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Ground damage caused by Typhoon “Hagibis” in Central and Eastern Japan

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ABSTRACT

Considered as the strongest storm to hit Japan in more than six decades, the super-typhoon “Hagibis” (locally referred to as Typhoon No. 19) struck the central and eastern parts of the country on 12 October 2019 and caused widespread damage across many low-lying lands, with rivers bursting their banks after hours of torrential rain and powerful winds. The passage of the typhoon, with direct impact to Tokyo and adjacent areas, necessitated mass evacuation advisories, paralysed transport systems and shut down commercial facilities. This paper presents some of the ground-related damages that occurred in central and eastern Japan caused by the passage of the typhoon, based on the first-hand experience and subsequent reconnaissance work conducted by the author, who was on research and study leave in Tokyo when the typhoon struck Japan. These are supplemented by additional data provided by his Japanese colleagues, with a focus on breaching of river dykes, landslides and other sediment disasters. Moreover, their impacts on the built environment are discussed. Finally, lessons learned from the disaster are summarised and their implications to the NZ setting are highlighted.

1 INTRODUCTION

Typhoon Hagibis ((locally referred to as Typhoon No. 19), the most powerful typhoon to hit Japan in six decades, devastated wide areas of Honshu Island, especially the Chubu, Kanto, and Tohoku regions, including the capital Tokyo, when it made landfall in the evening on 12 October 2019. Data from the Environmental Modeling Center (EMC 2019) showed that on 10 October, the typhoon had maximum sustained wind speeds of 259 kph (tagged as “Category 5” typhoon), and then weakened when it made landfall two days later, but still with gust speed reaching 140 kph and central pressure of 950 hPa. The typhoon then made slow progress, with a forward-moving speed of 30 kph, i.e., it lingered longer over the landmass and resulted in a high accumulation of rainfall in several regions. According to reports (e.g., Aon 2019; Air Worldwide 2019), the economic losses caused by the typhoon were expected to exceed US$15 billion, with insured losses minimally in the billions (US$). The government designated the disaster as "severe" and "extraordinary", as defined in the disaster recovery law, to enable the state to carry out reconstruction works for local governments and to increase subsidies to hard-hit areas for recovery projects.

The author experienced first-hand the wrath of the typhoon while on research and study leave at Tokyo City University (TCU). Following the disaster, a field survey and desktop investigation were immediately conducted and his preliminary findings have been reported elsewhere (Orense 2019). This paper provides supplementary information on ground-related damages that occurred, with emphasis on sediment disasters and river dyke breaches and their impacts on infrastructures. Finally, lessons learned from the disaster and their relevance to the New Zealand setting are discussed.

2 OUTLINE OF TYPHOON AND SUMMARY OF DAMAGE

When Typhoon Hagibis made landfall on 12 October 2019, many areas in central, eastern and northeastern Japan were devastated as a result of the record-breaking rainfall, hurricane-force winds and widespread flooding. According to the update of MLIT (2020), heavy rain warnings were issued in 13 prefectures, with a cumulative rainfall in excess of 1,000 mm recorded in Hakone (Kanagawa Prefecture) and exceeded 500 mm at 17 other locations. Figure 1 illustrates the distribution of the total precipitation in various parts of the country over a period of 72 hrs (10-13 October).

