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TSUNAMI DESTRUCTION IN JAPAN CANNOT BE PREVENTED WITH USE OF EXISTING SEAWALLS – Case Study: The Great Tsunami of 11 March 2011

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ABSTRACT

A megathurst magnitude 9.0–9.1 (M_w), undersea earthquake on 11 March 2011 off Japan's Tohoku region on the Pacific coast, generated massive tsunami waves. Extremely high waves and the resultant debris flow overtopped and destroyed the existing seawalls which offered little or no protection, thus resulting in thousands of deaths and causing extensive destruction of coastal facilities, including the Fukushima Daiichi nuclear plant. The tsunami destroyed easily the tidal gates on the roads connecting the port to the town, and since there was no seawall protection on the tsunami's path on rivers, there was also extensive inland damage upstream, as the waves striking over river banks reverted river flows, thus causing the water to rise and form even higher waves with greater inland inundation. Even weak tsunamis striking a river outlet on a coast can generate a high-volume river water flow reversal and potentially cause substantial damage upstream. The present government tsunami countermeasures in Japan for such river areas are unable to prevent such enhancement of tsunami damage and to provide adequate protection for inland areas.

Keywords: *river tsunami; tsunami countermeasures; Earthquake & tsunami; seawall protection; river flow reversal; upstream tsunami inundation enhancement*

1. INTRODUCTION

To use seawalls for protecting the mainland regions of Japan from locally or distantly generated tsunamis, it is necessary for the responsible civil defense authorities to have the ability to take into consideration and evaluate the height of a potential tsunami on populated coastlines and issue appropriate timely warnings. This is not always possible to do because of unpredictable factors contributing to unknown secondary tsunami height enhancement effects. Historically, many destructive local and distant earthquakes have generated tsunamis that struck Japan. Most of the locally generated tsunamis are from oceanic regions surrounded by oceanic trenches and characterized by tectonic subduction. The Japanese archipelago is surrounded by oceanic trenches - including the Chishima-Kamchatka Trench, the Japan Trench, the Izu-Ogasawara trench, and the Philippine Trench, where extensive subduction is taking place. However, besides earthquakes near trenches, destructive local tsunamis have been generated by a variety of other events, such as volcanic eruptions and landslides.

According to reports from Japan and elsewhere (Pararas-Carayannis, 2011; Aydan, 2011; Arikawa EtAl, 2012; Shigeo Takahashi EtAl., 2011, In Japanese; Arikawa & Shimosako, 2013; Raby EtAl. 2015), the 11 March 2011 off Japan's Tohoku region on the Pacific coast occurred at 14:46 JST on Friday, 11 March 2011 and had a moment magnitude of 9.0, and epicenter about 129 km east of Sendai off the coast of northern Japan. The coasts of Iwate, Miyagi, and Fukushima Prefectures were severely damaged and Hokkaido, Aomori, Ibaragi, Chiba Prefectures were also damaged, particularly due to the extreme tsunami generated by this earthquake. Immediately following the disaster extensive field surveys were carried out by the Japanese authorities and research organizations (Shigeo Takahashi EtAl., 2011 in Japanese) which included analyses of seismic and tidal records as well as of GPS wave meters, as reported in the scientific literature (Pararas-Carayannis, 2011).

The following sections describes briefly this 2011 disaster and some of the historical tsunamis that have impacted Japan, which originated from a variety of local or distant earthquakes or other local sources, with special emphasis given on the extensive inland damage upstream over river banks by reverted river flows.

2. EXAMPLES OF MISCELLANEOUS HISTORICAL TSUNAMI EVENTS THAT IMPACTED JAPAN

Historically, Japan has been struck by destructive tsunami waves generated from local and distant earthquakes, from volcanic eruptions and collapses of lava domes and of resulting coastal cliffs. The following sections describe briefly some of these mechanisms.

2A. Tsunami Generated from Distant and Local Earthquakes

More recently, the main generation of tsunamis that hit Japan was from distant sources such as that of the 1960 Chile earthquake, or from local earthquakes such as that of 2011 off the Island of Honshu (Pararas-Carayannis, 2012). For tsunamis generated from distant sources, such as that of the 1960 Chile earthquake which caused extensive damage in Japan, at least there was sufficient time for the Japanese authorities to issue a timely warning and take measures for preparation. However, this was not possible for the great magnitude M9.0 earthquake of 11 March 2011 off Honshu in northern Japan. This earthquake occurred off the coast at 4:46 JST on Friday, 11 March 2011. Its epicenter was 129 km east of Sendai (Pararas-Carayannis, 2011; Shigeo Takahashi EtAl., 2011 In Japanese).

Tsunami waves from this 2011 earthquake, not only were extremely high along the coasts but also reversed the flow of local rivers, causing the water to rise and form higher waves that traveled much further inland, and resulting in extensive damage to structures on river banks. Historically, even weak tsunamis striking a coast have often generated high-volume river water flow reversal and have caused substantial damage upstream. However, and until recent times, there was low awareness as to how tsunami waves propagate on rivers and on how destructive they can be.

2A. Tsunamis of Volcanic Origin and of Coastal Collapse of Cliffs

There have been many destructive tsunami events from such sources in Japan. For example, a 1792 collapse of a lava dome of Mt. Mayuyama of the Unzen volcano triggered an avalanche that resulted in a 20-meter tsunami which surged across the Ariake Sea and killed 14,524 people.

Large earthquakes near Japan can also cause coastal cliffs to collapse into the sea and also generate large waves. In 1958, a magnitude 7.7 earthquake in Araskaritsuya Bay resulted in the collapse of cliffs of a narrow fjord causing an avalanche into the sea which generated huge waves that inundated up to 524 meters inland across the adjacent shore.

