A Field Study on Long Period Oscillation in Hualien Port

Yung-Fang Chiu
Center of Harbor and Marine Technology
Institute of Transportation, Taichung
yfchiu@mail.ihmt.gov.tw

Jaw-Guei Lin
Department of Harbor and River Engineering
National Taiwan Ocean University, Keelung
jglin@mail.ntou.edu.tw

Yu-Feng Lin
Department of Civil Engineering
Dahan Institute of Technology, Huaien
linyf@ms01.dahan.edu.tw

Abstract

In order to fulfill the information about long period oscillations in Hualien Port, this study extended the sampling interval from 1200 seconds to 15000 seconds for the synchronous wave measurements in both Yen-Liao fishery port and Hualien Port. By using the digital filter analysis and FFT, the wave records are found, in both time domain and frequency domain, to contain the component waves with periods longer than 1000 seconds. Such phenomenon leads to a new possibility about the mechanism of harbor resonance in Hualien Port.

1 Introduction

Hualien port is the only commercial harbor along the middle east of Taiwan coast. Except for the Ho-Ping Industrial Port, the nearest commercial port is Su-Ao Port which is around 60 Km away from the Hualien Port at north side, and at the south side, the nearest fishery port is around 50 Km in distance. Therefore, from the point of view of either the safety of marine transportation or nearshore recreations, Hualien port plays an important role along the East Taiwan. Due to its long-narrow and parallel to the coastline layout and steep bathymetry outside the port, Hualien port (see Fig. 1) suffered from long period oscillation, especially during the typhoon intrusions, ever since the current layout was constructed, and seriously affects the safety of anchored ship that causes the evacuations at about 48 hours before typhoon landing alert.
In order to solve the long period oscillation problem in Hualien Port, a large amount of studies was done since 1989 that includes numerical simulations, hydraulic model tests and field measurements. Except for a conference entitled with “Hualien Port Harbor oscillation and its improvement” had been held in 1996, some relevant publications are Chang and Tzeng (1993 and 1995), Su and Chen (1995), Tzeng and Chien (1996), Su et al. (1996), Chien and Chiu (1996), Chang (1996), Tzeng(1998), Chien and Tzeng (1999), Juang (2000), Juang and Jian (2000), Hsiao et al. (2000), Lee et al. (2001), Lee (2001), Kuo et al. (2002), Chiu et al. (2003), Chang and Lin (2003), Chiu et al. (2003), Su (2003), and Chiu et al. (2004). In the last paper, Chiu et al. had made a detail review of the studies between 1989 and 2003, this section only briefly discuss their achievements.

1-1 Numerical Simulations

Su et al. (1996) used nearshore wave model - WP21 to discuss the wave motions in Hualien Port, and found the strong oscillations might occurred when the incident waves have periods of 42, 87, 92, 118 and 155 seconds. Juang (2000) and Juang and Jian (2000) used MIKE21-EMS to discuss the mechanism of harbor resonance during typhoon intrusion period, and addressed that the infragravity waves are the major causes and incident waves with periods of 100, 130, 160, 190 and 195 seconds can induce large degree of oscillations. Lee et al. (2001) studied by mild slope equation and boundary element method, and found that the incident waves with periods of 48, 56, 96, 116, 140 and 160 seconds may cause the long period oscillations in the harbor.

Although all these studies indicate that Hualien Port has several oscillation modes, but their results are different. The reasons that cause such differences should be the wave theories, numerical methods, or the grid sizes of computational mesh used in their studies are different. It should be pointed out that all these studies are focus on the natural frequency of Hualien Port, i.e. they treated the long period oscillations...
oscillations in the port as harbor resonance problem which are related to their natural frequencies.

1-2 Hydraulic Model Tests

In order to improve the harbor resonance problem, the Center of Harbor and Marine Technology (hereafter, IHMT) had conducted three major projects in 1996, 1997 and 2000. Chien et al. (1996) designed 4 new layouts by constructing jetty outside the harbor, or extending the east breakwater, or create a new opening at the middle of the east breakwater. Fig. 2 shows one of the layouts. Chien et al. (1997) designed another 11 new layouts coupled with the improvement of south shore protection and the reconstruction of east breakwater. Fig. 3 shows one of the layouts. Chiu et al. (2000) discussed the improvements of long period oscillations by the new construction of a coastal structure outside the harbor entrance (Layouts 1 and 2 in Fig. 4) or the extension of Hualien Fishery Port (Layout 3 in Fig. 4).

Concluding the results from these three major projects, one can find that only limited improvement can be found in all experiments, the long period oscillations still exist in the harbor. Chiu et al. (2004) concluded that once the major part of harbor layout was constructed, the improvement of harbor resonance or long period oscillation problem is highly difficult. Huge budget and time are needed, but the achievement is limited. Any harbor problem is better to be evaluated and be prevented at the earlier planning stage.