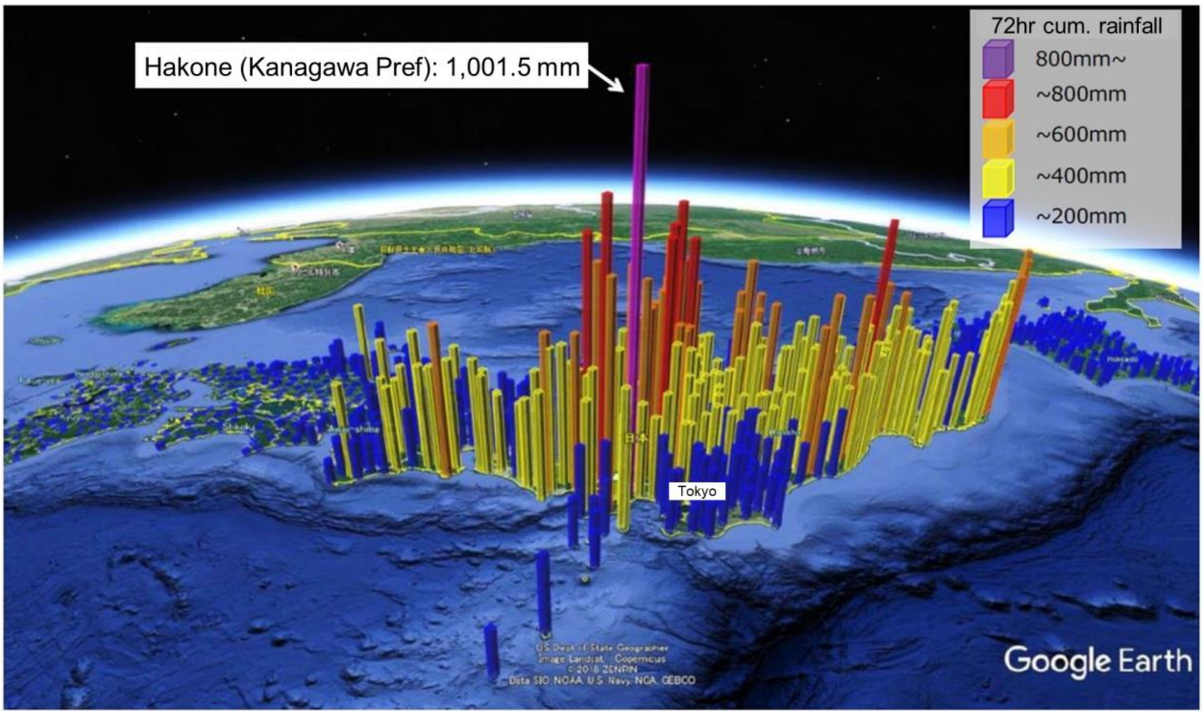

Figure 1: Distribution of 72 hr rainfall (modified from www.tokiorisk.co.jp/publication/column/017.html)

Per the latest update dated 12/02/2020 (MLIT 2020), at least 99 people were killed and 3 others were missing while 381 people were injured. The typhoon affected 98,914 residential houses (with 3,280 completely destroyed and 29,638 partially destroyed). In total, 187 public buildings and 13,550 non-residential structures were damaged as well. Moreover, up to 2.1 million people in 9 prefectures were issued evacuation orders during the passage of the typhoon.

As of 12/02/2020, the following damages were reported (MLIT 2020):

- Damage to river networks:
  - stop banks broke out in 140 sites along 71 rivers
  - flooding occurred in over 262 rivers in 16 prefectures

- Sediment-related disasters: in total, 952 cases broken down as follows:
  - Debris flows – 407 cases (in 13 prefectures)
  - Slope failures – 501 cases (in 20 prefectures, with 18 cases in the Tokyo Metropolitan area)
  - Landslides – 44 cases (in 6 prefectures, with 31 cases in Niigata Prefecture)
- Road networks:
  - State highways: 15 sections along 13 routes
  - National roads: 39 sections in 17 routes
  - Prefectural roads: 62 sections of 38 routes
- Railway networks:
  - 254 routes operated by 83 railway companies affected (including planned suspension)
- Airport facilities:
  - While there was no reported damage to airport facilities, 3,188 flights were cancelled
- Wastewater:
  - Treatment plants: inundation damage occurred at 17 plants and treatment function stopped
  - Pump stations: operation suspended at 31 locations due to flood damage
  - Manhole pumps: 104 pumps affected by flooding and ground damage (in 28 cities, 13 town and 2 villages)

3 GROUND-RELATED DAMAGES

3.1 Sediment disasters

In Japan, sediment disaster is the general term used for any phenomenon involving large-scale movement of soil and rock that threaten human life and property, typically due to heavy rain and earthquakes. A sediment disaster can be classified as either: (1) *debris flow*, which involves soil and rock mix with water (rainwater and groundwater) flowing down rivers and mountain streams; (2) *slope failure*, which comprises abrupt collapse of slope when the soil/rock becomes unstable due to heavy rain; and (3) *landslide*, which involves a soil mass moving downward slowly at the boundary of the discontinuous surface under the influence of groundwater and gravity.

Examples of sediment disasters that occurred following the passage of typhoon Hagibis and their distributions throughout the affected regions in Japan are illustrated in Figure 2. Many of these disasters occurred in the mountainous areas located along the path of the typhoon. At least 16 people were killed and 115 residential houses were destroyed, either completely or partially, as a result of these mass movements. Following the events, researchers conducted in-depth investigations on some of the slope failures and landslides that occurred through site inspections and aerial surveys, supplemented by field testing, and various causative factors, such as rainfall intensity, topography and geology were identified. Many of the cases involved "classic" rainfall-induced failure mechanism (i.e., rainfall infiltration leads to an increase in positive pore water pressure and/or elimination of suction in the soil, leading to a reduction in shear strength and when equilibrium can no longer be sustained in the slope, failure is mobilised along a slip surface).

