Field Surveys of Recent Storm Surge Disasters

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Abstract

In these ten years since 2004, there were more than ten big disasters in coastal area including six storm surge events and five tsunami events. The author performed post disaster surveys on all these events as the team leaders of survey teams. Based on those experiences, the author describes lessons of these events. Tsunami is now generally well known to coastal residents. Evacuation plans gradually become common for tsunami disasters. Storm surges arise more frequently due to strong storms but coastal residents are not well protected and not informed how to evacuate in case of surge emergency. From the field surveys conducted, it appeared that the damage depend on the geographical and social conditions of each of the areas that were visited by the author. It is now clear that such issues play important roles in disaster mechanisms. Therefore disaster risk management should carefully include local topography and social conditions of each area during the formulation of disaster prevention plans. In order to establish a reliable disaster prevention system, appropriate protection structures should be constructed, and these should be accompanied by a clear and concise evacuation plan for residents of a given area.

Keywords: Storm Surge; field survey; numerical model; local condition; evacuation plan

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1. Introduction

It was December 26, 2004 when Indian Ocean tsunami was generated and it attacked the coastal lines of Indonesia, Thailand, Sri Lanka and so on. Before this catastrophe, coastal disasters such as tsunamis or storm surges were thought to be local disasters. But for the case of Indian Ocean tsunami, there were impacts on wide areas including coasts of whole Indian Ocean. It was identified as a regional size disaster that gave serious influence to the whole world.

Since then during the decade, there were big coastal disasters including tsunamis and storm surges every year over the world as listed in Table 1. They are Storm Surge by Hurricane Katrina, USA (2005), Java Island Tsunami, Indonesia (2006), Storm Surge by Cyclone Sidr, Bangladesh (2007), Storm Surge by Cyclone Nargis, Myanmar (2008), Tsunami in Samoa Islands, Samoa (2009), Chilean Tsunami, Chile (2010), Tsunami in Mentawai islands, Indonesia (2010), Tohoku Tsunami, Japan (2011), Storm Surge by Hurricane Sandy, USA (2012) and Storm Surge by Typhoon Yolanda in the Philippines (2013). We surveyed disasters of all these events by ourselves and accumulated the analysis of field data including flood height distributions, interviews to the residents and so on. In the followings, brief review of the past storm surges are described and selected lessons are summarized from the field surveys. In the present paper, we focus on storm surges and do not describe on tsunamis.

2. Findings from each Storm Surge Disaster

2.1 Storm Surge by Hurricane Katrina, USA (2005) (Shibayama at al., 2006)

In 2005, Hurricane Katrina struck Mexican Gulf coast of the USA. A big storm surge and high waves attacked the coast of New Orleans city and Louisiana state coast. Disaster survey was done by Japan Society of Civil Engineers (JSCE) Team headed by the present author in coastal area covering from the lower part of Mississippi river and the Borgne Lake to Pascagoula of the Alabama State for nearly 300km in total (Shibayama at al., 2006). The major methodology used by the team were 1) hearing to the governmental organizations related, 2) observations and the measurements of heights of water marks, (Mississippi downstream part to Alabama state Gulf Shores) and 3) hearing to the residents.

The storm hit the New Orleans and coast of the Louisiana state. Along with strong wind and heavy rain, storm surge generated wind surge, pressure surge, wind wave and set-up due to wind waves together with high tide. They attacked the coast line and sea water flooded over the coastal area. The Louisiana coast had been attacked by strong hurricanes almost every year but the magnitude of Katrina was far greater than their recent experiences. For the case of New Orleans city, the city area was protected by levees but the levees were over flowed and destroyed by storm surge and the city was widely flooded.

As an example, Gulfport is located on the sand bar next to Biloxi. The south shore was attacked from Gulf of Mexico side and the north side was attacked from Big Lake (lagoon) side. Houses are totally collapsed in the city for around 250m from the coastline. It is considered that damage by wave attack was big in this area from the hearing of the residents. Fig. 1 show the section distribution of the watermarks. The maximum storm surge in