Fig. 2 Layout concept in IHMT 1996 project (Chien, 1996)
1-3 Field Observations

Tzeng (1996) analyzed the wave records inside/outside the harbor in 31 typhoon period between 1900 and 1996, and found that the typhoon wave energies were concentrated between wave periods of 11 and 15 seconds. The wind wave energies declined very fast as propagating into the harbor, but long period wave
energies increased. Long period component wave energies have evidently increased outside the entrance, but are concentrated at 137, 147 and 185 seconds in outer basin, and 147 and 185 seconds in inner basin. Free long waves induced by wave breaking or forced long wave accompanied with wave group are the possible mechanisms of Tzeng (1996) proposed for occurrences of such long waves in the harbor. Tzeng and Chien (1996) analyzed the field data between 1989 and 1994, and pointed out that during the Typhoon Tim in 1994 intrusion period, the dominant wave energies are concentrated at component waves with period of 47, 82, 98, 114 and 158 seconds. Kuo et al. (2002) analyzed 5 typhoon wave records between 1994 and 1997 and stated that the mechanism of long period oscillations in the harbor is directly related to the low frequency portion of wave energy outside the harbor, but not definitely related to the principal wind direction. Chang and Lin (2003) used least square method to develop a principal component wave period and related amplitude identification model, and showed that the principal wave periods were 87.6 and 152 seconds in harbor and 15, 52, 80 and 130 seconds outside the harbor during the Typhoon Tim intrusion in 1994.

1-4 Discussions of Previous Studies

From the above relevant studies, one can find that the characteristics of long period oscillations in Hualien Port had been widely discussed for many years, including field measurements, hydraulic model tests, and numerical simulations. The mechanism that causes such phenomenon, however, is still unclear: infragravity waves, forced long waves, edge waves or other sources. Su (2003) physically discussed the possible mechanism and stated that the infragravity waves with periods lie between 80 and 90 seconds or between 130 and 160 seconds can hardly exist in typhoon waves. Unless the regular surge, the field irregular wind waves also have less possibility to induce regular group waves, and conceptually inferred that edge waves are the most possible mechanism without any proof.

With one step further of discussion, due to the artificial input of incident wave condition and simplifications of the physical boundaries, the numerical simulations and the hydraulic model tests for harbor planning and design are actually tools only to find the optimal harbor layout or to investigate the characteristics of some specific layout. Field observations are actually the most suitable tool on fulfilling the wave information around the harbor in practice.

2 Evidence of the Existence of Long Period Oscillations

In this section, the field wave records measured inside the Hualien Port between 2000/9/6~2000/10/11 measured by IHMT and some of their analyses were used to show the existence of long period wave components. Each record was sampled 17 minutes in 2 Hz sampling rate with pressure wave gauges. The locations of wave stations are shown in Fig. 1. During that period, from the official records of Central Weather Bureau, Taiwan, a typhoon Bopha intruded between 2000/9/8 and 2000/9/10. Fig. 5 shows two wave records as examples, and the long period oscillations with period more than 100 seconds can be seen in the time series. Short period waves riding on long period waves was found in the figure, and such
phenomenon always causes the analysis problem that zero-up-crossing method is not available on identifying the individual waves because of the difficulty of de-trend process.

Figure 5 Wave record samples inside the Hualien Port (2000/9/6~2000/10/11)

Figure 6 shows the time sequences of total wave spectral energy ($m_0$) of several wave stations. Within two periods, from 2000/9/9 to 2000/9/17 and from 2000/9/25 to 2000/9/30, Hualien Port was subjected to large wave action. Fig. 7 shows the time sequence of stacked occurrence ratio of component wave energy with respect to the total wave energy of each wave record. The wave energies are summed up in different period intervals as shown in the legend of Fig. 7 to investigate the energy distribution in each wave record (in y-direction) and the variations in time (in x-direction). Together with Figs. 6 and 7, we can see that during the large wave action period, the short wave portion contains large wave energy, but in ordinary wave action period, wave energies were concentrated at wave periods larger than 100 seconds. Due to the short waves dissipated faster than long waves, and the filtering effect of connected channel between two basins, the waves in inner basin contains more long wave energy than outer basin. Such phenomenon leads to a thought that very long period waves can exist at any time, not particularly occur in typhoon period, and a question is arose that if the long period oscillation that affecting the ship anchorage safety problem in Hualien Port is the problem of the accumulation of wave energy in the natural frequencies of the harbor (resonance problem), or in very long period waves (oscillation problem)? The harbor resonance problem can be improved by changing the harbor layout or increasing the wave absorber in the harbor. However, if the very long period waves exists all the time and is coming from offshore then the problem cannot be solved easily.

