Hydraulic Analysis of Submergence Damage by Typhoon 9918

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1. INTRODUCTION

The study of natural disaster is one of the most important ones in order to protect the lives and properties of victims. Various studies about disaster by a high tide and high waves with an attack of typhoon have been done till now. These were inspected from a viewpoint of meteorology and coastal engineering. However, without the estimate for rainfall, inflow from the back hill, and chronological order of submergence to be distributed widely, the satisfactory accuracy is not guaranteed. Therefore, these estimates are big factors of submergence damage. An amount of breakwater wave overtopping was required in this study. Furthermore, the rainfall and rainwater inflow and submergence states were estimated using GIS with actual field survey, and hydrological and remote sensing data.

2. STUDY TARGETS

2. 1. Typhoon 9918

Typhoon 9918 attacked north Kyusyu and Yamaguchi areas in the early morning of September 24, 1999. This typhoon resembled Typhoon 9119 in power and course in 1991 (Figure 1). However, such damage magnitude as Typhoon 5915 in 1959 was brought by Typhoon 9918. Because this typhoon hit there at the same time of a flood tide and a high tide. Fortunately, Typhoon 9119 hit there at an ebb tide.
In addition, it was one of causes that an east wind was blowing a gale from the west Suo Nada Sea. A significant wave height and a significant wave period of the past maximum were observed off Kanda, Kita-kyushu, where the center of the typhoon passed

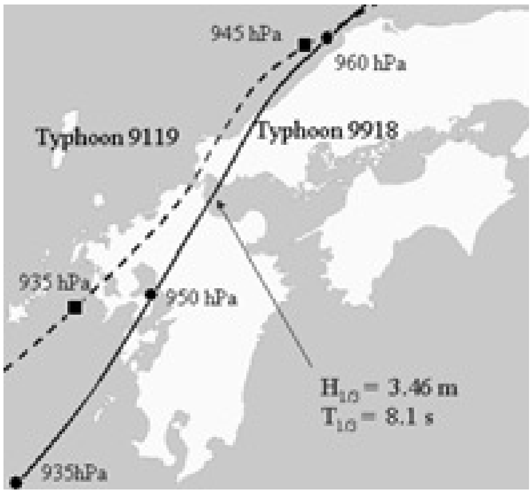

Figure 1 Courses of Typhoons 9918 and 9119

(Hashimoto *et al.*, 2000; Sato *et al.*, 2000).

2. 2. Study area

South New Moji area (about 180.6 ha), Moji district, Kita-kyushu city, Fukuoka prefecture, was the target in this study (Figure 2). This district was reclaimed land with two constructed banks. A bank of the north side (No. 1) has 814-m extension, while a bank of the south side (No. 2) has 1,171-m extension (Total extension becomes 1,985m). However, these banks were destroyed at 10 points by the wave force of the typhoon invasion (Takahashi *et al.*, 2000). A large amount of seawater invaded by wave overtopping and influence of bank collapse. Therefore, this area suffered the serious inundation damage. The bank No. 2 was divided into two (A and B) for convenience in this study (Figure 2). Especially, the bank No. 2A that received terrible damage was inspected. All the heights were described with a value of the chart datum level (C. D. L) in the following sections and figures.

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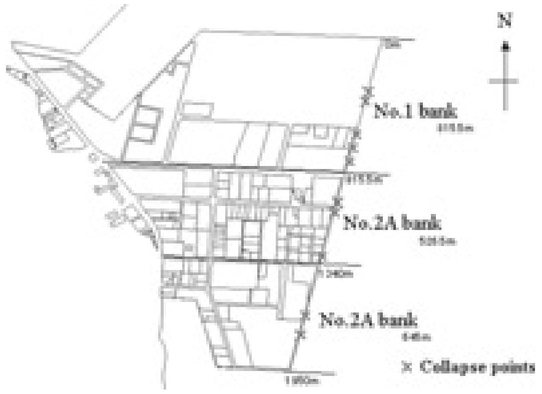


Figure 2 New Moji Port, south area

3. METHODS

The inundation of the coastal area by the typhoon invasion was formed by inflow from seawater, rainfall, and the back hill. The causes of inundation in the study area were analyzed by the following methodology. In addition, estimate of a storage amount in a submergence area was carried out.