| Year | Disasters                      | Locations            | Number of Losses and Unknowns | Special Remarks                      |
|------|--------------------------------|----------------------|-----------------------------|--------------------------------------|
| 2004 | Indian Ocean Tsunami           | Sri Lanka/Indonesia/Thailand | 220,000                     |                                      |
| 2005 | Storm Surge by Hurricane Katrina | USA                  | 1200                        |                                      |
| 2006 | Java Tsunami                   | Indonesia            | 688                         |                                      |
| 2007 | Storm Surge by Cyclone Sidr    | Bangladesh           | 5100                        | Construction of Cyclone Shelters     |
| 2008 | Storm Surge by Cyclone Nargis  | Myanmar              | 138,000                     |                                      |
| 2009 | Tsunami in Samoa Islands       | Samoa                | 183                         |                                      |
| 2010 | Chile Tsunami                  | Chile                | 500                         |                                      |
| 2010 | Tsunami in Mentawai Islands    | Indonesia            | 500                         |                                      |
| 2011 | Tohoku Tsunami                 | Japan                | Death 15.782 Unknown 4086   |                                      |
| 2012 | Storm Surge by Hurricane Sandy | USA (New York)       | 170 USA 80                  | 2-3.0m in Manhattan around 4.0m in Staten Island |
| 2013 | Storm Surge by Typhoon Yolanda | Philippines          | Death 4,011 Unknown 1,602   |                                      |
the area was 9.58m including surface wind waves.

From the field survey, it appeared that the number of lives lost depended on the geographical and social conditions of local area. For the retreat and recovery process, we should consider the local condition of the topography and the social conditions of the area. In order to establish a reliable disaster prevention system, we should design appropriate protection structures and also should design evacuation plan for residents in the area.

As results of the survey, the following conclusions are obtained (Shibayama et al., 2006).

1) Activity of storm surge is like flood and small waves with height less than 10cm were accompanied in Waveland.
2) Disaster mainly depended on water level and flow velocity and wave effect looks minor from the video which was recorded by a resident in Waveland.
3) The view of disaster site after storm surge looks like those of south Sri Lank or Banda Ache of Indonesia which we observed in our tsunami survey work in those areas.
4) Water with high momentum suddenly came and washed away houses and destroyed them.
5) It was found that the wave force is more effective on the damage than the inundation only in Gulfport.
6) The major difference from Japanese protection concept comes out from land use and density of population in coastal area and also the policy of central or local government.

2.2 Storm Surge by Cyclone Sidr, Bangladesh (2007) (Shibayama et al., 2009a)

Cyclone Sidr was one of the strongest cyclones in the Bay of Bengal which made flood due to storm surge in Bangladesh on November 15, 2007. Sidr invaded into the highly vulnerable low lying densely populated coastal areas of Bangladesh with heavy rain, winds of up to 215 km/hr, and a storm surge. Sidr is the strongest cyclone to hit the country since the cyclone killed over 140,000 Bangladeshis in 1991. Although, the death from Sidr number is five thousands but damage to homes, paddy field and livelihoods could be extensive. Field surveys were performed in the southwest of Bangladesh to learn lessons out of severe disasters due to Cyclone Sidr by Japan Society of Civil Engineers and the team was headed by Prof. T. Shibayama (Shibayama et al., 2009a). Spatial distributions of inundation heights were measured around the most damaged area.

Figure 2 shows the survey route and spatial distributions of measured storm surge heights. Water marks due to the storm was first detected based on interviews of witness. The elevations of each water mark were then measured...
using a laser distance meter as a height from the surface water level of a river and spatial locations of each site were also recorded using GPS. Surge heights elevations shown in Fig. 2 were then modified accounting for time-varying tidal water level around the river mouth. Fig. 2 also indicates the locations of several sites where we performed further detailed survey.

In Southkhali, according to our hearing, the first wave of the high tide came to the newly constructed bank after which the second wave flowed over the bank. The third wave of the high tide advanced on a shelter. The wave period of these bores was around one minute. The high tide continued about fifteen minutes. Women and children took mainly refuge in the second floor level of the shelter, where the inundation depth was 0.59 m over the floor, whose height was 2.99 m over the surface of the shelter’s embankment foundation. Some water entered through windows, the lower edges of which were of 3.74 m height over the surface of the shelter’s foundation. When the water came into the second level, the refugees were frightened and wanted to go outside but they could not open doors because of strong winds and flood water. Some traces were left when they forced themselves to open the doors. Many people evacuated on the shelter top, where they felt the space was not enough.

Many people were flowed before they reached this shelter, including a child swept away about 3 km. Several children caught trees to be spared. In this area about 300 people were died. In regard to evacuation, the following

![Figure 2. Survey route and measured storm surge heights. Capital letters in the map indicate the locations of (A) Rayenda Bazar, (B) Southkhali, (C) Somboniya, (D) Naltona, and (E) Kuakata. (Shibayama et al., 2009a)](image-url)
points are important: 1) education of disaster prevention, 2) certain communication channel of evacuation information (e.g. cell phones, radio and speaker for Alcoran), 3) construction of shelters considering adequate evacuation distance and enough capacity.

