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BUILDING DAMAGE AND TSUNAMI INUNDATION GIS DATASETS AFTER THE 2010 CHILE EARTHQUAKE

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Abstract: This paper presents the results of a field survey conducted by the authors after the 2010 Chile earthquake. The authors visited the affected area about a month after the earthquake. The GIS datasets for the damage levels of buildings in Talca and the tsunami-inundated areas in Talcahuano, Dichato, and Constitución are constructed in this study, and a series of fundamental analyses are performed using a digital elevation model (DEM). Further, the usefulness of satellite images captured after the earthquake to detect damaged buildings in Talca is discussed using the GIS datasets constructed in this study.

1. INTRODUCTION

The 2010 Chile earthquake occurred off the coast of the Maule Region of Chile on February 27, 2010, at 03:34 local time (06:34 UTC) with a magnitude of 8.8 on the moment magnitude scale. The epicenter was offshore from the Maule Region, approximately 335 km southwest of Santiago, the capital of Chile, and 105 km north-northeast of Chile's second largest city, Concepción. It is reported that a severe ground motion with the Modified Mercalli Intensity (MMI) scale of VII was felt widely in Chile and that the extensive damage was caused by the ground shaking and tsunami (USGS, 2010). The total economic loss estimates range from USD 15 to 30 billion, which correspond to 10% to 15% of Chile's real GDP (Bray and Frost 2010). According to the report on the scene, the actual death toll was 486 as of March 8, 2010, and approximately 370,000 homes were damaged.

The authors visited the affected area about a month after the event as part of an international research project "Enhancement of earthquake and tsunami disaster mitigation technology in Peru" (Yamazaki *et al.* 2010), which is under the research program "Science and Technology Research Partnership for Sustainable Development (SATREPS)" (JST 2008) supported by the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA). The lessons learned from the 2010 Chile earthquake are expected to apply to the earthquake disaster mitigation technologies in Peru because the two countries have common regional tectonics and social surroundings.

Three teams of Japanese and Peruvian researchers were dispatched by the SATREPS project to carry out field surveys. In this paper, the results of the field survey performed by Damage Assessment Group and Disaster Mitigation Plan Group are presented. The spatial damage data, topographical maps, and satellite images provided by different institutions are compiled by the geographical information system (GIS), and the primitive analyses are conducted to reveal the characteristics of the tsunami-inundated areas in view of elevations and damage incidents to adobe and unreinforced masonry buildings, which are also widely seen in Peru.

2. OUTLINE OF FIELD SURVEY

The authors arrived in Santiago on April 2, 2010. We drove to Concepcíon the next day and visited the tsunami-affected areas of Talcahuano, Dichato, and Constitución. We moved to Talca on April 7 and left Santiago on April 8. Before leaving, we visited Valparaíso and Viña del Mar. Figure 1 shows the locations of the cities that we visited during the survey.