2B. Inland Tsunami Destruction Caused by River Flooding of Embankments

Nearly all of Japan's rivers feature high-volumes of water flow because of melting snows and of heavy typhoon related rains. As a consequence, this large amount of water often overflows the edges of river embankments causing extensive flooding and destruction. Japan's tsunami-related countermeasures – at least until 2011 - ignored this vulnerability due to river flooding, which is also exacerbated by the earthquake-generated tsunami inundation. Often, existing seawalls did not provide adequate protection. For example, approximately 190 kms of an existing 300 kms seawall along the coast of Sanriku was destroyed by the massive tsunami generated by the great 2011 earthquake, resulting in great indirect losses, as well to the deaths of many people of vulnerable coastal communities (Raby EtAl. 2015). Approximately 190 km of the 300 km seawall along the Sanriku coast was destroyed by this massive tsunami. The above article "Consideration of Structure of Coastal Conservation Facilities", and the included photographs below as in figures 1 and 2 in the following section, document the extent of coastal damage to three Tohoku prefectures.

2C. Seawall Destruction by the 11 March 2011 off Japan's Tohoku region

The 2011 tsunami caused immense damage to seawalls and other protective structures along the coastal Tohoku region. Specifically, about 190 km of the coast's 300-km seawall was completely or partially destroyed. Also, the waves of the tsunami resulted in the inland deposition of sediments of up to 50 centimeters in thickness. The force of the tsunami wave impact and the flow of the debris contributed in the whole or to the partial destruction of the seawalls which had been designed to only withstand seawater hydraulic pressures. As shown in Fig. 1, a seawall on the coast of Yamamoto Town in the Miyagi Prefecture and the base of the levee were shredded by the force of the waves of the 2011 tsunami (Mano et al. 2013).

Fig. 1. Seawall destroyed by a tsunami (Mano et al. 2013)

Subsequent studies examined the failure mechanism of coastal levees on the Sendai Bay Coast hit by this 2011 gigantic tsunami, and determined that almost eighty percent of these intended to protect the land from storm surges were broken in various degrees of damage by the tsunami (Mano et al. 2013). However, following this disaster, both national and local governments decided to rebuild these levees to be durable to withstand even the force of mega tsunamis.

The height of the levee was high on the beach, and was designed to only withstand seawater pressure and to offer protection to storm generated surges, but of not of sufficient strength to protect from changes in the seabed topography due to tsunami flooding and subsidence of its foundation – in spite of the embankment's reinforcement with concrete (Fig. 2). In brief, tsunami waves containing large amounts of sludge and sediments are much more destructive. For example, the great Meiwa Tsunami of 1771 carried a 1000-ton rock to a point 35 m above sea level and 100 m from the coast on Ishigaki Island (Travel JP, Okinawa travel guide). Since this tsunami had a run-up height of 85 m, seawalls would offer no protection from its damaging effects. Additionally, ports have shipping routes that lead to the open sea. Therefore tsunami wave can impact ports through these shipping route openings. Figure 2 depicts a port's seawall, completely destroyed by a tsunami.

Fig. 2. Seawall of a harbor in Yamada completely destroyed by a tsunami.

The sturdy doors that blocked the road between the port and town were also easily destroyed. Simply, increasing a coastal seawall height will not mitigate sufficiently the damaging effects of tsunamis. Furthermore if a river flows through a town, a tsunami can strike and breach the river embankment.

The statement above is supported by the author's own experience with the 2011 tsunami, whose house is located about 20 km away from the sea in close proximity to the Sasame River. Soon after the earthquake, there was 1 meter fluctuation in the level of the river, relative to the tidal shift. Therefore, and based on what happened, the potential damage spreading upstream via rivers must be examined, as even weak tsunami can create a damaging wave of significant height, if the affected river is large and has a high-volume of water flow.

Based on the field observations of significantly high waves on rivers even at great distance from the shoreline, it must be evident that the present analysis of the Japanese government's tsunami and flood hazard maps for such region must be re-evaluated and appropriate countermeasures of worst-case scenarios must be adopted.

3. TSUNAMI DAMAGE PREVENTION MEASURES

The Japanese government has built a 400-km seawall on the Sanriku coast at the cost of 1 trillion yen and the coast is blocked by a long and high embankment. In urban areas with limited land, embankments are thin and can be easily destroyed by a tsunami. Seawalls are very expensive to build (2.5 billion yen/km) and are useless as they can only provide protection for smaller tsunamis. Moreover, failing seawalls can actually exacerbate the damages. Additionally, some residents trusting protection from seawalls, remain in their homes even after tsunami warnings are issued. Every few decades, a huge tsunami breaches the sea walls, threatens inhabitants, and causes numerous deaths. The 1896 Meiji Tsunami Tsunami killed 22,000 people along the Sanriku Coast. The 1933 Showa Tsunami, resulted in 3,000 people deaths, another 142 people died from the 1960 Chile Tsunami, and 22,000 more people died by the Heisei Tsunami in 2011.

This loss of human life has been happening on the Sanriku coast for decades, specifically four times in just 115 years, and has had adverse effects on other natural life. Lastly, even seawalls deprive young fish of their habitat, block nutrients flowing from land to sea and destroy natural landscapes.

In brief, past tsunamis and their resultant debris flows easily have destroyed seawalls. Additionally, tidal gates on the roads connecting the ports to the towns were also destroyed. Therefore, until 2011 there has been no really effective seawall protection in blocking a tsunami's inland inundation as the existing seawalls are inadequate as the rivers' embankments can be easily breached.

CONCLUSIONS

In addition to other measures, Japanese Civil Defense Authorities must also prepare for inevitable river tsunamis, as these can be generated from even weaker earthquake events. Unfortunately, the current administration's tsunami countermeasures must be revised in order to become more effective and prevent worse damage from future tsunamis

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