Infragravity waves in the Hualien Harbor

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***Abstract*-This study investigated the relationship between the group wave properties in the typhoon waves measured outside the Hualien Harbor and the long period waves inside. Groupiness factors defined with total run length, Smoothed Instantaneous Wave Energy History (SIWEH), and envelopes of the waves were used as group wave parameters. It was found that the standard deviation of the SIWEH and envelopes of the typhoon waves measured outside the harbor have relatively good relationship with the standard deviation of the long period wave measured inside the harbor. Spectral analysis on the envelopes of the waves outside the harbor showed that there was energy in the 60-300s period range.**

Keywords: SIWEH; envelope; total run length

I. INTRODUCTION

Generally two types of infragravity waves are considered in the coastal region: one is edge wave and the other is leaky waves generated through the release of the group bound long wave [1]. Edge waves are trapped in the nearshore by refraction and traveling along the beach [1]. Edge waves are mainly derived in theoretical considerations; it is very difficult to observe in the field. Reference [2] investigated the question of whether edge waves can be generated in the near-shore region, using numerical models. They concluded that no edge waves could be identified using 16 s waves obliquely incident on a straight-line beach. Although alongshore moving partial standing wave fronts can be observed, they are products of oblique incident wave, wave shoaling and wave reflection. However, until now it is still an open question that whether edge waves are responsible for the harbor's resonance. On the other hand, infragravity wave generated by group wave has been mentioned in many studies. Surf beat, coined by [3], is the infragravity wave induced by group waves, which are frequently observed at the shore. One explanation [4] for the surf beat is that a group of high breakers transport a large volume of water onshore, which raised the mean water level. As a result, the shoreline tends to act as a source of long-period waves. These long waves move seaward and along shore, which may excite resonance in the nearby harbor.

It has been recognized that there are bound long waves accompanying group waves. Reference [5] showed theoretically that, using radiation stress, as wave groups move shoreward there is a set-down wave which is bound to the group wave, having the same period with the group wave period. The set-down in shallow water beneath groups of waves of amplitude a is given by [5]:

$$\bar{\varsigma} = -3ga^2 / 2\omega^2 d^2 \qquad (1)$$

where ω is the short wave frequency, d the water depth. It can be seen that the set-down is proportional to the square of group wave amplitude and inverse proportional to the square of water depth and short wave frequency. Reference [6] demonstrated theoretically that without wave breaking, the natural harbor oscillation can be excited directly by set-down beneath wave groups. He also showed experimentally that when the group period is close to the natural period of the harbor, resonance would occur with the set-down behaving as if it were a real long wave. The experiment was designed to avoid wave breaking outside the harbor entrance. His experimental work indicated that although set-down increases as the square of the primary wave height, the height of resonant long wave excited inside the harbor by set-down nearly proportionally to the primary wave height itself.

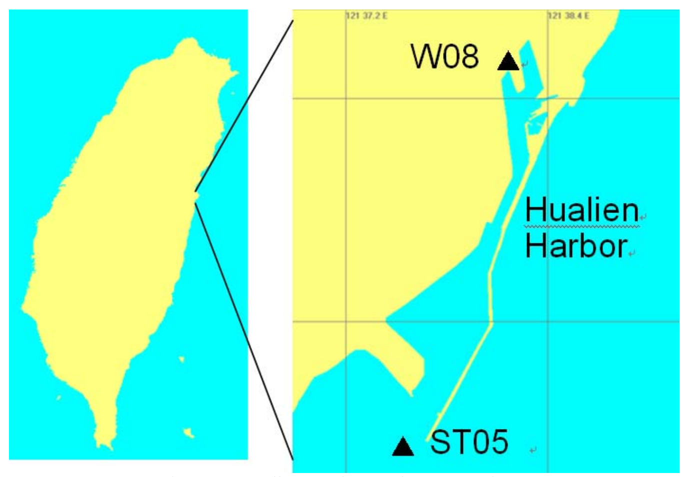

Figure 1 Hualien Harbor and wave stations.

Hualien Harbor located in the eastern coast of Taiwan. The harbor, about 3.5 km in length, has a long axis in the direction of NNE to SSW with its entrance facing SSW direction. The harbor can be generally divided into outer and inner harbors with a connecting channel of 100 m wide between the two. The outer harbor is funnel shaped with average depth of 14 m, while inner harbor "M" shaped with mean depth 10 m. An important feature about the harbor is a 4 km long concave beach located south of the harbor entrance. It can be reasoned that as group waves in typhoon swells reached the concave beach infragravity waves are generated. That is to say, group waves can be a source of the long period wave, which excites resonance in the harbor. Hence it is important to examine the group waves and its effect on the resonance of the harbor. The objectives of this study is to investigate group waves as a possible source of the infragravity waves for the resonance in the harbor and to find possible remedy for the resonant problem. This study consists of examining wave information recorded in the past typhoons inside and outside the harbor.

