Tsunami characteristics of the 26 December 2006 tsunami offshore Hengchun peninsula, Taiwan based on tide gauge observations

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1. Introduction: Two M_w7.0 earthquakes occurred offshore Henchun peninsula, Taiwan within 8 min (20:26 and 20:34, Taiwan standard time) on 26 December 2006. A minor tsunami was generated after the occurrence of the earthquakes and the tsunami signals was clear and instrumentally recorded for the first time. Although there was no tsunami induced runup or inundation was recorded from the event and only a minor damage was evidence due to the strong shock from the earthquakes, the recorded observations at tide gauge stations still provide an opportunity to justify the tsunami characteristics and related issues in Taiwan for purpose of disaster risk management. Here, several open issues which have not been addressed in region of Taiwan before were highlighted: to what extend could the tsunami-induced wave oscillation last and at which mode could the feature of wave oscillation become significant? This study aims to address these questions with answers based on this recent event while the detail analysis was left to the future work.

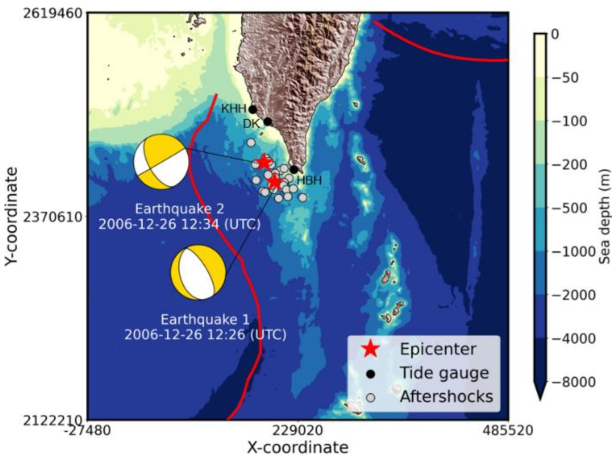

Figure. 1 Map of study area and focal mechanism of two M_w7.0 earthquakes occurred offshore Hengchun peninsula. The beachballs, which explained the focal mechanism of earthquakes, were plotted based on the CMT solutions suggested by GCMT. The red star symbols and gray circle symbols denoted the epicenter of two mainshocks and aftershocks, respectively. The red solid lines represented the subduction zones located offshore Taiwan, Manila Trench and Ryukyu Trench. Abbreviations were as follows: KHH = Kaohsiung, DK = Dongkung, and HBH = Houbihu for CWB tide gauge stations.

2. Data and Methods: Three tide gauge records of 36 h (from 0:00 26 December 2006 to 12:00 27 December 2006, Taiwan standard time) in Kaohsiung, Dongkung, and Houbihu (the location is shown in Figure 1) was obtained, processed, and analysis in present study. The tide observed data were provided by Central Weather Bureau (CWB), R.O.C. with sampling rate of 6 min at each station. The sea level data was de-tided by removing the long period (>2 h) tidal constituents, but no resampling or interpolation was applied to the observed records. The Root-Mean-Squared Amplitude (RMSA) is applied in this study as an approach to measure the duration of high tsunami energy wave at each site. The RMSA was applied to observations recorded at all three tide gauge stations with moving time window length of 24 min. Here, the tsunami duration represents the time interval which the recorded sea level is above that of the background signals (i.e. before the arrival of first wave). For estimating the spectra of tsunami, the Fast Fourier Transform analysis (FFT) was applied. The tsunami data of background signals (0~-5 h), tsunami signals 0~5 h, and tsunami signals 5~10 h at each station were adopted for analysis. For examining the tsunami-induced components, the spectral ratio $S_R(\omega) = S_{obs}(\omega) / S_{bg}(\omega)$ was computed from the tide gauge recorded signals, where $S_{obs}(\omega)$ denotes the observation signals of tsunami and $S_{bg}(\omega)$ is the background signals (i.e. those signals prior the occurrence of tsunami).The tsunami source periods, wave oscillation mode, and decay of tsunami energy at each site were then evaluated and discussed based on the spectral ratio calculated using the formula.