However, there were some cases where the mechanism involved was not straight-forward. According to existing guidelines, an evacuation advisory needs to be specified by the prefectural authorities for residential areas near slopes if the slope gradients are in excess of 30° (i.e., areas designated as sediment disaster alert area). Now, some slopes in Gunma and Tochigi Prefectures with inclinations as low as 20° failed, but because they were not designated as sediment disaster alert area, no warning advisory was issued. For example, in Takumi, Tomioka City where a landslide killed three people, it was found that a 20 cm thick whitish layer was horizontally distributed for about 20 m in length at a depth of 3 m from the ground surface (see Figure 3). It turned out that the whitish layer was a clay layer in which pumice, associated with the eruption of Mt. Asama, has weathered for tens of thousands of years. The layer, which was impermeable, was overlain by highly permeable topsoil while below was a hard sedimentary layer. As a result, the infiltrating water from the typhoon was concentrated on the clay layer, which suddenly failed together with the upper layer, causing a sediment disaster. These clay layers are formed by complex natural conditions, such as the type of pumice and the condition of groundwater. Although the distribution of pumice from volcanoes is known to some extent, it is difficult to predict where the weathered clay layers are located.

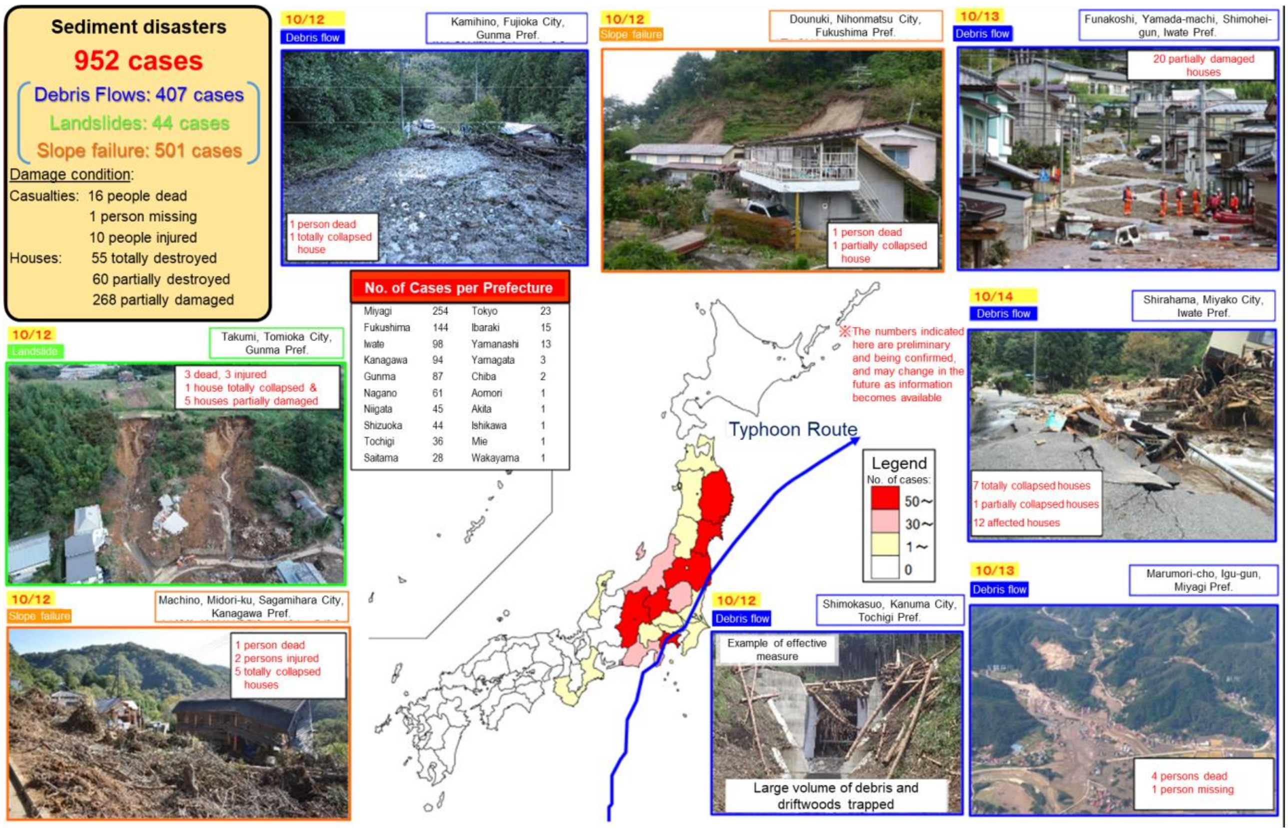

Figure 2: Sediment disasters, including debris flow, landslides and slope failures, due to passage of Typhoon Hagibis (modified from www.mlit.go.jp/river/sabo//jirei/r1dosha/r1typhoon19191224jiten.pdf)