II. Wave Data and Methods

Wave data were acquired from the Institute of Harbor and Marine Technology. The wave data consists of those measured outside the Hualien Harbor at ST 05 and inside the harbor at the Wharf 08, ST05 and W08 in Fig. 1, respectively. The waves were measured by pressure gauges, and the nominal station depths were 15 m at ST05 and 10 m W08. Measurement schedule was 600 s every hour at the hour with a sampling rate of 2 Hz. These measurements were designed to obtain simultaneous wave data inside and outside the Hualien Harbor during passages of typhoons. We analyzed waves of Typhoon Haitang in July, 2005 (Fig. 2). Hourly wave data start from July 16, 2005 at 19:00 and end on July 19 at 07:00.

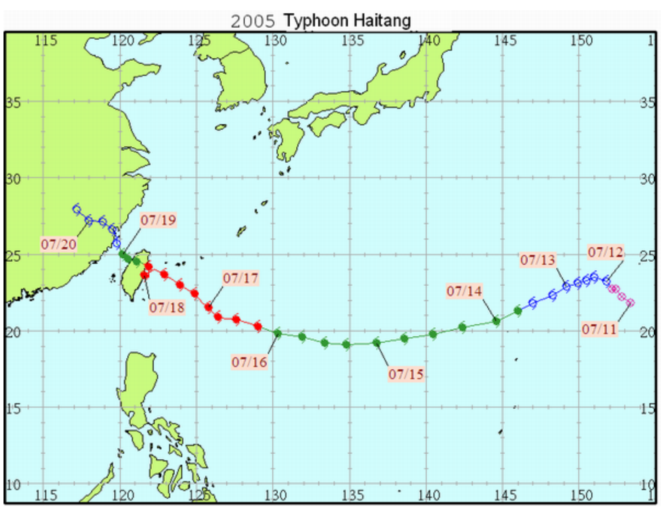

Figure. 2 Track of Typhoon Haitang, 2005.

As mentioned previously, for wave groupiness, we examine the run length, groupiness factor defined by Smoothed Instantaneous Wave Energy History (SIWEH), and the standard deviation of the wave envelope. The groupiness of the waves measured outside the harbor were examined, and it was compared to the parameters of the infragravity waves obtained inside the harbor.

The length of wave group can be described by run length [7]. A run of high waves is defined as the number of consecutive wave heights that are higher than a specified threshold value. The length of a total run of waves is the total number of waves that occur between the time of the first exceedance above the specified threshold value and the time of the first re-exceedance above the same specified threshold value. To examine the group characteristics by total run length, one needs to specify a threshold level. In this study, we use 75% of significant wave height as the threshold level and calculate the mean of all total run lengths in the waves measured in each hour at ST05.

The groupiness of a series of waves is also characterized by a groupiness factor based on smoothed instantaneous save energy history. Let $\eta(t)$ be the time series of the surface wave elevation. Reference [8] defined the smoothed instantaneous wave energy history (SIWEH) as:

$$S(t) = \frac{1}{T_p}\int_{-\infty}^{\infty} \eta^2(t+\tau)Q(\tau)d\tau \tag{2}$$

where T_p is the peak spectral period, τ the time lag, and $Q(\tau)$ represents a low pass filter defined by:

$$Q(\tau) = 1 - \frac{|\tau|}{T_p} \qquad |\tau| < T_p \tag{3}$$

The SIWEH is the squared wave elevation time series, smoothed with a filter having a width equal to the peak spectral period of the waves [8]. To represent the groupiness of the waves, they defined a goupiness factor ($GF1$):

$$GF1 = \frac{1}{\overline{S}}\sqrt{\frac{1}{T_N}\int_0^{T_N}\left(S(t) - \overline{S}\right)^2 dt} \tag{4}$$

where $\overline{S}$ and T_N are the mean of $S(t)$ and data time length respectively. The $GF1$ in (4) is actually a coefficient of variation of the SIWEH $S(t)$.