3. Tsunami amplitudes and durations: Among the tide gauge records observed in Southern Taiwan, the maximum tsunami amplitude from trough-to-crest at each station were 16 cm (Kaohsiung), 24 cm (Dongkung), and 59 cm (Houbihu), respectively. On the other hand, the respective arrival times of tsunami at each station were 52 min (Kaohsiung), 28 min (Dongkung), and 16 min (Houbihu), while the arrived first wave at Kaohsiung and Dongkung were not recorded as the largest. In addition to the significant difference of primary wave parameters, the time series distribution of sea level recorded at Kaohsiung and Dongkung are significantly different to that observed at Houbihu with a bell-shape distribution. (Figure 2a) The RMSA diagram illustrate when high tsunami energy waves appear and how long the tsunami amplitude recorded at each station was above the basic oscillation level before the occurrence of tsunami, as shown in Figure 2b. The maximum RMS amplitude recorded at Houbihu was estimated as 2-3 times higher than those recorded at Kaohsiung and Dongkung, while the tsunami durations were estimated for about 3.9-6.4 h in various stations. Either the primary wave characteristics or the difference of tsunami durations suggested a different mechanism of tsunami wave was responded at various site during the 2006 tsunami.

4. Spectral analysis: In order to explore various response of tsunami wave mechanism at different site, the discussion was conducted based on the spectral evolution. As shown in Figure 3a, the periods of pre-dominant peak from the tsunami observation signals (both 0~5 h and 5~10 h) are different to those from background signals at most stations. As suggested by Rabinovich et al., 1997, the wave components observed at coastal observation are associated to both tsunami source and bathymetry. Here, assuming the bathymetry condition before (background signals) and during the tsunami event (observation signals) were approximately equal, the spectral ratios were considered free from the bathymetry effects and presented the amplification of energy due to tsunami in comparison to background signals. The spectra ratios at all stations were shown in Figure 3b. In comparison of spectral ratios change within time interval of 5 h, the rate of tsunami energy decay in Dongkung was estimated as approximate 0.01, while a relatively smaller rate of 0.1 was measured in Kaohsiung and Houbihu. This result also explained why the tsunami duration at Kaohsiung and Houbihu were significantly longer in comparison to Dongkung in terms of wave energy.

To examine the tsunami source periods, according to the theory, the pre-dominant tsunami source periods are mainly dictated by fault rupture dimensions and sea depth around the source. Based on the distribution of aftershock epicenters and empirical scaling relations proposed by Papazachos et al., 2004, the approximate rupture areas of two earthquakes were estimated as 800 km^2, with fault length and width of 40 km and 20 km, respectively. The sea depth around the source areas are range from 100~200 km, as shown in Figure 1. On these senses, the approximate pre-dominant periods which dictated by tsunami source could be estimated as 15.1~21.3 min (dictated by fault width) and 30.1~42.6 min (dictated by fault length). From geographical locations of tide gauge stations (Figure 1), the first tsunami wave propagated toward Kaohsiung and Dongkung which were likely pre-dominant to the source component dictated by fault length, while Houbihu might receive a relatively shorter period components which mainly led by fault width. From spectral analysis, the spectral peaks revealed by tsunami observations at the first 0~5 h show the results which were fairly consisted with those estimated from theory. The other peaks (13.9, 23.5, 51, and 76.5 min) revealed from the tsunami observation of later phase (tsunami 5~10 h) were likely attributed to non-source phenomena such as wave oscillation. (Figure 3b)