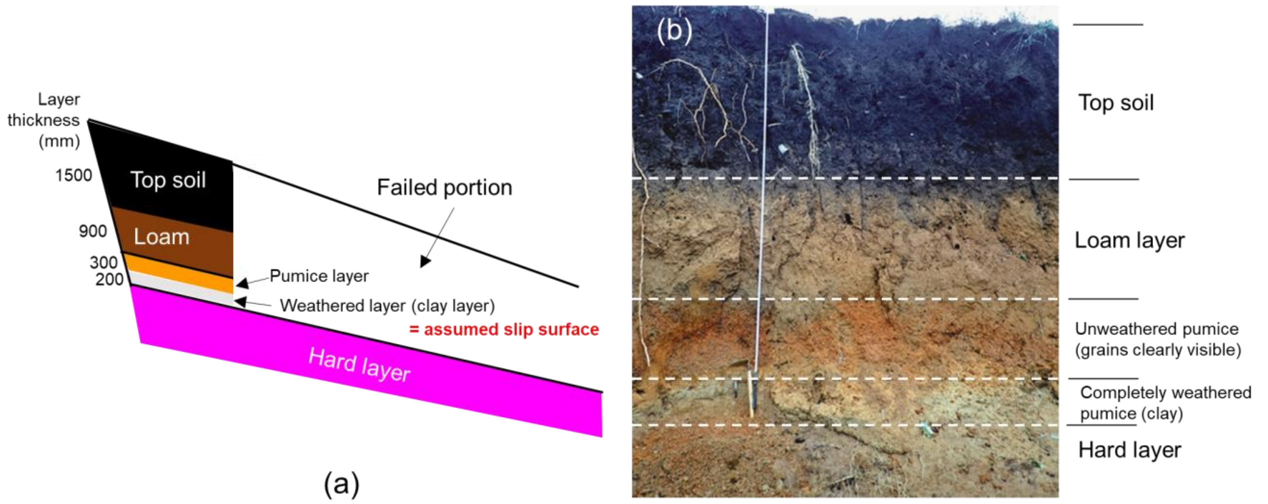

Figure 3: Landslide in a pumiceous layer in Takumi, Tomioka City: (a) schematic of slope profile; (b) cross-section of stratified layers, showing the location of weathered pumice layer where slide appeared to have been mobilised (modified from www.jiban.or.jp/file/saigai/houkoku/goto_20191218.pdf)

3.2 Breaching of river dykes

The mechanism of dyke breach or failure can be in the form of: (1) overtopping, when the floodwater simply exceeds the lowest crest of the dyke system; (2) scouring of the foundation; (3) seepage/piping through the dyke body, and (4) sliding of the foundation. These failure conditions are influenced by the dyke's geometrical configuration, hydraulic conditions (e.g., river level and seepage), and material properties (e.g., grading, cohesion and compaction).

One of the features of Typhoon Hagibis is that many river dykes in central and northeastern Japan were breached and the turbulent floodwaters engulfed people and villages. Per the damage reports, river dykes failed at around 140 sites along 71 rivers in seven prefectures, primarily due to the large volume of rain that fell over a wide area due to the intense strength of the typhoon. Figure 4 illustrates the distribution of these breached river dykes. Among these, 12 sections failed in nationally-managed rivers (i.e., administered by MLIT) while 128 sections collapsed in prefecture-managed rivers. As of 08/11/2019, reinforcement works have been completed in all collapsed dykes in nationally-managed rivers while temporary river dykes have been completely set-up in all prefecture-managed dykes.