Another method for studying groupiness is to analyze the envelope of the surface wave profile. Assuming that the sea surface elevation at a point can be approximated by summing N wave components [9]:

$$\eta(t) = \sum_{m=1}^{M} R_m \cos(2\pi f_m t + \theta_m) \tag{5}$$

where R_n, f_n, and θ_n are the amplitude, the frequency, and a random phase angle, respectively, of the nth wave component. The random phase angle is assumed uniformly distributed in the interval (0, 2π). The Hilbert transform, $\hat{\eta}(t)$ of $\eta(t)$ is given by [10] and [11]:

$$\hat{\eta}(t) = \sum_{m=1}^{M} R_m \sin(2\pi f_m t + \theta_m) \tag{6}$$

We may define an analytical function:

$$AF(t) = \eta(t) + j\hat{\eta}(t) = A(t)\exp\{j[\theta(t) + \phi]\} \tag{7}$$

where $i = \sqrt{-1}$. In the above equation, $A(t)$ is the envelope function defined by:

$$A(t) = \sqrt{\eta^2(t) + \hat{\eta}^2(t)} \tag{8}$$

and $[\theta(t) + \phi]$ is the instantaneous phase angle:

$$\theta(t)+\phi=\arctan\left(\frac{\hat{\eta}(t)}{\eta(t)}\right) \tag{9}$$

Based on the envelope function *A(t)*, ref. [12] then defined a groupiness factor, *GF2*, as follow:

$$GF2=\frac{\sqrt{2}\sigma_A}{\overline{A(t)}} \tag{10}$$

where σ_A and $\overline{A(t)}$ are the standard deviation and the mean of *A(t)* respectively. As can be seen, this dimensionless groupiness factor is related to the variation of the envelope of the wave profile normalized by the average of the envelope height.

In this study, we calculated the mean total run length, *GF1*, and *GF2* for the typhoon waves obtained outside the harbor (ST05) and compare them to the infragravity wave elevations, obtained by using 30s low-pass filter, measured inside the harbor (W08) to see if there are any correlation between them.

III. Results and Discussion

Shown in Fig. 3 was scatter diagram of mean total run length of the wave surface measured outside the harbor and 30 sec low-pass filtered mean wave period of the wave surface fluctuation measured inside the harbor. The figure shows that inside the harbor, the mean infragravity wave period was in the range of 55-110 sec, while the mean total run length of the wave outside the harbor ranged from 4 to 11 waves. However the correlation between these two parameters was extremely low, with a coefficient of 0.04.

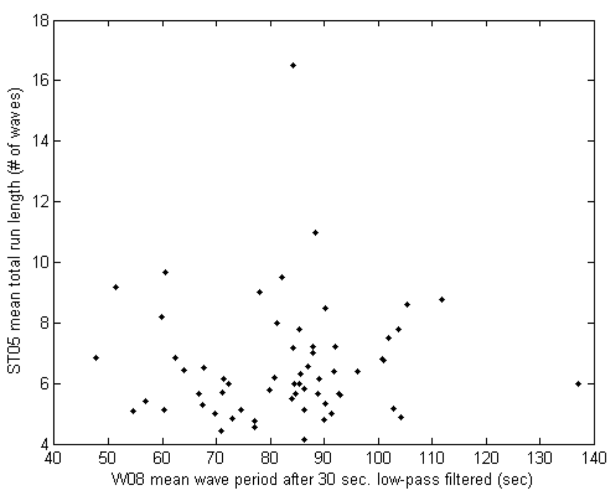

Figure 3 Total run length of the wave measured outside the harbor (ST05) vs. 30 sec low-pass filtered mean wave period of the wave surface fluctuation measured inside the harbor (W08).

Fig. 4 is a plot of Group Factors (*GF1* and *GF2*) of the waves measured outside the harbor against the standard deviation of the 30 sec low-pass filtered wave surface fluctuation measured inside the harbor. One can see that correlations between the *GF*s of the outside waves and the standard deviation of the long waves in the harbor are also poor, with coefficients of -0.45 and -0.44, respectively.

