Variation of Impact along the East Coast of Eastern Samar Due to Typhoon Haiyan in the Philippines

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The east coast of eastern Samar in the Philippines faces to the Pacific Ocean and suffered significant damage due to storm waves caused by Typhoon Haiyan. The coast has various characteristic features such as fringing coral reef, varying beach slopes, pocket beaches and well-developed mangrove forest especially inside Matarinao bay. This paper aims to investigate how this characteristic coast was affected by the catastrophic typhoon event mainly through observations of satellite images. Various types of optical satellite images were utilized to capture the changes before and after the typhoon event. Comparisons of satellite observations and numerically computed wave height distributions along the coast clearly showed that the coast inside the bay was strongly protected by sand spit with fringing reefs and thus mangrove strip inside the bay was less damaged. It was also found that estimated penetration distance of wave runup on the beach showed certain correlation with the local width of fringing coral reefs.

**Key Words**: typhoon Haiyan, coastal damages, remote sensing, the Philippines

1. INTRODUCTION

The Philippines is highly prone to tropical cyclones due to its geographical setting in the West Pacific Ocean1. Surrounded by sea water with relatively high surface temperature, the Philippines receives considerable number of typhoons every year2.

Typhoon Haiyan is the second deadliest typhoon recorded in the Philippines and became the strongest typhoon at the time of landfall. The typhoon reached Eastern Samar on November 8, 2013, at around 4:40 am in local time. While most severe damages were observed in Tacloban, this study focused on the east coast of Eastern Samar Island, where faces directly to the Pacific Ocean. Observed inundation heights along the coast were much higher than numerically predicted wind-driven storm surge level while phase-averaged wind-driven wave generation model predicted significantly high stormy waves3. The coast is mostly covered by fringing coral reef, which should have potential of significant wave attenuation through combined effects of bed friction and breaking. On the other hand, the reef may have certain influence on amplification of the water level on the reef due to setup and wave trapping effects.

Focus of this study is thus to capture the overall inundation characteristics along the coast of Eastern Samar and investigate how these characteristics are related to various physical features such as width of fringing coral reefs, estimated wave heights, and local beach topography conditions. Damages of alongshore vegetation including mangroves were also examined through the analysis of satellite images and numerical wave simulations.

2. STUDY AREA

This study especially focuses on the southern part of Eastern Samar. Along nearly 80 km of coastline strip of the east coast, several sites were selected for this study.

Fig.1 illustrates the map of study area and small map on the right upper corner shows the typhoon track overlaid on the Philippines country boundary.
3. MATERIALS AND METHOD

(1) Data
Very High Resolution (VHR) satellite images were used to capture the impact of the typhoon Haiyan on the target coast. WorldView-2 pan sharpened multispectral, 50 cm resolution satellite data were used to capture the area before the typhoon. The image mosaic consist of images from the year of 2011 to those of November, 2013. Satellite images after the typhoon were obtained from the USGS Hazard Data Distribution System under the publicly provision policy. The system is dedicated for the provision of quick and easy access to imagery and geospatial data during emergency response and recovery operation. Several images, including QuickBird and WorldView-2 data with 3m-resolution were used. Since the data were highly distorted due to instant provision of data for emergency response activations, all the post typhoon images were rectified to pre disaster images. The Google Earth images, after the typhoon event were used to fill the gaps of post typhoon image data set.

LANDSAT 8, 30m-resolution satellite images were used to evaluate the change of vegetation cover specially mangrove coverage along the coast of Matarinao bay. The data were freely obtained from the U.S Geological Survey (http://eros.usgs.gov/) before and after the attack of typhoon Haiyan.

Right after the typhoon, the post disaster survey was jointly conducted between Japan Society of Civil Engineering, JSCE, and Philippine Institute of Civil Engineers, PICE, and this study applied their survey results such as beach slopes, inundation boundary and inundation height at some locations (Fig. 1). The research team later conducted a follow-up survey. All the data were provided for this analysis.

(2) Feature extraction and analysis
Post disaster VHR satellite images contained uneven illumination and haze which could lead to erroneous results in automated classification. Hence, visual interpretation techniques were adopted for extracting information from VHR satellite data. Fig. 2 illustrates the quality of pre and post typhoon VHR satellite data.

Coral Reef (CR), Coastline before Typhoon (CBT) and Sand Encroachment Line on the Land (SELL) were extracted from the satellite data. SELL is a good indicator of inundation extent due to storm waves and it was clearly recognized by the clearance of soft vegetation cover near the beach.

Then proximity analysis was performed by taking the CBT as the baseline. Distance to SELL and edge
of CR were calculated at 100m interval along CBT. Fig. 3 shows the flow chart of the analysis. The distance analysis performed with the help of the Digital Shoreline Analysis System\(^6\) which is a freely available software application that works within the Environmental Systems Research Institute (ESRI), ArcGIS software (v. 10).

(3) Image classification
Vegetation analysis was performed to detect the changes inside the Matarinao bay using medium resolution LANDSAT-8 multispectral imageries. In the first step, band 2 to band 7 were used for the iso-clustering which clustered the natural grouping of pixels in multivariate data. The clustered results were used for the final unsupervised 40 classes of classification with the Maximum-likelihood algorithm. In the final step of classification, 40 classes were further narrowed down to several classes by cross interpretation using aid of VHR satellite images and field observations. The selected classes are mangrove, forest, mixed forest, disturbed forest (after typhoon), bare land, sea, clouds and shadow. All the image processing was conducted within ArcGIS software and its tools.