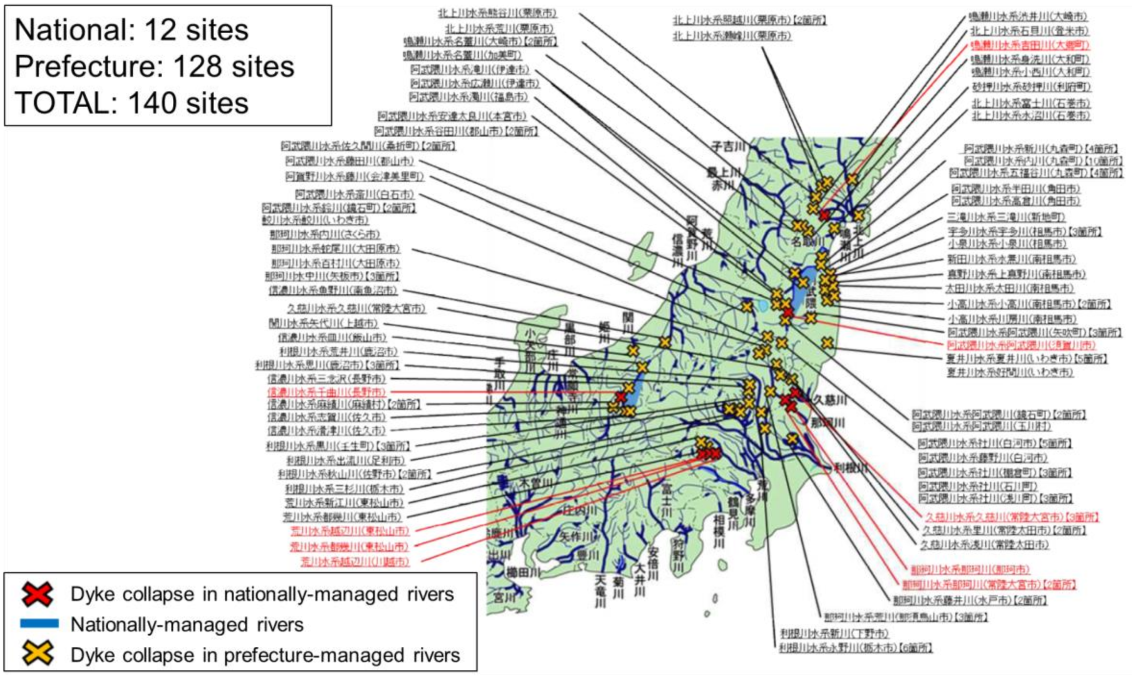

Figure 4: Locations of failed dykes (modified from www.mlit.go.jp/policy/shingikai/content/001317859.pdf)

Some examples of the breached river dykes are illustrated in Figure 5. One of the most widely reported dyke breaches occurred along Chikuma River in Hobo, Nagano City. It was reported that the breach occurred over a 70 m-section of the dyke in the early morning of 13 October, killing 2 residents and flooding many houses and fields. The rushing floodwater, which reached the second floor of nearby residential houses, inundated as far as the National Highway Route 18, which was about 100 m away from the river bank. Almost the entire area along the Abukuma River, which meanders through a number of cities in the largely agricultural Fukushima Prefecture, was flooded after the typhoon moved north along the river's stream, dumping huge amounts of rain that caused the dykes to break in at least 14 places. In Kawagoe, Saitama Prefecture, the Oppe River embankment failed in the wee hours of 13 October near a point where the main and branch streams merged, submerging the area and temporarily isolating a nursing home. Subsequent investigations revealed that workers evacuated during the height of the heavy rain and left two pump stations discharging water from tributaries into the main river. In Hitachiomiya, Ibaraki Prefecture, a flood alert was issued at around 5:20 am on 13 October for areas along the Kuji River, whose dyke burst at three locations.