Figure 2 shows the route of our field survey in Santiago

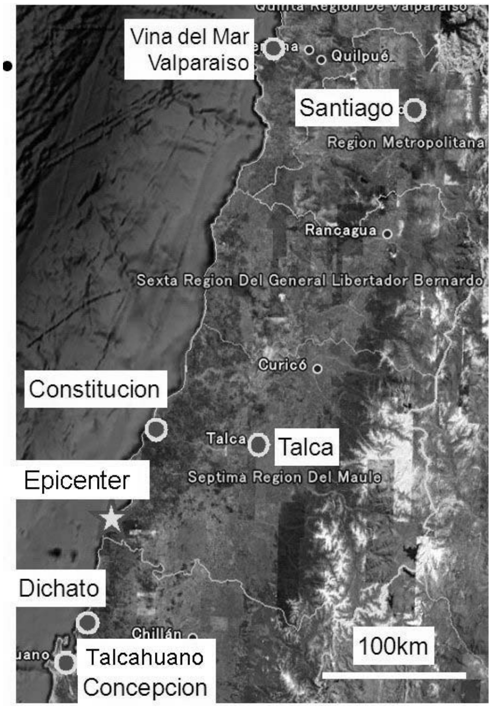


Figure 1 Locations of cities visited by the authors

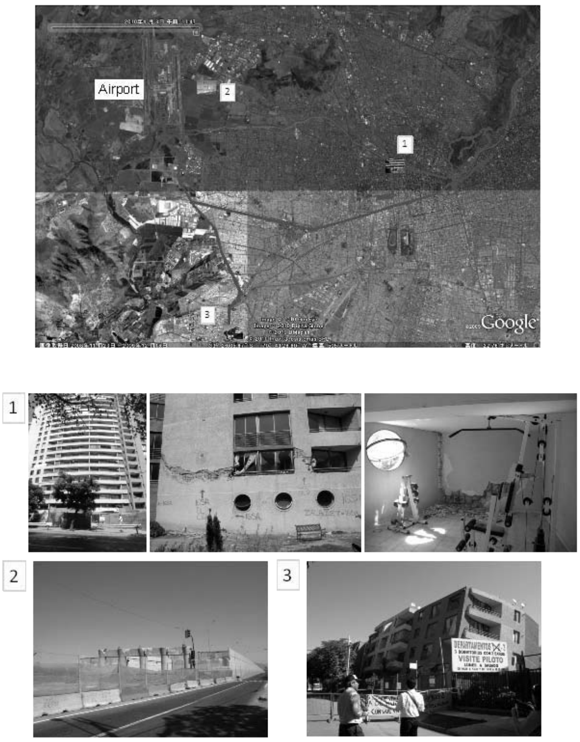


Figure 2 Survey route and field photos in Santiago—April 2, 2010

and some field photographs. The route was recorded by a portable GPS device during the survey and the location of the photo shooting could be identified as the location data were embedded in the Exchangeable Image File Format (EXIF). An RC building with 20 stories constructed in 2003 suffered from shear failures in columns and walls at the first and the second stories. A collapsed highway bridge and an

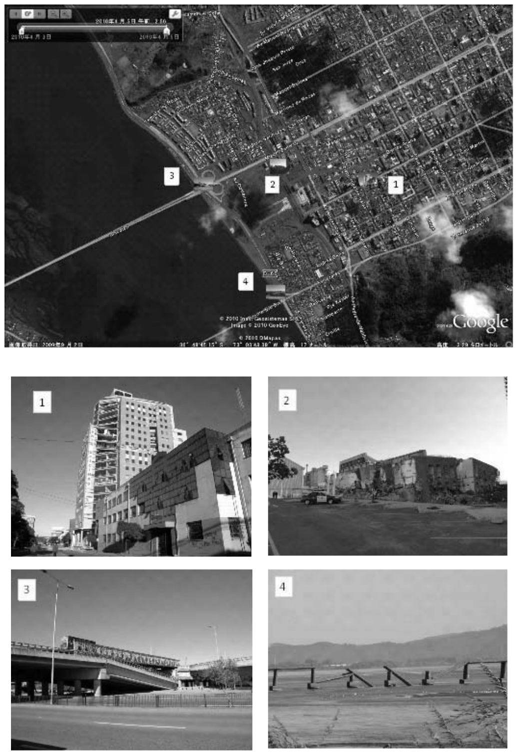


Figure 3 Survey route and field photos in Concepcíon—April 4, 2010

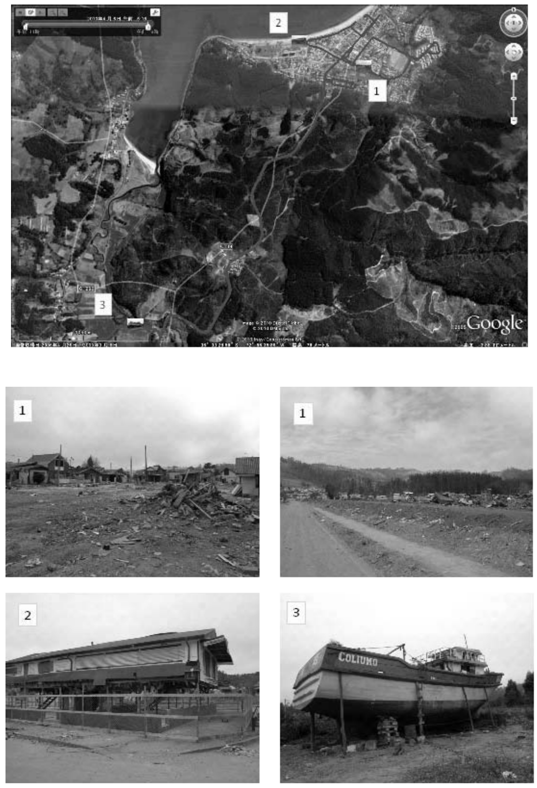


Figure 4 Survey route and field photos in Dichato—April 5, 2010

RC building with the collapsed first floor were found. The locations of these sites are also shown in the survey route in Fig. 2.