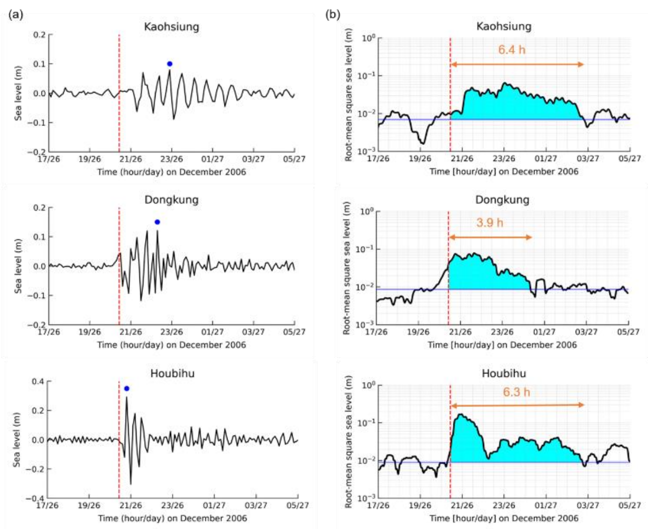

Figure 2. (a) Time series of sea level change for 26 December 2006 tsunami recorded at three tide gauge stations. (b) The RMSA diagrams at various site of observations. The red dashed lines denoted the occurrence time of first mainshock. The blue circle symbols presented the arrival time of maximum sea level. The cyan blue shaded areas illustrated the tsunami duration at each station. The orange arrows stand for the range of tsunami duration.

5. Conclusions and future works: In present study, the tsunami characteristics of recent event, 26 December 2006 Hengchun earthquake tsunami, was studied based on the analysis of tide gauge observation data. The main findings are:

(1) The maximum tsunami amplitude from trough-to-crest recorded at three station are 16 cm (Kaohsiung), 24 cm (Dongkung), and 59 cm (Houbihu), respectively, while the first wave observed at Kaohsiung and Dongkung are not recorded as the largest. The late arrival of maximum waves were attributed to the wave oscillation due to the repeat reflection and refraction of tsunami wave among the shallow beach on the continental shelf.

(2) The duration of high tsunami wave energy was estimated from 3.9 h to 6.4 h in various stations and the rate of tsunami energy decay within 5 h was estimated range from 0.1 to 0.01 at various site. These results suggested a need of longer warning duration than usual for the future tsunami event in southern Taiwan due to the excited high energy waves.

(3) The tsunami source periods were identified as 15.1-21.3 min and 30.1-42.6 min. The other peak periods (13.9, 23.5, 51, and 76.5 min) were attributed to non-source phenomena of tsunami wave associated to wave oscillation due to the action between tsunami and bathymetry.

(4) The focal characteristics of tsunami in southern Taiwan were discussed based on the recorded signals in tide gauge stations, while a future work of detail analysis on tsunami wave propagation among continental shelves was strongly recommended to coherence the understandings from this work.

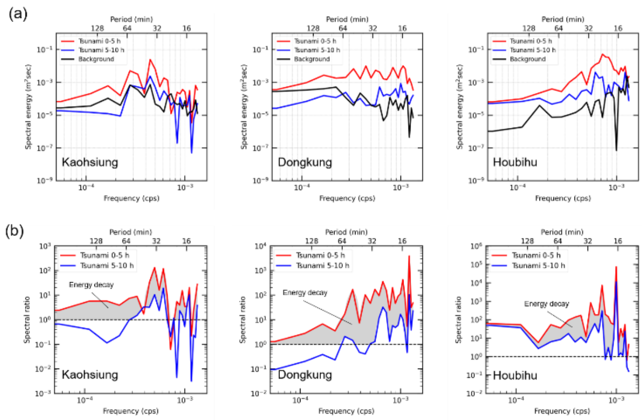

Figure 3. (a) Tsunami spectra and (b) calculated spectral ratios at each tide gauge station. The black, red, and blue solid lines represent results of background, tsunami 0~5 h, and tsunami 5~10 h, respectively. The gray shaded areas stand for the decay of tsunami energy within two periods of time.

References:

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