Considering Hualien Port is around 3000 m in length, from a simple calculation that the wave length of first resonance mode is 4 times the harbor length (12000 m), the related wave periods lie between 87 seconds (in deep water) and 903 seconds (in 18 m depth at harbor entrance). Such large difference is because of the fast
variation of the sea bottom around Hualien Port. This conceptual range will be used in identifying the long period components.

In general, field wave observations can be done by many kinds of instrument, but the data sampling is always sampled 20 minutes in 2 Hz sampling rate within every 2 hours, or sampled 10 minutes in 4 Hz sampling rate within every 1 hour.

![Graphs showing time sequence of total wave spectral energy](image)

**Fig. 6 Time sequence of total wave spectral energy ($m_0$) (2000/9/6~2000/10/11)**
Therefore, there are 2400 data points for each wave record which can be used in wave statistics. When using the Fast Fourier transform (FFT) for spectral analysis, 2048 data points are usually employed and the longest wave period can be resolved is 512 seconds for 2 Hz case and 256 seconds for 4 Hz case. With such limited length of data, the very long period component waves cannot be fully identified. So, the question stated above is not easy to answer.

3 Long Time Field Wave Observations around Hualien Port

In order to enrich the long period wave information of Hualien Port, our study using the pressure wave gauges and extending the sampling interval from 1200 seconds (20 minutes) to 15000 seconds (250 minutes) in 2 Hz sampling rate continuously measured the wave motions in Hualien Port and in Yen-Liao Fishery Port for a short period. As shown in Fig. 8, Yen-Liao Fishery Port is a simple port which located around 19 Km south from Hualien Port. Due to steep bottom slope and
deep water depth outside the Hualien Port that causes the difficulty on setting a wave station at offshore sea bottom, the measurement of Yen-Liao Port was treated as a reference of waves outside the Hualien Port. The observations discussed in this paper were done in April, 2006 in Hualien Port with 2 wave stations (one at outer basin and one at inner basin, measured synchronously, see Fig. 1), and in June, 2006 in Yen-Liao Fishery Port with 1 wave station (see Fig. 8). Within these two periods, weak frontal lows had approached, but the sea surfaces are still calm.

Totally, there are 11 records obtained in Hualien Port, and 7 records obtained in Yen-Liao Port. Each record contains 30000 data points for 15000 seconds. Figs. 9 to 11 show two of the wave records in each wave station. The records in Figs. 10 and 11 are respectively measured at the same time. The long period wave motion is not so conspicuous in Yen-Liao Port (Fig. 9), but is dominant in the inner basin of Hualien Port (Figs. 10 and 11), wave motions with period more than 1000 seconds exist. In inner basin, the short period waves quickly decay and make the long period wave motions noticeable.

After the de-mean and de-trend processes to eliminate the tidal fluctuation for each wave record, digital filter was used to extract the time series of component waves with wave periods shorter than and equal to 30 seconds, between 20 and 200 seconds, and longer than 200 seconds from the original. Fast Fourier Transform was also involved to find their power spectrum. In order to compare the variation of wave energies between different wave groups, the wave period interval was divided into four parts: (A) below 30 seconds; (B) between 30 and 200 seconds; (C) between 200 and 2000 seconds; and (D) above 2000 seconds. The results are discussed as follow.

![Fig. 9 Wave record measured in Yen-Liao Fishery Port in June, 2006](image-url)
3-1 Waves in Yen-Liao Fishery Port

Figure 12 shows the results related to the wave records shown in Fig. 9. Fig. 12(a) shows two original and related filtered component wave time series, Fig. 12(b) shows the spectra, and Fig. 12(c) shows the distributions of non-dimensional accumulated spectral energy. In order to investigate the variations of wave energy in wave periods, instead of wave frequencies, the x-axes in Figs. 12(b) and 12(c) are all expressed by wave period. In Fig. 12(a), after the isolations by digital filtering, the long period wave motions for periods longer than 200 seconds can be found in
the time series. Although the water fluctuation is small (below 10 cm), but their existences are affirmative. For the time series of wave periods longer than 200 seconds, we may also found a single oscillation act as carrier wave that almost covers the whole time interval with around one cycle. Considering the period of semidiurnal tide is around 44700 seconds, this component wave should not be tide-related. All these evidences show that the wave motions in Yen-Liao Port does contain very long period component waves. Fig. 12(b) show that the spectral densities of long period component sometime will higher than the gravity waves. The spectral densities in interval B are smaller than in interval A in general, the difference is around O(10) to O(10^3); the spectral densities in interval C lies between intervals A and B; and the spectral densities in interval D have same level as in interval A. The long period wave components of wave period longer than 1000 seconds are dominant in our measurement. The dominant periods above 200 seconds are 500, 600, 800, 900, 2500, 3750, 5000, and 7500 seconds. The spectral peaks between 30 and 200 seconds can hardly be identified. From Fig. 12(c), the component waves in interval A (gravity waves) contains the largest portion of spectral wave energy, and interval D takes the most of the rest, only small portion of wave energy is contained in intervals B and C.