Figure 3 shows the survey route in Concepcíon. An RC

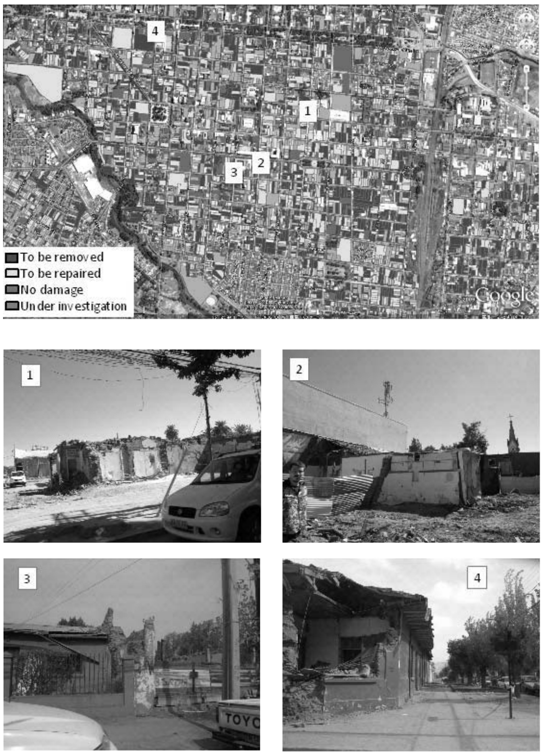


Figure 5 GIS file to show the damage levels of buildings in Talca and locations of field photos

building with the damaged middle floor was found at the site numbered 1. An RC building with 15 stories had collapsed completely at the site numbered 2. The road bridges collapsed at sites 3 and 4. The temporary bridge girder was constructed two days after the earthquake at site 3. Although the photos are not shown in this paper, the adobe and unreinforced masonry constructions were severely damaged in the urban area.

Figure 4 shows the survey route in Dichato. It is reported that more than 80% of the built-up area in Dichato suffered from tsunami (Humboldt State University Preliminary Tsunami Survey Team, 2010). As shown in the field photos, the buildings collapsed because of the tsunami waves. A ship was conveyed against the river flow because of the tsunami and eventually found at site 3.

3. CONSTRUCTION OF GIS FOR BUILDING DAMAGE AND TSUNAMI-INUNDATED AREA

3.1 Building Damage GIS in Talca

Talca is the capital of both Talca Province and Maule Region. Its population is approximately 200,000, and it is approximately 250 km south of Santiago and 60 km northwest of the epicenter of the 2010 Chile Earthquake. According to USGS (2010), Talca was affected with a severe ground motion with the MMI scale of VII.

During our survey, we interviewed officials from Maule Regional Office to investigate the damage of buildings. As a result of our interview, an image file that shows the damage levels of buildings was provided. The polygons, which

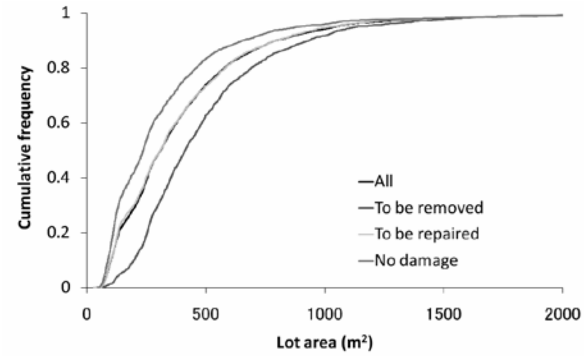


Figure 6 Cumulative frequencies of the areas of building lots with respect to the damage level

indicate the building lots, are classified into four levels, namely, to be removed, to be repaired, no damage, and under investigation. It should be noted that the image file was compiled with the damage dataset as of March 31, 2010.

In this study, the location of the image file was established in terms of map projections. The satellite image and road data presented in Google Earth were employed as a base map to georeference the image file. Then, the image file was converted to a GIS file with polygons to identify the damage levels of buildings. Figure 5 shows the developed GIS file presented by Google Earth and some field photos to show the examples of damaged buildings.