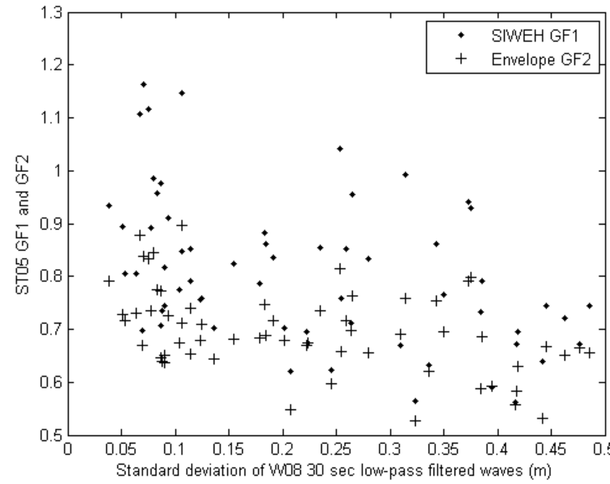

Figure 4 Group Factor of the wave surface measured outside the harbor (ST05) vs. standard deviation of the wave surface fluctuation measured inside the harbor (W08).

The poor correlations shown in Figs. 3 and 4 can be attributed to the way how the group factors *GF1* and *GF2* are defined. From (4), one sees that *GF1* is the standard deviation of SIWEH S(t) normalized by the mean of *S(t)*, and *GF2* the standard deviation of the envelope *A(t)* by the mean of *A(t)*. However, from our data it was seen that the fluctuation of the infragravity waves inside the harbor is related to the mean height of the waves outside the harbor. Also the means of *S(t)* and *A(t)* are also positively related to the mean wave height. Hence we plotted the standard deviation of SIWEH measured outside the harbor and standard deviation of the wave surface fluctuation measured inside the harbor in Fig 5, which did show a relatively good correlation with a coefficient of 0.74.

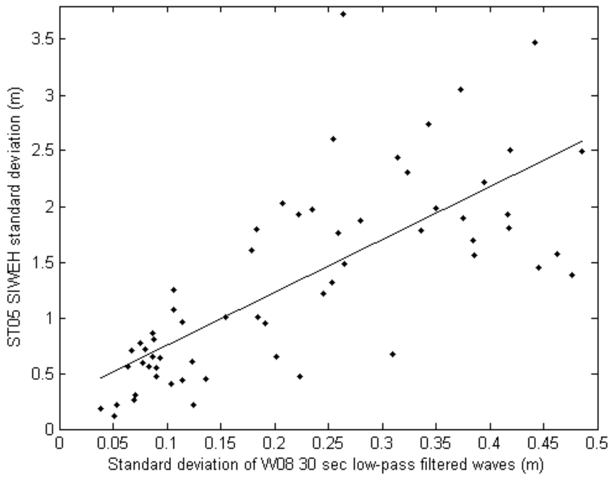

Figure 5 Standard deviation of SIWEH measured outside the harbor (ST05) vs. standard deviation of the wave surface fluctuation measured inside the harbor (W08). The correlation coefficient is 0.74.

To the same effect, the plot of the standard deviation of envelope of the wave surface measured outside the harbor against the standard deviation of the wave surface fluctuation measured inside the harbor shows good correlation also (Fig. 6).

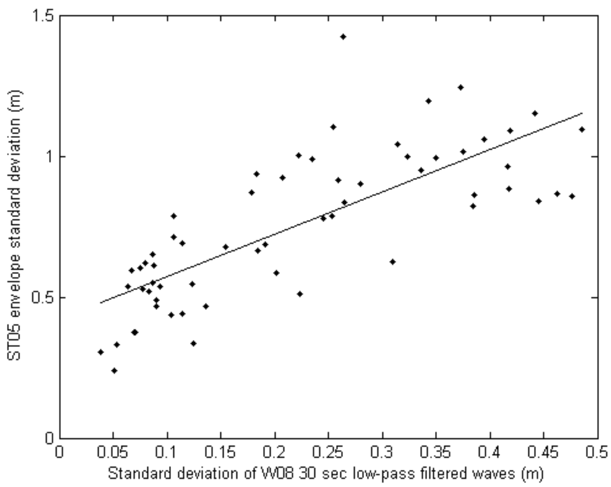

Figure 6 Standard deviation of envelope of the wave surface measured outside the harbor (ST05) vs. standard deviation of the wave surface fluctuation measured inside the harbor (W08). The correlation coefficient is 0.76.

IV. Conclusion

This study investigated the relationship between the group wave properties in the typhoon waves measured outside the Hualien Harbor and the infragravity waves inside the harbor. The usual groupiness factor defined by total run length, SIWEH and wave envelope show poor relationship between these factors and the intensity or period of the infragravity waves inside the harbor. However, we found that the standard deviations of the SIWEH and wave envelope measured outside the harbor has good correlation with the standard deviation of 30s low-pass filtered waves measured inside the harbor. This suggest that to find the source of the infragravity waves inside the harbor, the group wave characteristics outside the harbor may deserve further study.

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