Inundation heights along the Baleshwar River and the Burishwar River were relatively high compared to those observed on the coast of Kuakata although these sites are far from the coast. Embankments along the river had been eroded before the storm while dikes on the coast significantly functioned to reduce the damages of the coastal area behind. Many people witnessed that storm surges inundated with bore-like waves. Contour measured against storm surges should account for the physical mechanisms for the development of such bore-like waves and possible damages due to such waves. As observed in Kuakata and Somboniya, embankment showed significant roles to minimize the damage. Development of riverbanks especially around the river mouth is one of most essential countermeasures to be carried out in Bangladesh. Shelter functioned to save significant number of lives although the numbers of shelter needs to be increased to match the number of residents and the distribution of them.

2.3 Cyclone Nargis, Myanmar (2008) (Shibayama et al., 2009b)

The cyclone ‘Nargis’ hit the southern part of Myanmar on May 2nd and 3rd 2008. This strong cyclone caused more than 138 thousands of loss of lives, enormous number of casualties as well as fatal damages to houses and paddy fields. Particularly both the downstream areas of the Irrawaddy and Yangon River basins were seriously damaged. In the present field survey, the activities were limited to the area near Yangon city due to strong governmental restrictions. As results of field survey through interviews to residents and measurements by using the laser type distant meter, it was found that the tide due to the storm surge was up to 3 to 4m and came up to around 50 kilometers upstream of the river mouth of Yangon River. Fig. 3 shows the distribution of measuring points and storm surge heights.

According to interviews with the local residents, it appears that significant flooding took place at inland areas as a result of the upsurge through the tributaries or channels from the main river. Even though the situation was catastrophic, it seems that most residents had not evacuated. One of the reasons for this could be related to the fact that the cyclone passed through the area investigated in the late night May 2nd to the early morning of May 3rd. Residents stay in their homes in dark. Another reason is because of an underestimation or the lack of perception of the threat of storm surge.

Apart from the investigation, the tracks for the present and past cyclones (1945-2007) had been analyzed based on a string of best track data. The results reveal that quite a small number of cyclone (roughly 2 times on average every 10years) have hit the southern coast of Myanmar compared to the number of cyclones that hit the coast of Bangladesh, and that the route that Nargis traced is rather unique. Since the residents have few experiences of storm surge, they didn’t get any image of the possible disasters when the storm surge came.

Surveys of height of storm surge and interviews to residents reveal that people in disaster area in Myanmar were not accustomed to the attack of cyclones. The storm surge traveled through rivers and small scale channels and flooded over paddy area and villages. The basic mechanism of storm surge disaster was similar to the case of cyclone Sidr in Bangladesh but the result was very different. Bangladesh has long and severe experiences of storm surge and has prepared to the attacks. An example of Bangladeshi preparedness is construction of cyclone shelters. It is worthwhile for Myanmar engineers to learn lessons from Bangladeshi case.

2.4 Storm Surge by Hurricane Sandy, USA (2012) (Mikami et al., 2013)

On October 29th, 2012, Hurricane Sandy made landfall along the east coast of the United States and generated
storm surge in New York and New Jersey. The flooding in New York caused heavy damage on infrastructures such as an electricity and a subway system. Table 2 is a summary of storm surge heights measured by the Waseda survey team headed by Prof. T. Shibayama (Mikami et al., 2013). The storm surge heights were 2.5 to 3 m in Manhattan and around 4 m in Staten Island.

In Manhattan, flooded water intruded into subway system through stations. Also underground floors of buildings were flooded. In highly urbanized area like in New York, protections against water intrusion into underground structure and area have weak points. For the case of New York City, the subway system was stopped before the arrival of storm. Residents in high flood risk area were also ordered to evacuate before flooding.