3. 1. Estimate of inflow from deep water waves

The existing design standards for banks and dikes are derived from the instructions by Goda (*JSCE*, 2001). Generally, an amount of wave overtopping is estimated with the diagrams of wave overtopping designed by Goda (1990) in Figure 3. An amount of wave overtopping was calculated under the following conditions in this study.

The target was bank No. 2A (Its extension is 526.5m). One point of representative equivalent deep water waves in the offing wave height H_0' in front of the bank was used. The representative equivalent deep water waves and the representative-period equivalent deep water waves in the offing were referred to data by Kita-Kyushu-City Harbor Office (Table 1). The target time was 5:00 to 10:00 a.m., September 24. Most of collapse parts were at jointed concrete parts. The collapse time was not clear precisely. It was supposed to be before 7:00 a.m. because the surge was the most prominent at that time. Those conditions were classed in standing straight banks without vanishing-wave-tetrapod concrete block mounds.

Data at Kanda, Simonoseki, and Kagumeyoshi meteorological observatory stations were used for rainfall in the study area (Table 2). The serial rainfall during Typhoon 9918 passage was added up every meteorological observatory. The rainfall of the study area was calculated with the isohyetal method. The penetration or the losses were not considered in this study by the following reasons. It was shown that study area was paved more than 60% from a result of supervised land cover classification with NVIR bands of Terra/Aster (Bands 1, 2, and 3N in Figure 7). Analysis for chronological order of water levels in the whole reclaimed land was not enough at this step, too.

Next, rainwater inflow from the back hill was estimated as follows. Area of the basin where rainwater flowed into the target area was obtained by 50-m-mesh DEM. The runoff coefficient was estimated to be 0.8 because the back hill was a steep incline (*JSCE*, 1985).

3. 2. Storage discharge

A storage amount is a volume of between the ground and submergence surfaces. The ground level data were made from a result of ground elevation survey-

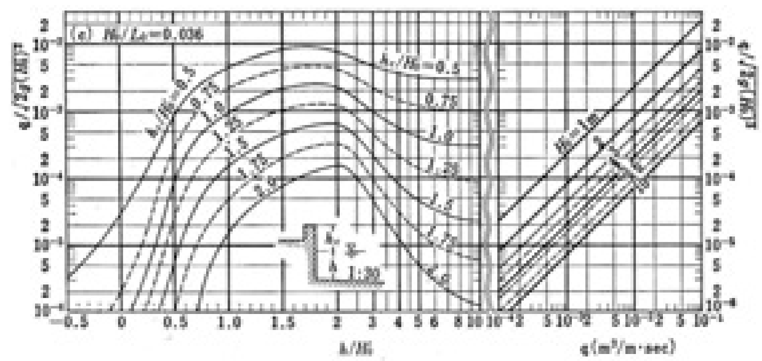


Figure 3 Goda diagrams for wave overtopping

Table 1 Parameters for estimate of wave overtopping

Time	Tide (m)	Frequency T (sec)	Wave length L_0 (m)	Depth h (m)	Equivalent deep water wave H_0' (m)	H_0'/L_0	h/H_0'	h_C (m)	h_C/H_0'
5:00	3.18	6.2	59.97	6.68	1.94	0.032	3.44	2.32	1.20
6:00	4.08	6.9	74.27	7.58	2.37	0.032	3.20	1.42	0.60
7:00	5.18	8.1	102.35	8.68	2.73	0.027	3.18	0.32	0.12
8:00	5.31	8.1	102.35	8.81	2.31	0.023	3.81	0.19	0.08
9:00	4.62	6.3	61.92	8.12	1.64	0.026	4.95	0.88	0.54
10:00	3.88	4.2	27.52	7.38	0.80	0.029	9.23	1.62	2.03

