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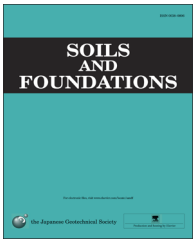

Lessons for countermeasures using earth structures against tsunami obtained in the 2011 Off the Pacific Coast of Tohoku Earthquake

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Abstract

Since many infrastructures, such as sea walls, sand beaches, forests, etc., were severely damaged or destroyed by the tsunami that occurred due to the 2011 Off the Pacific Coast of Tohoku Earthquake, it is said that the resistant functions of the above structures against tsunami attacks did not perform well. However, some structures are known to have resisted the tsunami, based on field surveys conducted after the earthquake by the authors and others; and thus, the resistant functions of those infrastructures against tsunami should be estimated more properly. This paper focuses on earth structures, including river levees and road embankments, both damaged and undamaged, at 13 sites in Miyagi Prefecture, Chiba Prefecture, and Ibaraki Prefecture. They have been investigated through field surveys and other related data, such as satellite photographs taken before and/or after the tsunami. Furthermore, 10 dug pools, eroded by the flood stream on the back side of sea walls and banks during the tsunami, are also investigated to clarify their effects against tsunami attacks for use as future hardware countermeasures. Based on the above field investigations, several important lessons on hardware countermeasures against tsunami, using earth structures, are discussed. And, performance-based design concepts for reconstruction after this earthquake and for the reduction of future tsunami damage are discussed and proposed.

Keywords: The 2011 Off the Pacific Coast of Tohoku Earthquake; Tsunami; Earth structure; Dug pool; Hardware countermeasures; Performance-based design (IGC: C8/E7/H4/H7)

1. Introduction

Many infrastructures, such as sea walls, sand beaches, and forests were severely damaged by the tsunami flood which occurred due to the 2011 Off the Pacific Coast of Tohoku Earthquake. However, post-earthquake field surveys, conducted by the authors and others (Tokida and Koizumi, 2011a–c; Tokida and Tanimoto, 2011) from April 30 to May 3, July 8 to 10, and September 10 to 12, 2011, revealed that some structures were able to resist the tsunami attack. It is now a major concern, therefore, whether or not these damaged structures can satisfactorily resist future tsunami attacks.

The main objective of the current study is to investigate the effectiveness of such structures in resisting and/or reducing damage from tsunami. This study is based on field surveys which were conducted on earth structures, including river levees and road embankments, both damaged and undamaged, at 13 sites in Miyagi Prefecture, Chiba Prefecture, and Ibaraki Prefecture. Other relevant data, including pre- and post-earthquake satellite images, are used. Moreover, 10 dug pools, eroded by the flood stream of the tsunami on the back side of sea walls and banks, are also investigated.

Based on the discussions presented herein, important lessons on the use of earth structures as hardware countermeasures against tsunami attacks are learned.

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A new performance-based design approach is also proposed for use in designing post-tsunami reconstruction works and countermeasures against future tsunami attacks.

2. Earth structure and damage

2.1. Objective earth structure

Typical structures used to reduce tsumani damage may be classified into 3 areas, breakwater, detached breakwater, manmade reefs, natural reefs in sea areas, sand beaches, sea walls, wave dissipation blocks, sand dunes, fishing ports in coastal areas, forests, lagoons, lakes, canals, river levees, road embankments, and railway embankments in inland areas.

Based on the results of field surveys conducted by the authors and others (Tokida and Koizumi, 2011; Tokida and Tanimoto, 2011, 2012), it was revealed that these structures can contribute to a reduction in tsunami height, flood depth, run-up height, and flow velocity and/or water pressure.

In this paper, focus is placed on earth structures and banks, which are not covered by structures such as blocks and which do not touch the water area daily, to investigate their resistance characteristics against tsunami for use as future countermeasures. River levees and road embankments are also included, as they are similar to the above conditions.

The selected objective earth structures of the current study are located on the Sendai Plain in Miyagi Prefecture and along the Asahi Coast in Chiba Prefecture, as shown in Figs. 1 and 2, respectively. The main characteristics of these structures are summarized in Table 1. The structures in Miyagi Prefecture total 9 and include 2 river levees, 1 road embankment, 2 banks, and 4 artificial banks, whereas those in Chiba Prefecture include 3 banks at 3 sites. Table 1 also includes a summary of a sand dune, located in Ibaraki Prefecture, which has eroded slopes. It is thought to be a good a reference when considering the resistance features of earth structures.

