about 30 times for layout A and B. The shape of spectra for layout J and Q are quite similar as those of layout A and B, but low frequency energy density becomes smaller. In order to get a better quantitative understanding, the frequency is divided into two intervals, low frequency band between 0.06Hz and 0.3Hz, and main frequency band between 0.8Hz and 1.2Hz. There are corresponding to prototype wave period 204.1 sec to 40.8 sec for long period wave band and 15.3sec to 10.2sec for main period wave band. The sum of wave energy for low frequency and main frequency bands are tabulated in Table 3 and plotted as shown in figure 15 and figure 16. In all layouts, long period wave energy component contained in the incident wave measured at offshore (ch:09) is very limited. But, the terminal #22 and #8 in the harbour basin of layout A, long period wave energy component enlarged by harbour resonance. The reduction of long period wave energy component is not significant for layout B, that is similar as regular wave tests. Layout J and Q, long period wave energy component inside the basin gets much better, especially layout Q. On the other hand, figure 16 shows the main period wave energy component. The incident wave obtained at offshore station is much higher than those measured at terminal #22 and #8 in the basin.

Table 3 shows the wave height ratio computed by the view point that wave height is the square root of wave energy. Because the long period wave energy for irregular wave is the sum of energy in the range of 40 sec and 204sec. Hence, the wave height ratio listed in table 3 can be considered as the average of the wave height ratio for the same period of regular wave tests. The result of irregular wave tests are quite consistency with those of regular wave tests as show in figure 12 and 13.



Figure 14 Wave Spectra Measured at Incident Location (# #), Terminal #22 and #8 for Different Layout in Model Tests

	Ene Wa	rgy of I ve Band	Long Pe I (cm×	ríod cm)	Energy of Main Period Wave Band (cm×cm)					
Layout	Α	В	J	Q	A	B	J	Q		
Offshore Incident	0.71	0.60	0.68	0.70	152.5	143.1	181.0	170.0		
Terminal	6.50	4.53	3.38	2.00	28.1	15.3	11.0	13.6		
#22	(3.0)	(2.8)	(2.2)	(1.7)	(0.43)	(0.33)	(0.25)	(0.28)		
Terminal	3.91	4.83	2.05	1.51	5.5	3.5	0.9	1.1		
#8	(2.3)	(2.8)	(1.7)	(1.5)	(0.19)	(0.16)	(0.07)	(0.08)		

 Table3
 Wave Energy and Wave Height Ratio of Long Period and Main Period Wave Bands for Different Layouts

Note: () the wave height ratio is defined as the square root of (terminal wave energy /incident wave energy).



Figure 15 Wave Energy of Low Frequency Band Inside and Outside the Harbour for Different Layouts



Figure 16 Wave Energy of Main Frequency Band Inside and Outside the Harbour for Different Layouts

VI. Discussion

- The spectra of the offshore permanent station shows no extraordinary long period wave energy component. Because the accelerator of wave rider can not detect low frequency motion. A pressure type wave gauge had been installed at the offshore station at typhoon season in 1996. The spectrum of waves measured by pressure type wave gauge indicates that typhoon wave has long period energy component at the offshore station.
- 2. Long period wave energy amplified by harbour resonance can be reproduced in hydraulic model by using either regular wave or irregular wave. The amplification ratio in prototype is larger than that in model, because the friction loss at small scale physical model is larger than in the field.
- 3. The shape of the outer basin is like a triangle, the maximum width is about 800m which equals a half wave length of period 140sec approximately. Hence the harbour basin is resonated in transverse direction which is consistent with the video records of ship motion under the action of typhoon wave and the visual aspect in the model test. Layout B doesn't change the harbour geometry, the resonance amplitude remains the same order of magnitude. Layout J constructs a short groin at the basin or layout builds a jetty at the harbour entrance, the long period wave energy can be eliminated by breaking the resonance mode or disturbing the incident waves.
- 4. Down-time harbour operation due to the berthing ship motion enlarged by the agitation of long period harbour resonance. Although, layout J and Q can reduce the long period wave energy, but it still exist in the basin. It is necessary to perform ship motion test to evaluate down-time harbour operation for various feasible layouts.
- 5. By taking ship maneuvering and sediment at the entrance into consideration, at this stage layout Q is proposed for the harbour improvement in the future.

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