Table 2 Rainfall each meteorological observatory on September 24, 1999 (unit : mm)

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	Total
Shimonoseki	5	7	2	1	0	2	4	8	21	0	50
Yahata	10	3	2	2	0	3	9	19	16	1	65
Kagumeyoshi	3	1	1	1	0	4	9	29	12	1	61

ing in the target area. The submergence data were obtained from the flood damage reports by Kita-Kyushu City. Finally, ground elevation profiles of the target area were made from these data.

4. RESULTS

4. 1. Inflow of deep water waves

Wave overflow was calculated from the values estimated by the Goda diagrams. The result was shown in Table 3. Inflow of seawater became about 2 times by bank collapse. The total estimated amount of rainfall in the submergence damage was 55 mm in depth, and it was about 27,000m^3 in the whole target area. A basin area of the reclaimed land was about 554,000m^2 (Figure 4). This area exceeded the back area of bank No. 2A. The estimated amount of water that flowed into the back area of bank No. 2A was about 6,000m^3. The rainfall storage amount at the disaster increased by 30 % considering the inflow from the back hill.

4. 2. Storage amount

An average submergence surface was obtained from the heights of the ground and submergence (Figures 5 and 6). However, it did not form a smooth surface by influence of surge fluctuations and a spatial distribution of the measurement points. The average submergence surface was estimated as +6.7 m. The result was shown in Table 4. It was found out that most of the areas were flooded. In particular, the damage through East and West roads were huge. The result of ground elevation surveying showed the tendency that roads sank lower than the circumstance. In the

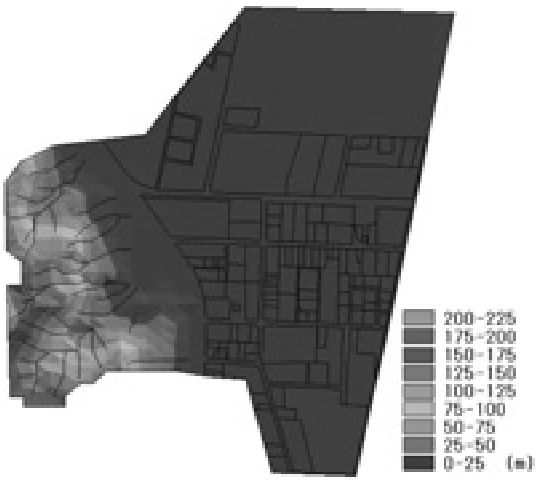


Figure 4 Basin area

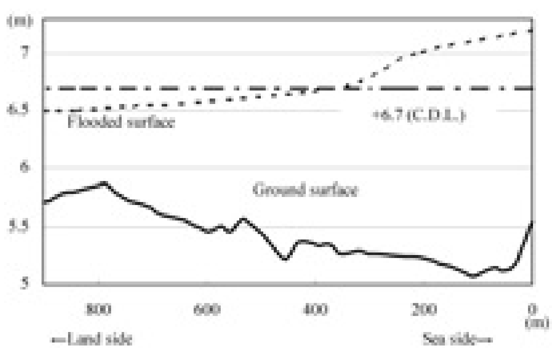


Figure 5 Flooded water and ground elevations

Table 3 Inflow from the sea (unit : m³)

Time	No collapse section	Collapse section	Total
5:00	0	0	0
6:00	9,444	1,272	10,716
7:00	90,065	67,398	157,463
8:00	62,313	62,951	125,264
9:00	1,553	4,603	6,156
10:00	0	0	0
Total	163,375	136,223	299,598