In all, 5617 polygons were projected to the map coordinate system. 1559 (27.8%), 1872 (33.3%), and 1864 (33.2%) buildings were classified as to be removed, to be repaired, and no damage, respectively. The typical construction types in Talca are adobe and unreinforced masonry buildings, which are primarily used for older constructions with 2–4 stories (dating back to before the 1960s–70s). Modern buildings that were designed according to the current codes suffered minor, repairable damage, while a large number of adobe and unreinforced masonry constructions suffered significant damage (MCEER, 2010).

Figure 6 shows the cumulative frequencies of the areas of building lots with respect to the damage level. The mean of all the georeferenced areas was approximately 430 m^2 and was almost equal to that of the areas associated with the buildings to be repaired. The mean of the lot areas of the buildings to be non-damaged was approximately 340 m^2, which was considerably smaller than that of the buildings to be removed. On the basis of the results, it has been speculated that the newer buildings are constructed in relatively small lots; however, the construction periods are not available at this moment.

Recent advancements in remote sensing technologies and their applications have made it possible to use remotely sensed imagery for estimating the damage distribution due to natural disasters. Among them, high-resolution optical satellite imagery, which has become available in the last decade, has made satellite remote sensing more useful in disaster management since even the damage status of individual buildings can be identified (Saito *et al.* 2004, Yamazaki *et al.* 2005). Figure 7 compares the pre- and

(a) Pre-event (Jan. 1, 2008)

(b) Post-event (March 10, 2010)

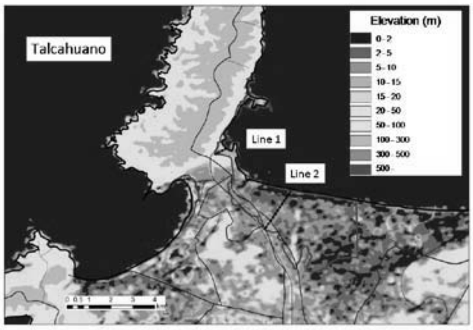
(c) GIS data

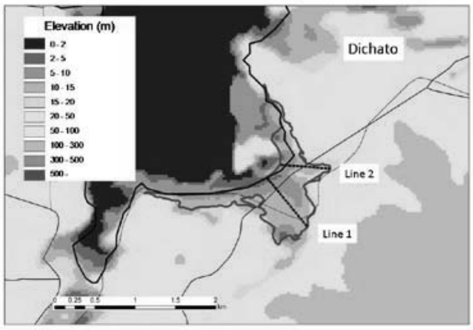
Figure 7 Comparison between pre- and post-event satellite images to detect affected buildings

post-event high-resolution optical satellite images with the GIS dataset shown in Fig. 5. As for the pre- and post-event images, the image captured by QuickBird on January 1, 2008, which is presented in Google Earth, and that captured by WorldView-2 on March 10, 2010, are employed in this study. A comparison of the pre- and post-event images revealed that some of the affected buildings could be visually detected, but not all the damaged ones could be identified appropriately. Since the post-event image was captured with the large off-Nadia angle (40.3°), the quality of image is not sufficient for visual damage inspection. Moreover, the number of affected buildings whose roofs had completely collapsed is small in Talca. Hence, it can be concluded that the damaged buildings in Talca are difficult to be detected through visual damage inspection using satellite images.

3.2 Development of GIS for Tsunami-Inundated Area

Various institutions released the maps to show the damage distribution at their Web sites after the 2010 Chile earthquake. The tsunami-inundated areas interpreted from satellite and aerial images were published by National Office of Emergency of the Interior Ministry (ONEMI) of Chile





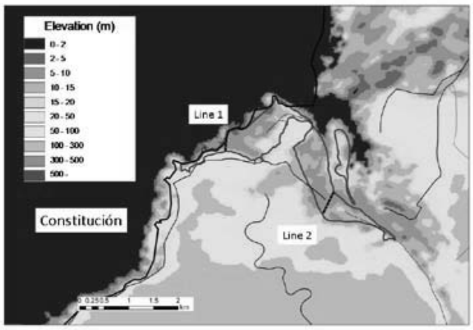


Figure 8 Tsunami-inundated areas in Talcahuano, Dichato, and Constitución

(SNIT 2010). On the basis of the maps, the number of affected buildings and that of causalities were estimated.

