LOCALLY CONCENTRATED SEVERE BEACH EROSION ON SEISHO COAST CAUSED BY TYPHOON T0709

Yoshimitsu TAJIMA[1] and Shinji SATO[2]

[1]Member of JSCE, Associate professor, Dept. of Civil Eng., The University of Tokyo
(Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan)
E-mail:yoshitaji@coastal.t.u-tokyo.ac.jp
[2]Fellow of JSCE, Professor, Dept. of Civil Eng., The University of Tokyo
(Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan)
E-mail:sato@civil.t.u-tokyo.ac.jp

This paper studies severe beach erosions of Seisho coast caused by the typhoon No.9 in September 2007. Special focus is put on locally concentrated erosions and damages behind the Oiso-Spur, where the area with relatively shallow water depth, h < 100m, convexly extends toward the offshore. Field survey was first carried out to capture alongshore distributions of hydrodynamic forces that directly cause beach erosions and damages on the Seisho Bypass, the expressway along the coast. To quantitatively compare the intensity of hydrodynamic forces, inundation heights were measured at 28 locations along the coast. Measured inundation heights showed spatially periodic distributions along the coast and the peak of measured inundation heights was at Ninomiya Interchange, where the most severe damages were observed.

Wave and current conditions during the storm surge were analyzed based on the hydrodynamic data recorded at Hiratsuka Experiment Station located about 7 km east from the most damaged area. Applying spectrum analysis, recorded time-varying surface water elevations and current velocity components were decomposed to hourly averaged wave heights, periods and directions within two separate ranges of wave periods. Hourly averaged heights of long wave components significantly increased as the typhoon approached to the damaged area.

Numerical analysis was finally performed to investigate the physical mechanisms of observed local concentrations of damages and beach erosions. Depth-averaged 2DH non-linear shallow water equations were applied to compute near-shore dynamics including long-wave propagations. Wind shear stress and radiation stresses of short wind waves were introduced as external forces in the momentum equations. Computed results clearly showed that long wave components concentrated around the most damaged site due to refraction and reflection effect of the Oiso-Spur and the estimated along-shore distributions of long-wave heights surely corresponded to the measured distributions of inundation heights.

Key Words : *storm surge, long wave, beach erosion, longshore current, wave setup*

1. INTRODUCTION

In September 2007, the typhoon No.9, T0709, hit the Japan Pacific Coast and caused severe damages on the near-shore area. Seisho coast, shown in **Fig.1**, is one of the coasts that suffered most significant damages by T0709. While Seisho coast has long coast lines, damaged area was concentrated behind the Oiso-Spur, where the area with relatively shallow water depth of h < 100m is convexly extended toward the offshore. According to Sato et al. (1998), Seisho coast had suffered severe damages in 1997 by the typhoon No. 20 and, similar to the damages due to T0709, the damaged area along the coast was also locally concentrated. It should however be stressed that the location of the most damaged area was about 6km west from the site where T0709 caused the most severe damages. The ultimate goal of this research is thus to understand physical mechanisms of the locally concentrated damages on Seisho coast caused by typhoon T0709 and to apply obtained new findings to consider effective damage prevention measures against storm surges.

In this paper, we first summarize the field survey carried out to capture the quantitative distributions of hydrodynamic forces that directly caused damages on the coastal area. Wave and current data recorded at Hiratsuka Experiment Station are then analyzed to describe the characteristics of local hydrodynamic force conditions during the storm. Numerical analysis is then performed to represent the hydrodynamic characteristics during the storm. Based on these analyses, finally, we discuss the physical mechanisms of locally concentrated damages and beach erosions caused by T0709.

2. FIELD SURVEY

Field survey was carried out on November 20th, 2007 to observe overall damages of the coast and to quantitatively capture alongshore distributions of hydrodynamic forces during the storm caused by T0709. In this survey, we measured the local elevations of the highest water marks along 20 km-long coastline from the east side of the Sagami River mouth to the Sakawa River mouth. **Fig.2** shows the geography of the surveyed area and alongshore distributions of measured elevations of wave run-up based on the datum of Tokyo Peil. A mark of washed vegetation area, as shown in **Fig.3**, was first used to detect the highest water marks. Especially near the most damaged area, i.e., around Ninomiya- Interchange as shown in **Fig.2**, the coast was covered by concrete seawall and thus there was no vegetation area. When water marks of vegetation area were not available, we looked for a water mark of flown debris or witness' information. At the most damaged site, as shown in **Fig.4**, splashing water overtopped the Seisho-Bypass and thus **Fig.2** just shows the elevation of the Seisho-bypass as a height of run-up wave. As seen in **Fig.2**, observed alongshore distributions of run-up heights had somewhat periodic undulation and the location of observed highest run-up area corresponded to the place where Seisho-Bypass was most severely damaged.