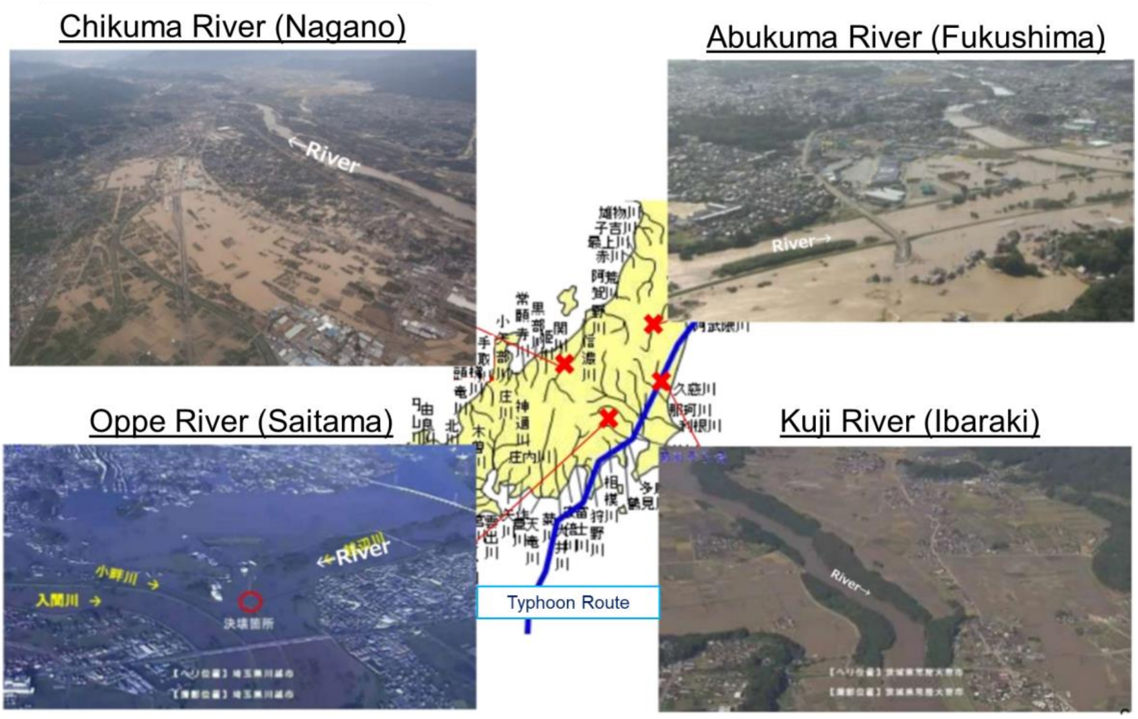

Figure 5: Examples of breached dykes (modified from mlit.go.jp/policy/shingikai/content/001317859.pdf)

3.3 Effects of flood and sediment disasters on infrastructures

Severe flooding triggered by the torrential rain submerged large areas in central Japan. Most of the affected areas were located near rivers, where in many cases, the dykes and floodwalls either collapsed or were overtopped. More than 1000 km^2 of areas near Abukuma River were inundated. In other cases, areas underwent inland flooding due to the intense rain that overwhelmed existing drainage infrastructure.

3.3.1 Damage to Tokyo City University Campus

The author experienced the impact of flooding when his dormitory, located adjacent to Tokyo's Tama River, was inundated by >1.3m high flood water. The nearby campus of Tokyo City University (TCU) was also submerged, not by breaching of the Tama River, but by inland flooding which was induced by the overflowing of two tributaries (Tanizawa River and Maruko River) running nearby (see Figure 6(a)). As a result, many university buildings were flooded up to the first floor, while buildings with basement floors, such as the library basement floor and some research areas, were filled with floodwater (see Figure 6(b)). About 83,000 books in the library basement were destroyed. The author then joined the university's Department of Urban Engineering Reconnaissance Team to investigate the damage caused by the inundation of the inland waters and collect valuable information necessary for implementing effective countermeasures.

3.3.2 Damage to Railway infrastructure

Train services were severely disrupted due to severe flooding and ground damage. The Central Japan Railway Co. cancelled their high-speed Tokaido shinkansen train services from 12-13 October. Various railway facilities of East Japan Railway Co. (JR East) were affected by the typhoon as a result of flooding and sediment disasters. Some of these damages to railway infrastructures are depicted in Figure 7. Ten Hokuriku bullet trains (consisting of 120 cars) were submerged when the Abukuma River overflowed and inundated the train depot located near the bank of the river. As a result, the inundated trains were scrapped with the damage worth US$300M. A railway bridge of the Ueda Dentetsu Railway Company, which crossed the Chikuma River, collapsed into the water below. Local small railways also encountered damage, particularly to railway tracks, and suspended operations across several routes.