In general spectral analysis by FFT, the low frequencies portion with frequency nears to two frequency units (2fΔ, where fΔ = 1/NDt and Δt is sampling time) are always be treated as numerical error and be neglected. According to such concept, in our measurement, the sampling interval is 15000 seconds, and the sampling rate is 2 Hz, the frequency unit (fΔ) should be 0.000067 Hz (= 1/15000 Hz). The longest resolvable period is 1/2fΔ = 7500 seconds and is suggested not to put into discussions. From the time series in Fig. 12(a), however, these components do definitely exist and should be taken into account.

As mention before, Yen-Liao Fishery Port is a simple and small fishery port, the harbor layout has ‘F’ form and facing to the south. Due to it is fully connected to the open sea, its long period wave components can be assured to be affected by the offshore waves, and should have directly relation to the long period wave components outside the Hualien Port.
Fig. 12 Analyzed results for wave records shown in Fig. 9 (measured in Yen-Liao Fishery Port in June, 2006)

3-2 Waves in Hualien Port

Figures 13 and 14 show the results related to the wave records shown in Figs. 10 and 11. In each figure, Fig. (a) shows two original and related filtered component wave time series; Fig. (b) shows the spectra; Fig. (c) shows the distributions of non-dimensional accumulated spectral energy; and Fig. (d) shows the distributions of dimensional accumulated spectral energy.

In Fig. 13(a), the wave motions for periods longer than 200 seconds are found in outer basin of Hualien Port with small water fluctuation (below 4 cm). Fig. 13(b) shows that long period components near 7500 seconds are still exist, and more peaks occur between 200 and 2000 seconds. The spectral densities in interval B are still smaller than in interval A with difference of O(10), but is increased in interval C to the order of in interval A; spectral densities in interval D are still dominant but smaller than in interval C. The dominant periods above 200 seconds are 700, 900, 1200, 1500, 2500, 3750, 5000, and 7500 seconds. The spectral peaks between 30 and 200 seconds can hardly be identified. From Fig. 13(c), the wave energies are still concentrated in intervals A and D, intervals B and C only contain a small portion of wave energy. Such tendencies also appear in the results...
(a) Time series of wave profile

(b) Power spectrum

(c) Non-dimensional accumulated wave energy distributions
Fig. 13 Analyzed results for wave records shown in Fig. 10(a) (measured in outer basin of Hualien Port in June, 2006)

(d) Dimensional accumulated wave energy distributions

(a) Time series of wave profile

(b) Power spectrum
Fig. 14 Analyzed results for wave records shown in Fig. 11(a) (measured in inner basin of Hualien Port in June, 2006) in inner basin in Fig. 14. The dominant periods above 100 seconds in inner basin are 170, 200, 280, 700, 1200, 3750, and 7500 seconds.

As mentioned above, two wave records and their analyses of outer basin in Fig. 10 and of inner basin in Fig. 11 were measured synchronously. Comparing the results of record 1 (left column) in Figs. 13 and 14, the total energies in inner basin and outer basin seem to be equal, the energies for short periods declined in inner basin but long period wave (more than 1000 seconds) energies increased rapidly. The results of record 2 (right column) in Figs. 13 and 14 show that short period waves in outer basin contain more energy than that in inner basin. On the contrary, long period waves in inner basin contain more energy than that in outer basin. The wave energies for wave periods lie between 20 and 1000 seconds between outer and inner basins have very little difference.

4 Results and Conclusions

From the above discussions, some conclusions are made:

1. The extension of sampling interval of field wave observation is much helpful on collecting the full information of wave motions. Very long period wave components can be found around the harbor, which are always neglected in traditional observations. The extension is suggested.

2. Long period waves exist not only inside the Hualien port, but also in Yen-Liao
Fishery Port. Large wave energies appear in wave periods more than 100 seconds, especially in wave periods more than 1000 seconds. However, since the data only collected in two days, the characteristics of long period waves can not be fully described. Further long term and large area observations are suggested for future studies.

3. Due to the long period component waves found in this study might not be the harbor scale or the tidal scale, the long period oscillations in Hualien Port exist not only in typhoon intrusion period, but also in ordinary days. Therefore, the mechanism of oscillations, caused by natural periods of the harbor, or by the intrusions of offshore long waves, should be clarified before discussing the improvements of the oscillations.

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6 References