The earth structures considered in this study are characterized, as shown in Table 1, in terms of the structure height, the physical condition of the slope, the slope, and other factors. This characterization is based on field surveys and other available information. As the conditions of a tsunami, such as tsunami height and run-up height, can generally not be measured during the tsunami, these factors for the Sendai Plain are estimated by the tsunami traces and on the basis of the height of the earth structures and the ground level measured in the field, based on the tsunami height of 10 m, which is generally considered on the Sendai Plain.

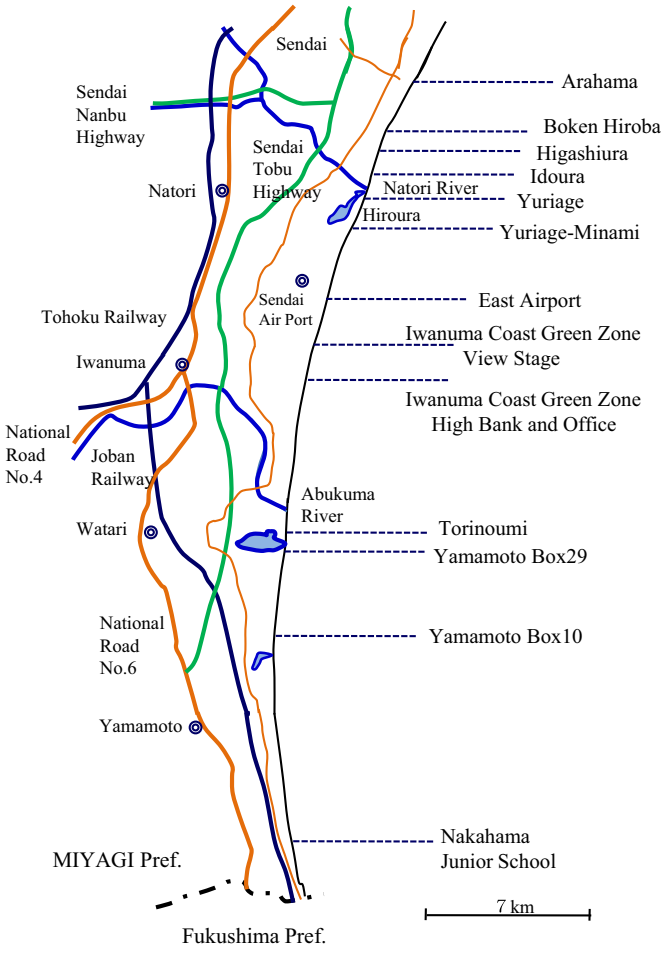

Fig. 1. Field survey sites on Sendai Plain in Miyagi Prefecture.

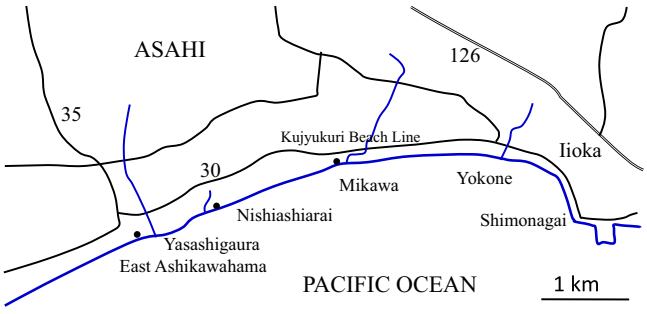

Fig. 2. Field survey sites on Asahi Coast in Chiba Prefecture.

2.2. Damage to earth structures

The damage induced by the tsunami and/or the conditions before the earthquake are explained for each earth structure in Table 1 with the lessons learned.

2.2.1. Example 1: Idoura

Photo 1 is a satellite image of a levee newly constructed along the existing Teizan Canal at Idoura in the Wakabayashi area of Sendai City. The new levee is approximately 3.9 m high and 1.5 km long and is located around a lagoon whose width is approximately 200 m. The purpose of this levee is to reinforce the Teizan Canal whose height is approximately 2 m. The photo shows that the coastal zone was washed away by the tsunami.

Although the estimated overflow depth of the tsunami, shown in Table 1, is 3.85 m, which is a little less than that of the new levee, the lawn on the surface of the front slope of the levee was not eroded, but the sand that was washed away