Table 2: Surge height distribution in New York (Mikami et al., 2013)

| Location                          | Latitude       | Longitude      | Surge Height (m) | Surge Depth (m) | Classification          |
|-----------------------------------|----------------|----------------|------------------|-----------------|-------------------------|
| South Street Seaport              | N 40°42.343′   | W 74°00.186′   | 2.65             | 1.14            | Mudline (inside)        |
| Fulton Street                     | N 40°42.373′   | W 74°00.200′   | 2.59             | 1.99            | Mudline (outside)       |
| Fulton Street                     | N 40°42.396′   | W 74°00.216′   | 2.82             | 1.89            | Mudline (outside)       |
| Fulton Street                     | N 40°42.403′   | W 74°00.204′   | 2.69             | 1.72            | Mudline (outside)       |
| Fulton Street                     | N 40°42.415′   | W 74°00.232′   | 2.96             | 1.57            | Mudline (inside)        |
| Fulton Street                     | N 40°42.432′   | W 74°00.225′   | 2.87             | 1.21            | Mudline (inside)        |
| Fulton Street                     | N 40°42.456′   | W 74°00.262′   | 2.61             | 0.59            | Mudline (inside)        |
| Pier 11                           | N 40°42.197′   | W 74°00.381′   | 2.62             | 1.26            | Mudline (inside)        |
| Wall Street                        | N 40°42.287′   | W 74°00.392′   | 2.51             | 1.35            | Mudline (inside)        |
| Wall Street                        | N 40°42.323′   | W 74°00.453′   | 2.68             | 0.44            | Mudline (inside)        |
| New Dorp Beach (Staten Island)     | N 40°33.987′   | W 74°06.112′   | -                | 0.76            | Mudline (inside)        |
| New Dorp Beach (Staten Island)     | N 40°33.727′   | W 74°05.842′   | 4.03             | 2.22            | Drift on a tree         |
| New Dorp Beach (Staten Island)     | N 40°33.862′   | W 74°05.682′   | 3.44             | 1.88            | Mudline (inside)        |
| Wolfes Pond Park (Staten Island)   | N 40°30.764′   | W 74°11.572′   | 4.22             | 2.55            | Drift on a tree         |
| East River side (E 23rd St)        | N 40°44.120′   | W 73°58.469′   | 2.57             | 1.26            | Mudline (inside)        |
| East River side (E 25th St)        | N 40°44.206′   | W 73°58.453′   | -                | 1.24            | Mudline (outside)       |
| East River side (E 30th St)        | N 40°44.416′   | W 73°58.346′   | -                | 1.16            | Mudline (outside)       |
| Substation                        | N 40°43.742′   | W 73°58.515′   | -                | 1.32            | Mudline (outside)       |
| Substation                        | N 40°43.604′   | W 73°58.419′   | -                | 0.96            | Mudline (outside)       |
| Hudson River side (St Clair Pl)    | N 40°49.071′   | W 73°57.676′   | -                | -               | Eyewitness ("reached here") |

2.5 Storm Surge by Typhoon Yolanda in the Philippines (2013) (Shibayama et al., 2014)

The typhoon was formed in the southern Pacific Ocean in November 2013, and it was one of the most violent storm events so far in the 21st century. This typhoon caused catastrophic damage to the Philippines coastal area due to its high winds and the storm surge generated by it. The surge went on to flood over coastal settlement in Leyte Gulf. The storm surge inundated Tacloban city and caused widespread devastation, with maximum recorded
inundation heights of 7.02m.

Fig. 4 shows the survey result of Joint Survey Team headed by Prof. T. Shibayama. It shows that in Leyte Island, the heights were 4 to 8 m and in Samar Island they were 2 to 6 m. In Leyte, in the coasts of Tacloban, Palo and Tanauan, highly populated areas of low income residents were flooded by sea water with high momentum. In some places, surge attacked as bore waves and destroyed low quality houses that were located in low ground with high density. Those conditions results more than four thousand losses of lives.

**Fig. 4.** Distribution of measured storm surge heights along the Leyte Gulf coast. Depth contour lines (20 m and 50 m) are obtained from the GEBCO_08 Grid which is organized with a grid size of 30 seconds (Shibayama et al., 2014).

### Surveyed City and Municipalities

**Leyte island**
- L1. Tacloban City
- L2. Palo
- L3. Tanauan
- L4. Tolosa
- L5. Dulag
- L6. MacArthur
- L7. Abuyog

**Samar island**
- S1. Santa Rita
- S2. Basey
- S3. Marabut
- S4. Balangiga
- S5. Giporlos
- S6. Quinapondan

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**3. Conclusions**

According to the results of recent storm surge disaster surveys, it appears that storm surges arise more frequently compared to tsunami but coastal residents are not well informed how to evacuate in case of surge emergency in particular in Asian countries. From the field surveys conducted, it appeared that the number of lives lost and economic damage depend on the geographical and social conditions of each of the coastal areas. It is now clear that such issues play an important role in disaster mechanisms and that disaster risk management should carefully include local topography and social conditions of each area during the formulation of disaster prevention plans including defense structures and evacuation planning.
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