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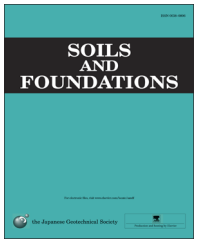

The impact of the 2011 Tohoku earthquake tsunami disaster and implications to the reconstruction

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Abstract

The authors conducted a comprehensive study to identify the impact of the 2011 Tohoku tsunami disaster and to understand the lessons towards the reconstruction of Tohoku to build tsunami-resilient community. First, the authors identified the extent of tsunami inundation zone by field measurement and satellite remote sensing. A specific index for optical satellite images was applied for the extraction of tsunami inland penetration calibrated with the ground truth data (field survey data). Second, an integrated investigation of field measurement and aerial photo and video inspections with spatial information sciences was performed to understand the hydrodynamic aspect of tsunami inland penetration with a form of tsunami flow velocity and hydrodynamic force, and the preliminary results lead to new understandings of structural vulnerability against the 2011 tsunami with a form of tsunami fragility curve and an implication for land use management and relocation planning to reconstruct resilient coastal communities.

Keywords: The 2011 Tohoku earthquake and tsunami; Remote sensing; GIS; Structural vulnerability; Fragility curve; Numerical modeling

1. Introduction

On 11 March, 2011, a devastating tsunami accompanied with M9.0 earthquake attacked the northern Pacific coast of Japan, and the coastal communities especially in Iwate, Miyagi, and Fukushima Prefectures were totally devastated. The total affected area by the tsunami was reported as 561 km^2 along the Pacific coast of Japan (Geospatial Information Authority of Japan (GSI), 2011a), and the maximum tsunami run-up height reached up to 40 m in Iwate Prefecture (Mori et al., 2011). As of 27 June 2012, National Police Agency reported 15,866 dead (4671 in Iwate, 9523 in Miyagi, and 1606 in Fukushima) and 2946 missing, 130,441 buildings/houses were collapsed or washed-away (National Police Agency, 2011). The economic impacts were estimated as 16–25 trillion yen (Cabinet Office, http://www.bousai.go.jp/oshirase/h23/110624-1kisya.pdf), while FY2011 national budget of Japan was 92 trillion yen (Ministry of Finance Japan, 2011).

Having passed more than two years since the event occurred, the devastated areas started moving forward to reconstruct their communities. Approximately 82,000 residents who lost houses moved from shelters to temporary houses (supplied 53,000 units) and rental housing (Ministry of Land, Infrastructure, Transport and Tourism, 2011). Though the recovery process is still underway, local governments

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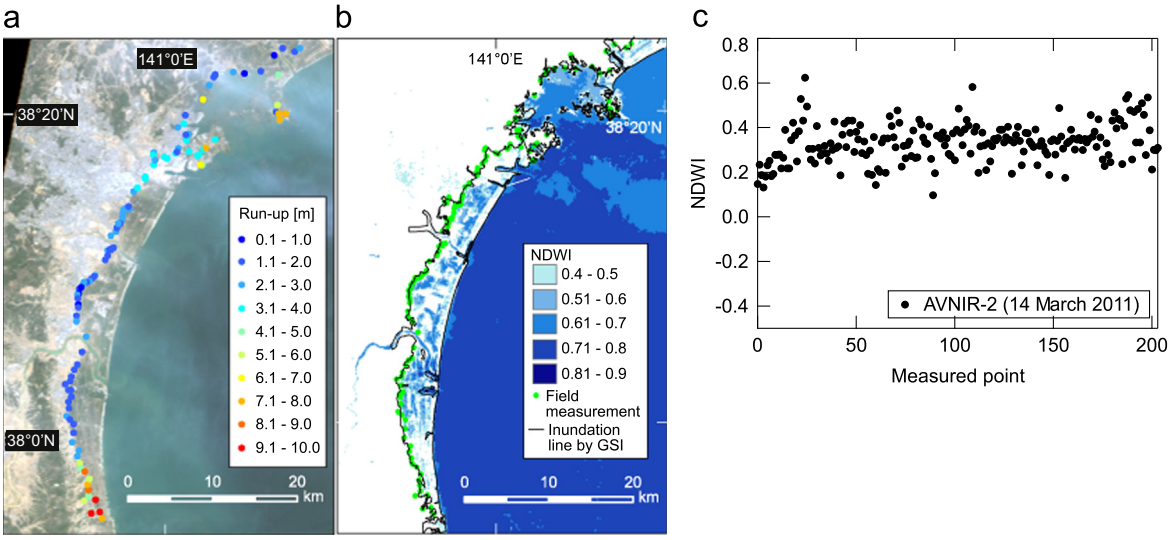