In order to do the change analysis, the same classifications were applied to both pre and post images. Obtained vegetation change results were then compared with the wave heights inside the bay estimated through the following numerical analysis.

(4) Numerical analysis of wave-sheltering effect
As seen in Fig. 1, Matarinao bay is highly sheltered by the peninsula located at the north of Salcedo and thus mangrove forest is well developed especially inside the bay while the bay directly faces the Pacific Ocean. In order to investigate overall characteristics of “sheltering effect” of the bay under the stormy wave conditions, we carried out numerical experiments. This study applied a linear mild slope equation\(^7\) for computations of wave shoaling, refraction and diffraction around the bay. Focusing on diffraction and refraction, breaking dissipation was not accounted for in this computation. Incident wave angle was set to be 4 degree northward from the east based on the numerical estimation of wind-driven waves\(^8\). We assume that wave spectra is highly concentrated during the storm and single incident wave period, either \(T=15s\) or \(20s\), incident angles of \(4^\circ\), \(9^\circ\) and \(14^\circ\) northward from the east, and \(1^\circ\) and \(4^\circ\) southward from the east, were applied for computation of wave field of highly concentrated frequency spectrum. Then spatial distributions of computed wave heights were integrated with weight determined based on Mitsuyasu-type wave directional spectra\(^8\) with \(S_{max}=75\). Bathymetry data were obtained from National Mapping and Resource Information Authority and used for the study.

4. RESULTS AND DISCUSSION

(1) Alongshore distribution of CR and SELL
Fig. 4 illustrates the local variation of the SELL in Section 2 (in Fig. 5). As seen in the figure, there are several rocky cliffs exposed to the shoreline and
these cliffs form pocket beaches along the coast. The VHR satellite images clearly show the changes before and after the typhoon event. Furthermore, sand movement towards sea clearly visible in post disaster images.

Fig. 5 shows the alongshore distribution of distance from CBT to either CR or SELL estimated through the satellite images. Fig. 6 shows the relationship of each distance. The figure distinguishes the data obtained from the different four sections, specified in Fig. 5, by using different symbols. In the figure, data was not plotted at several locations where rocky cliffs were exposed to the coral reef.

Fig. 6 appears to have different relationships in different sections. Section 1 is around Hernani and angle of shoreline toward incident waves differs from the other sections. Section 2 and 3 show a peak of SELL along the CR and this results somehow implies that the reef with certain width may cause amplification of stormy waves. Absence of good terrain data limits the further explanation. In section 4, around Guiuan, low-elevated wide plane is extended behind the shoreline and thus observed distance between CBT and SELL was much longer than those of the other sections.

(2) Vegetation Analysis

Fig. 7 (a) and (b) show the LANDSAT-8 images used for the analysis and (c) shows the results classification analysis. It is clearly visible that strip of mangrove inside the bay remains unchanged even after the typhoon event (yellow color). On the other hand, red color represents the damaged mangrove on the small islands outside the bay.
In contrast, pink color represents the disturbed forest, mixed forest and other vegetation. Since the surrounding coastal edge of the bay was not damaged, most of the damages in pink color could be due to wind force, non-wave interaction mechanism. Other categories represent the remaining land cover classes. The vegetation analysis need to be further investigated with ground truth data and supervised image classification.

(3) Wave-sheltering effect of Matarinao bay

Fig. 8 shows the bathymetry data and the results of computed wave heights when incident wave period was $T=15s$ and $20s$, respectively. It is clearly visible that wave heights inside the bay is much smaller than those along the north coast of the bay where Hernani is located. It is also interesting to note that refracted waves tend to concentrate on the coast behind the peninsula where the area of damaged forest (pink color in Fig.7) was also relatively high near the coastal strip than other coastal areas of the bay. Further on-site investigation should be needed to identify the influence of this local concentration of wave heights behind the peninsula. The numerical computation results are intimately relate with vegetation change especially around the bay mouth (red color in Fig.7). Small islands near the bay mouth were highly damaged even though that part covered with mangrove vegetation. Along the Hernani coast, mixed forest was the dominant land cover category before the typhoon and these areas were significantly changed after the typhoon.

It should also be pointed out that similar wave concentrations around Hernani and the coast behind the peninsula were also observed with different incident wave angles. As seen in the Fig.8(b) and (c), wave angle was abruptly altered at the edge of reef and influence of these reef bathymetry on concentration of waves need to be further investigated.

5. CONCLUSIONS AND FUTURE STUDY

The mapping of the typhoon impact using remote sensing and numerical modeling provided clear evidence of variation of damage along the coast which could be further extended for detail assessment. Vegetation analysis was performed using the different seasonal LANDSAT-8 images (April and December) due to presence of higher percentage of cloud coverage. The seasonal effect on change analysis could be minimized by using the same seasonal images. It was found that overall vegetation coverage had been reduced after the typhoon event.

Another interesting observation was the comparisons of pre and post images clearly showed the evidence of movement of eroded sand both landward and seaward of the shoreline.

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