Table 4 Estimated storage volume

Ground height (m)	Depth (m)	Area (m^2)	Quantity (m^3)
4.9 - 5.1	1.6	3,096	4,954
5.1 - 5.3	1.4	17,763	24,868
5.3 - 5.5	1.2	56,594	67,913
5.5 - 5.7	1	114,701	114,701
5.7 - 5.9	0.8	85,216	68,173
5.9 - 6.1	0.6	100,341	60,205
6.1 - 6.3	0.4	29,214	11,685
6.3 - 6.5	0.2	11,724	2,345
6.5 - 6.7	0	3,174	0
Total			354,843

Figure 6 Ground elevation map

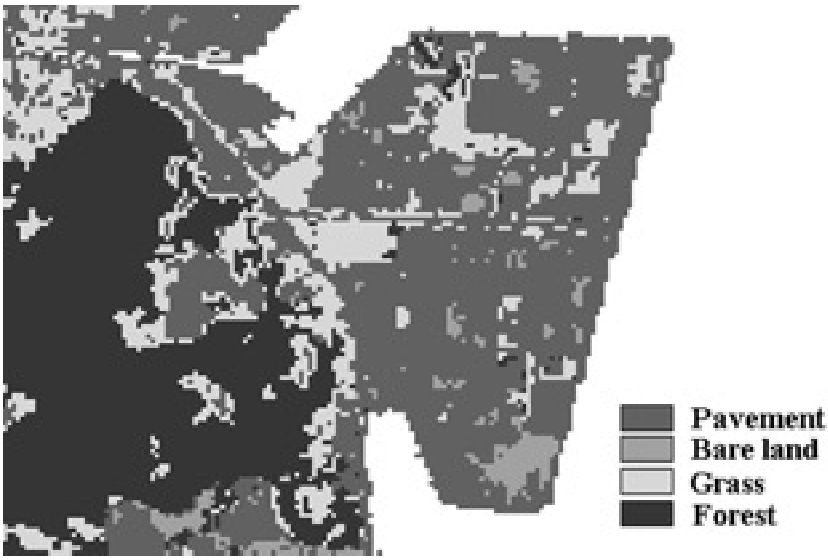
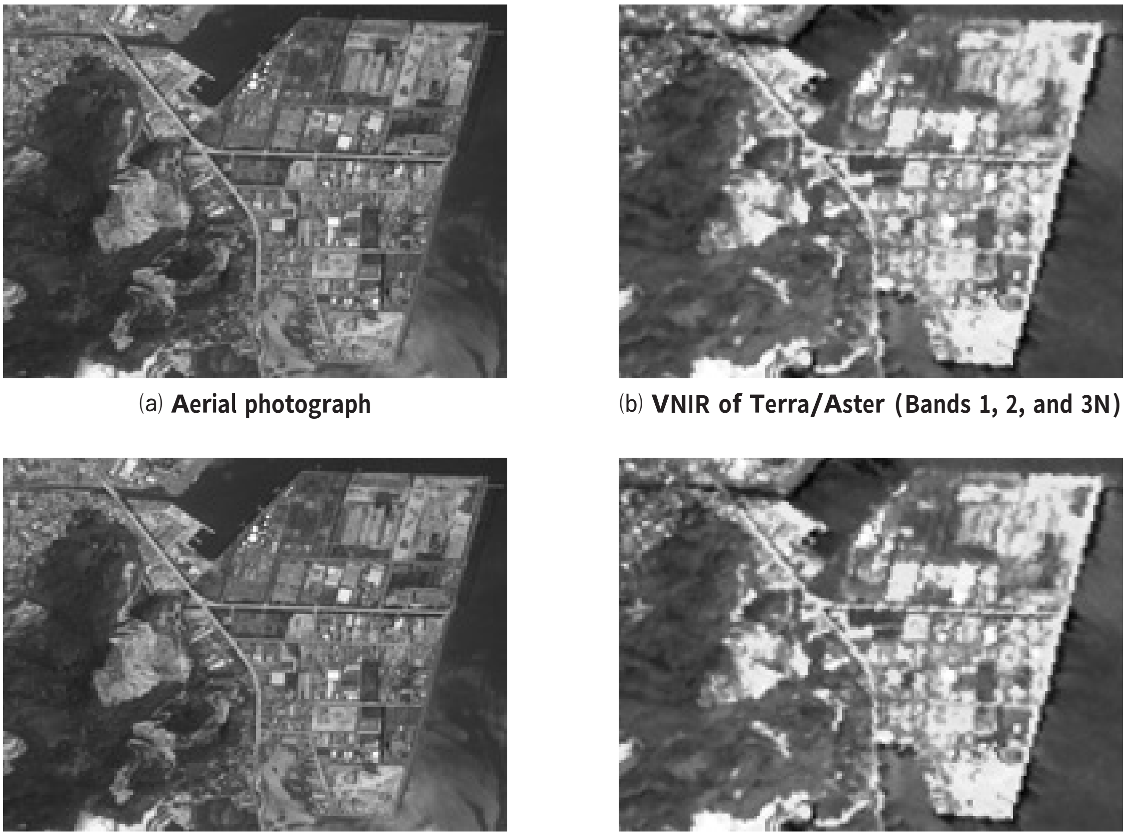