Fig. 1. (a) ALOS AVNIR-2 image of Sendai plain, acquired on 14 March 2011 with the measurement of the run-up heights at tsunami inundation limit (Abe and Abe, 2011). The datum line is Tokyo Peil (T.P.). (b) Spatial distribution of NDWI for mapping tsunami inundation extent. Green dots are the survey points of tsunami inundation extent used for thresholding of NDWI-0.4. Black solid line indicates the inundation limit surveyed by Geospatial Information Authority of Japan (GSI) (2011a). (c) Distribution of NDWI from ALOS/AVNIR-2 image sampled along the tsunami inundation limit. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

completed the draft of reconstruction plan including infrastructure design, transportation, land use management, urban design, relocation, and economic and industrial outlooks.

This paper aims to summarize the impact of the 2011 Tohoku tsunami disaster with particular regard to structural damage, to understand the lessons towards reconstruction of Tohoku region. To identify the tsunami impact, we conducted an integrated studies of field measurement, satellite image analysis, aerial photo inspection with the approach of spatial information sciences. The findings lead to understanding structural vulnerability against the 2011 tsunami and provide an implication for land use management and relocation planning to reconstruct resilient coastal communities.

2. Extracting tsunami inundation zone by optical satellite images

2.1. Field survey

The significant feature of the 2011 tsunami was the wide extent of inundation zone. In fact, on the Sendai plain, the tsunami inundated more than 5 km inland to have caused total devastation and the tsunami inundation on the Sendai plain remained for several days because of the wide-area subsidence (Imakiire and Koarai, 2012). Since the event occurred, many Japanese groups have conducted emergency field surveys to measure the tsunami inundation and run-up heights, flow depths. Our group focused on mapping the inundation limit of the coast of Tohoku region to understand how the tsunami left the wide extent of the impacted areas. We conducted high-resolution surveys of the inundation limits and heights in the few-centimeter accuracy by using RTK-GPS measurement system (Promark 3) in Miyagi, Iwate, and Aomori Prefectures (Abe and Abe, 2011). The horizontal measurement interval is ranging from approximately 500 m to several kilometers and we measured nearly 300 sites until the end of April 2012 (Fig. 1(a)).

2.2. Tsunami inundation zone estimated from ALOS/AVNIR-2 image

In 2006, the Japan Aerospace Exploration Agency (JAXA) launched the satellite, Advanced Land Observing Satellite (ALOS), which has been developed to contribute to the fields of mapping, precise regional land coverage observation, disaster monitoring, and resource surveying. ALOS was loading three types of sensors: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM); the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2), which observes land covers; and the Phased Array type L-band Synthetic Aperture Radar (PALSAR), which enables day-and-night and all-weather land observation. Unfortunately, on 12 May 2012, ALOS completed its operation after 6.5 million scenes of image acquisition for five years (Japan Aerospace Exploration Agency (JAXA), 2011). After the 2011 Tohoku earthquake, ALOS captured whole part of Sendai plain, approximately 500 km^2 from Sendai city to the south of Yamamoto town, Miyagi Prefecture. We used the post-event image of AVNIR-2 data which was released immediately after the acquisition, 14 March 2011. This image was significantly contributed to quick understanding of the tsunami inundation extent (Rao and Lin, 2011).

Here, mapping tsunami inundation extent was conducted through the analysis of AVNIR-2 image with the ground truth calibration from the field survey. A unique feature of tsunami inundation zone is the sea water penetration on land. Thus, the optical satellite remote sensing for mapping tsunami affected area focuses on extracting water body from the post-event image. Here, we introduced the Normalized Difference Water