Besides measurements of run-up heights of stormy

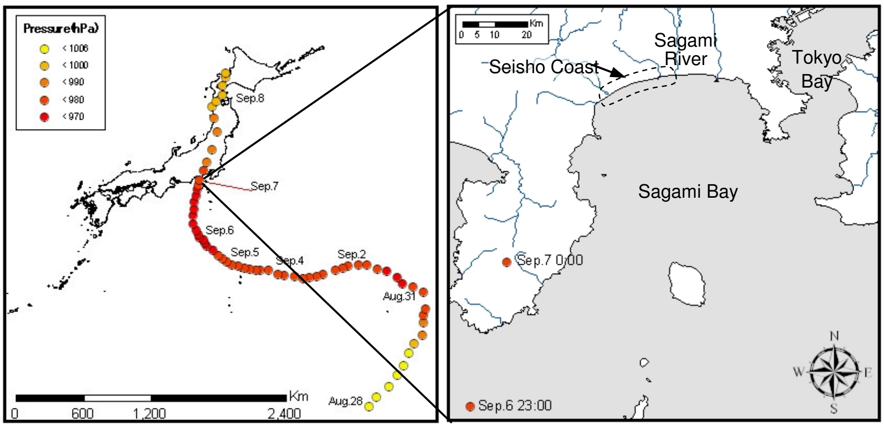

Fig.1 Overview of damaged area and tracks of T0709.

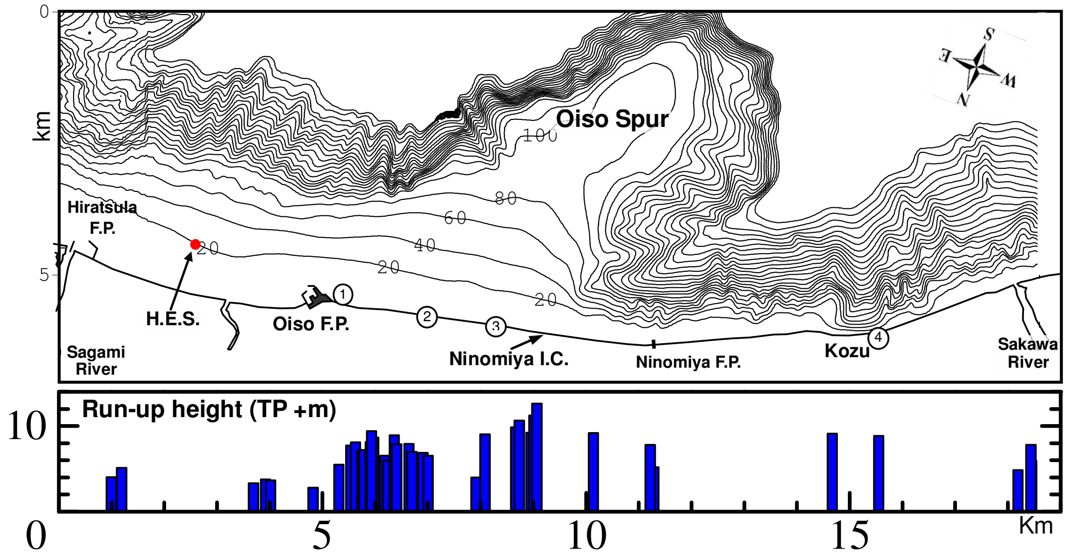

Fig.2 Alongshore distributions of measured elevations of local highest water marks.

Fig.3 Vegetation area eroded by storm waves (at **Fig.2**, #2)

Fig.4 Waves splashing on Seisho Bypass around Ninomiya Interchange.

waves, we also observed severe topography changes along the coast. **Fig.5** shows the photograph taken around the west-side of Oiso fishing port, indicated by number "1" in **Fig.2**. As seen in this picture, sandy beach was completely washed away and underneath rocks and gravels of relatively large grain sizes were exposed to the surface. Considering the fact that the other side of Oiso fishing port kept fine sandy beach even after the event, this observed severe erosion should be mainly due to unbalance of westward longshore sediment transports. **Fig.6** shows the collapsed seawalls near Ninomiya Interchange, where is indicated by number "3" in **Fig.2**. In front of the seawall, sandy beach was severely eroded during the storm and bed elevation subsided for about 4 meters in height. Eventually, subsidence of the sandy bed collapsed of the foundation of the seawall and the structure was finally collapsed. **Fig.7** shows the eroded beach observed around Kozu, indicated by number "4" in **Fig.2**. As seen in the figure, the pre-storm bed elevation was about 1m above the one shown in the figure.