In this study, the tsunami-inundated areas were projected onto a map coordinate system, and the topographical conditions were evaluated in terms of the elevation. The inundated areas in Talcahuano, Dichato, and Constitución were converted to the GIS data and compared with the digital elevation model (DEM). The DEM employed in this study is the ASTER Global Digital Elevation Model (GDEM) developed by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) (ERSDAC 2009). The ASTER GDEM is a highly accurate DEM covering all the land on earth with the spatial resolution of 30 m.

Figure 8 shows the tsunami-inundated areas in Talcahuano, Dichato, and Constitución and the distributions of the elevation derived from the ASTER GDEM. The elevations in the inundated areas are lower than 20 m on the

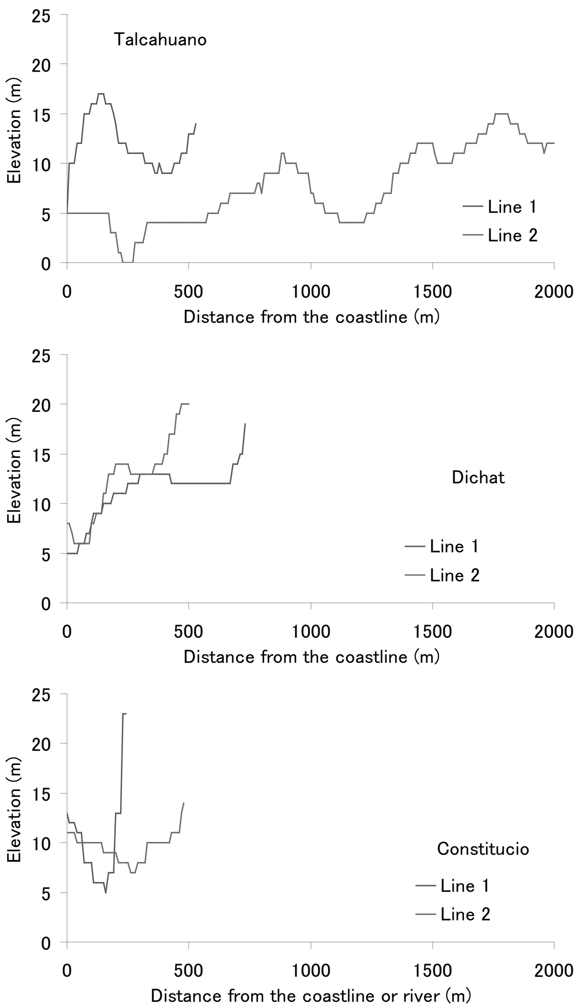


Figure 9 Elevations along the transverse lines set in Fig. 8

whole except for a certain area in Constitución. As shown in the figure, we set the two traverse lines in each inundated area. The elevations were extracted along the two lines. The extracted elevations are illustrated in terms of the distance from the coastline in Fig. 9. As for Line 2 in Constitución, the elevations are presented with respect to the distance from the Maule River. The relatively low elevations and slow grades result in long travel distances of the tsunami wave. According to Line 2 in Talcahuano, the tsunami wave could travel approximately 2000 m from the coastline. Line 1 in Constitución was assigned to identify the surveyed site by Imamura *et al.* (2010). According to their report, the tsunami runup height was 28.3 m at the site. Since the DEM used in this study is a global dataset that consists of 30-m grid cells, the elevation at the site is estimated to be approximately 23 m. The slope is estimated to be approximately 67% and is almost equivalent to that reported by Imamura *et al.* (2010), which is 63.5%.

As shown in Fig. 10, the inundation depth was measured at several sites in the three cities. The inundation depth along the beachfront street in Talcahuano was larger than 150 cm, but a depth of 55 cm was observed in its bystreet (site 4). Figure 11 summarizes the measurements in the three cities. The inundation depth is presented with