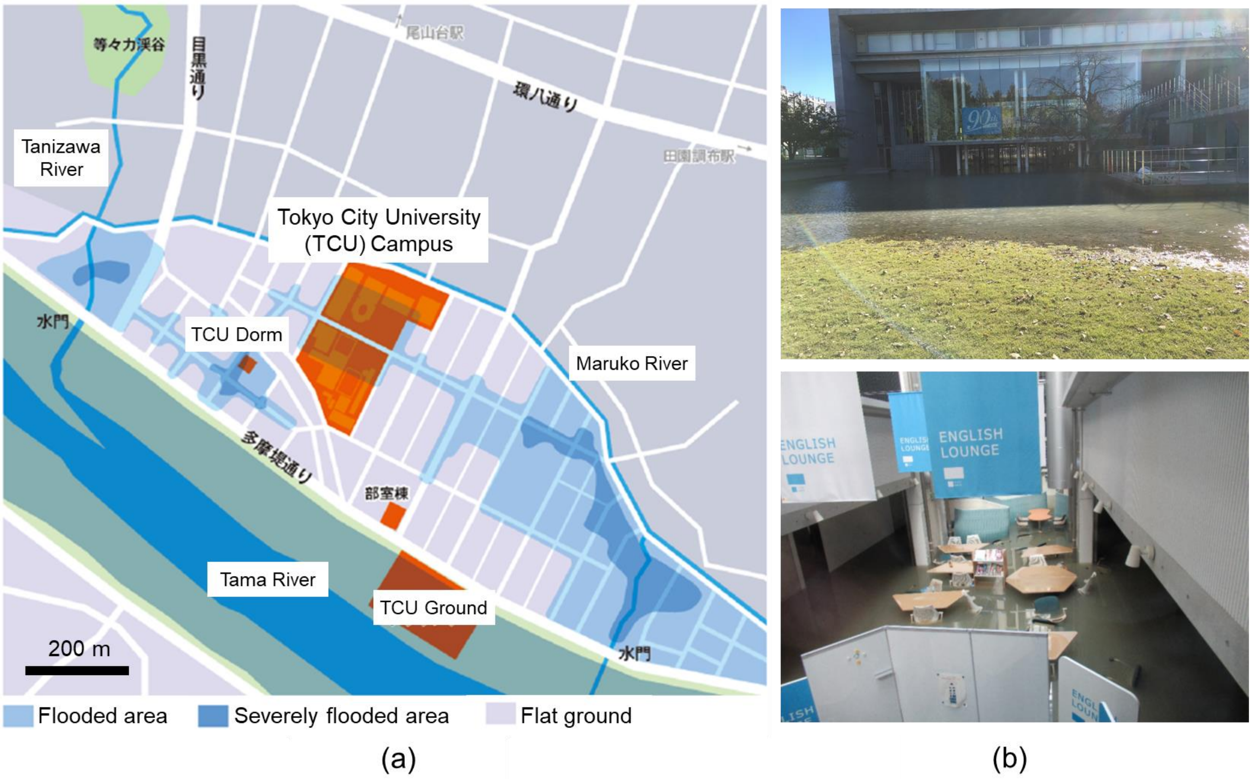

Figure 6: Extent of flooding adjacent to TCU campus (modified from univ-journal.jp/column/201929656/); and (b) photos of submerged university buildings within the campus.