3. ANALYSIS OF WAVE AND CURRENT DATA DURING THE STORM

Wave and current conditions during the storm surge were analyzed based on the hydrodynamic data recorded at Hiratsuka Experiment Station located about 7 km east from the most damaged area (**Fig.2**). Applying spectrum analysis method, time-varying surface water elevations and current velocity components were decomposed to mean current components, short and long wave components whose wave periods fall in the ranges of T (s) <30 and 30< T (s) <300, respectively. **Fig.8** shows hourly time-series of estimated mean current components, root-mean- square wave heights and wave periods of short and long wave components, respectively. As seen in the figure, both short and long wave heights increase when T0709 approaches to the site and reach their peaks around midnight on September 6th. The heights of long wave components increase more rapidly than those of short waves. This feature corresponds to the fact that amplitude of the bounded long wave undulation is proportional to the square of local short wave heights. Magnitude of mean current velocity also increases as short wave heights increases. During the storm, westward current, i.e., alongshore current dominated north-ward current. This westward longshore current reasonably corresponds to the observed features in that west-side of the Oiso fishing port was severely eroded while the other east side was not eroded and remained as fine sandy beach.

4. NUMERICAL ANALYSIS

In order to investigate the physical mechanisms of observed local concentration of damaged area, we performed numerical analysis based on unsteady depth-integrated 2DH non-linear shallow water equations. In this model, short wave radiation stress and wind shear stress were introduced to the momentum equations as external forces that induce near-shore current and set up of mean water level. Energy balance equations coupled with Tajima and Madsen's (2002) breaking and broken wave

Fig.5 Eroded coast on the west side of Oiso fish port (Fig.2, #1).

Fig.6 Damaged sea wall at Oiso (**Fig.2**, #3)

Fig.7 Eroded beach around Kozu (**Fig. 2**, #4).

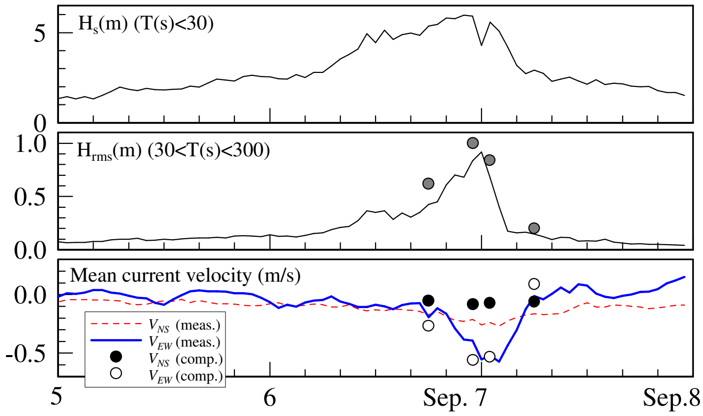

Fig.8 Time-varying wave conditions of short ($0<T$(s)<30) and long waves ($30<T$(s)<300) and mean current components.

dissipation model was applied to compute spatial propagation and deformation of short wave energy. Based on the estimated wave energy distributions, the model computes spatial distributions of wave radiation stress which are directly applied to the 2DH momentum equations. In order to account for the influence of long wave fluctuations, slowly varying surface water level and corresponding volume flux were introduced at the offshore boundary. Time-varying incident long wave conditions were determined as summation of multiple sinusoidal waves of different wave periods and phase differences. Phase differences of each wave was randomly assigned on each wave component and, based on the observed data at Hiratsuka Experiment Station, the range of the wave period was set within $50<T$(s)<90. Assuming uniformly distributed frequency spectrum, amplitude of each sinusoidal wave was also set constant and its magnitude was determined so that the predicted long wave heights at Hiratsuka Experiment Station agreed with the observed data.

Figures, **Fig.9** and **Fig.10**, show spatial distribution of predicted mean current velocity and wave heights of long wave components when the short wave heights at Hiratsuka Experiment Station was maximum during the storm, i.e., at 23:00 on September 6th. In the figure, long wave heights are expressed as root-mean-square of instantaneous surface water fluctuations around the mean water level. As seen in the figure, strong westward longshore current was computed around the Hiratsuka and Oiso fishing ports and predicted longshore current velocity at Hiratsuka Experiment Station agreed well with recorded data. Moreover, this current velocity well explains the observed severe erosion on the west side of the Oiso fishing port. As seen in **Fig.10**, spatial distribution of the root-mean-square long wave heights had peaks in front of Ninomiya Interchange, i.e., the most damaged area. It is also interesting to note that the peaks of long wave heights in **Fig.10** also have periodic fluctuations along the coast. Based on these computed results, we may be able to deduce following features of long waves in front of the most damaged area: (i) long waves are refracted and gather behind the Oiso-Spur to increase their wave heights; (ii) there exists edge waves propagating eastward and the edge waves are partially reflected in front of Ninomiya Interchange due to sudden increase of the water depth and form partial standing waves along the shore. These features somehow