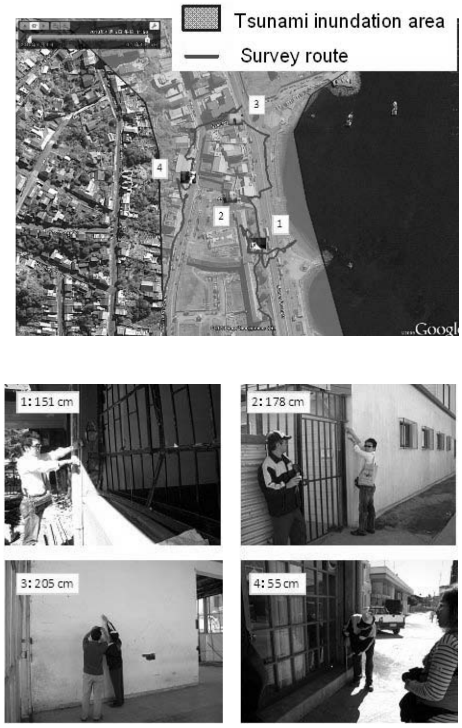


Figure 10 Measurement of tsunami inundation depth in Talcahuano

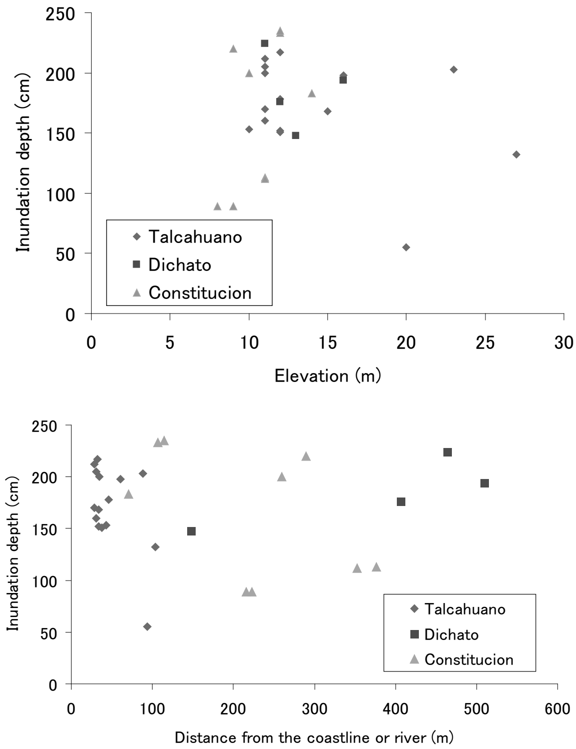


Figure 11 Summary of the measurement of tsunami inundation depth

respect to the elevation and the distance from the coastline. As for the results in Constitución, the records are shown with respect to the distance from the Maule River. A clear tendency is not seen in the relationship between the tsunami inundation depth and the elevation. The recorded depth in

Talcahuano and Constitución decreased with an increase in the distance from the coastline or the river; however, this tendency is not seen from the records in Dichato because of the insufficient number of measurements.

4. CONCLUSIONS

In this paper, the results of a field survey conducted after the 2010 Chile earthquake by the authors during April 2–8, 2010, are presented. The GIS dataset for the building damage in Talca was developed by establishing the location of the image file in terms of map projections. The usefulness of high-resolution satellite images to detect the building damage in Talca was investigated with the aid of the constructed GIS dataset. Moreover, the tsunami inundation maps published by ONEMI were georeferenced, and the characteristics of the inundated areas were evaluated in view of the elevation.

According to the relationship between the building damage levels and the lot areas, the mean of the areas associated with the non-damaged buildings was the smallest, while the mean of the areas associated with the buildings to be removed was the largest. In Talca, modern buildings that were designed according to the current codes suffered minor, repairable damage, while a large number of adobe and unreinforced masonry constructions, which were built in the 1960s–70s, suffered significant damage. On the basis of these circumstances, it has been speculated that the newer buildings may be constructed in relatively small lots; however, the construction periods are not available at this moment. According to the results of a visual damage inspection using pre- and post-event satellite images, it was concluded that the damaged buildings in Talca could not be appropriately detected because of their damage patterns and the quality of the post-event satellite image.

A comparison of the georeferenced tsunami-inundated areas with the elevations obtained from the ASTER GDEM revealed that the elevations in the inundated areas were lower than 20 m on the whole except for a certain area. A clear tendency was not seen in the relationship between the tsunami inundation depth and the elevation. The recorded inundation depth in Talcahuano and Constitución decreased with an increase in the distance from the coastline or the river.

These findings of our field survey after the 2010 Chile earthquake will be expanded in the earthquake and tsunami disaster mitigation technology in Peru through the SATREPS project.

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