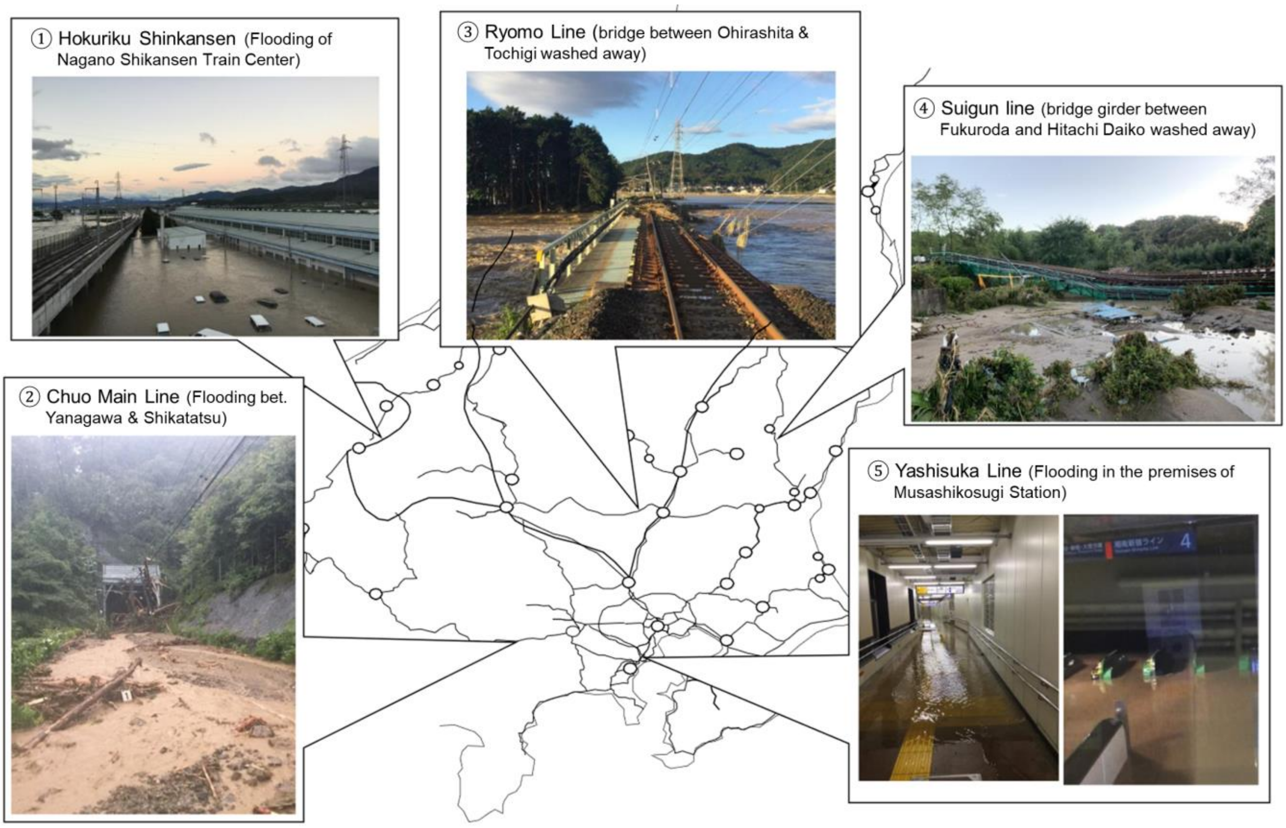

Figure 7: Damage to JR-East facilities (modified from www.jreast.co.jp/press/2019/20191013_ho01.pdf)

4 SUMMARY

4.1 Key observations and lessons learned

From the reconnaissance work and information collected from various sources, the following are the main observations and lessons learned from this large-scale disaster.

- The amount of rain that fell during the passage of typhoon Hagibis was unprecedented, with >1,000 mm of rain falling in some areas. This caused widespread flooding in many places due to overflowing of rivers, breaching of river dykes and inland flooding when the rainwater was not able to drain out.
- The intense rain caused many sediment disasters, including debris flows, slope failures and landslides. While some disaster mitigation systems that were in-place worked, the intensity of the typhoon and the amount of rainfall it brought were unprecedented, almost beyond what the systems were designed.
- In terms of ground-related damages, both "hard" countermeasures, such as strengthening river dikes, and "soft" countermeasures, such as evacuations of high-risk areas, were available. However, existing community planning and urban structures may be inadequate to deal with intensifying natural disasters.
- While many river dykes performed well, there is a likelihood that more intense typhoons would strike urban centres in the future. There is a need for a thorough review of Japan's flood control countermeasures in order to prepare for such increasingly abnormal weather.

4.2 Implication to NZ setting

Widespread flooding induced by intense rainfall and dyke breach is not new to New Zealand. As extreme weather is becoming more frequent and catastrophic due to global warming, NZ's coastal regions are becoming more prone to storms and flooding. The lessons learned from the impact of typhoon Hagibis are equally applicable to New Zealand setting. Various flood protection and sediment disaster measures designed from past experiences need to be re-evaluated. While structural (hard-type) approaches, such as building stronger flood defence systems would work, there is a limit to their effectiveness when we think that intense rainfall is becoming the new norm. Non-structural (soft-type) approaches, such as improved flood warning and evacuation systems, can significantly reduce the impact of flooding and potentially save more lives.

5 CONCLUDING REMARKS

As a country frequently experiencing natural disasters, Japan has developed various disaster mitigation measures and many are already in place; yet, typhoon Hagibis still caused unprecedented damage to life and property. With the forecasted increase in future rainfall intensities, geotechnical engineers need to re-evaluate the way we design such measures, with a focus on both "hard" and "soft" components.

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