Figure 7 Land-cover classification of the study area

reclaimed land, seaward is lower than land side for drainage. However, some points became the topography like a hollow by local settlement. Drainages for rainwater existed in the target area. However, there were no water gate or no countercurrent prevention functions. Accordingly the rainwater drainage in the target area was in bad condition. Most rainwater concentrated into the target area. It was shown that the amount of water was considerably large by results of this study.

5. DISCUSSION

The submergence damage by Typhoon 9918 was evaluated in the south part of New Moji area. The main cause of inundation was wave overflow and



(a) **Aerial photograph**
(b) **VNIR of Terra/Aster (Bands 1, 2, and 3N)**
(c) **SWIR of Terra/Aster (Bands 4, 5, and 9)**
(d) **TIR of Terra/Aster (Band 13)**

Figure 8 Various images of the study area

bank collapse, but the topography of the reclaimed land and the back hill became causes of damage expansion, too. Improvement of estimate accuracy for submergence damage was proposed as a future theme. It is necessary to investigate elevation of the ground, land covers of the target area, and rainwater drainage function more in detail in order to analyze surge of water in the inundation area particularly. NVIR bands of Terra/Aster were used for land cover classification in this study (Figure 8b). These bands detect presence of vegetation very well, but classification of roadsides and bare land was not so well. Besides, Terra/Aster data have six SWIR bands (bands 4 to 9 in Figure 8c) and five TIR bands (bands 10 to 14 in Figure 8d). White pixels in Figure 8 were identified as bare land by actual ground truth. However, the reflections were obviously different in accordance with bands in other bare lands. Using those bands, a method to estimate indispensable information such as permeability of soils, the roughness, a ground elevation, or soil moisture will be developed in future in order to investigate the submergence damage more precisely. Construction of non-routine water budget simulation in a target area at typhoon invasion will be executed. Finally, detailed reproduction at the disaster should be carried out, and it will be contributed to inundation damage reduction in a coastal area.

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台風9918号による浸水被害の水理解析

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本研究では9918号台風襲来による浸水災害について、護岸越波量と冠水状態の推定に加え、GIS を用いて降雨量と雨水流入量の推定を行った。対象地は福岡県北九州市新門司埋立地区である。護岸越波量の推定は合田による直立護岸の越波流量推定図を用いて行った。平均降雨量は近隣3箇所の気象庁測候所における記録を用いて算定した。背後地からの雨水流入量は50m メッシュ DEM より流域界を切り、平均降雨量に流出係数を乗じて求めた。冠水位の分布は地盤高測量結果と湛水深より推定した。これらの結果より、被害原因および埋立地構造上の問題点についても考察した。