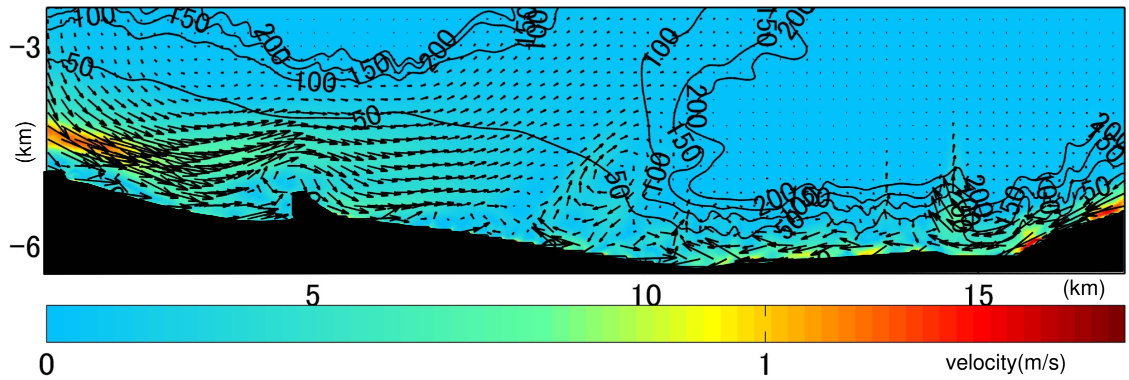

Fig.9 Predicted mean current velocity around the damaged area.

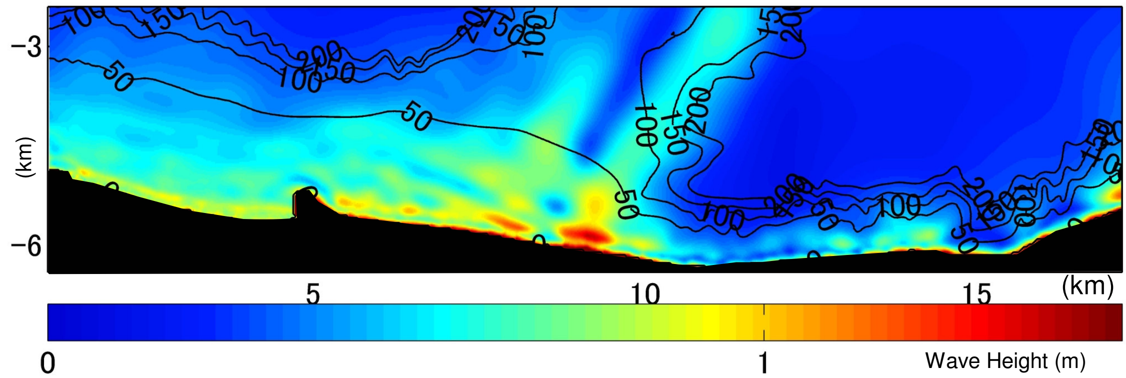

Fig.10 Predicted root-mean-square wave heights of long wave.

explain observed alongshore distributions of wave run-up heights.

5. CONCLUSIONS

In order to explore the physical mechanisms of locally concentrated damages and erosions due to T0709, we first carried out field survey on Seisho Coast. Measured height of water marks showed certain undulation along the coast and had its peak where the most severe damages were observed. The most severe beach erosion was also found near the most damaged area where the eroded bed level was about 4m below the pre-storm bed level.

Wave and current conditions during the storm were analyzed based on the hydrodynamic data recorded at Hiratsuka Experiment Station. As the center of T0709 nears the Seisho coast, both short wave and long wave heights increased and had their peak around midnight of September 6th. At the same time, mean current velocity also had its peak and westward current was dominant.

Numerical analysis was performed to understand the physical mechanisms of observed local concentrations of damages and beach erosions. The model accounted for the influences of short waves, long waves and mean current velocities induced by wind and radiation stresses due to short waves. The model predicted relatively strong westward mean current velocity near Oiso fishing port and this feature reasonably explained severe beach erosions observed on the west side of the port. Predicted long wave heights also showed alongshore undulation and had their peak near the most damaged area and this feature reasonably corresponded to the observed alongshore distributions of measured water mark heights.

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