5. RESTORATION PLANNING

5.1 Structural Measures for Hazard Prevention

The tsunami is not the only natural hazard in the Maldives. It is also necessary to consider stormy waves and the storm surge caused by broken waves.

5.1.1 Structural Measures in Low-Lying Areas

To prevent and mitigate disasters from the tsunamis and storm surge, especially in the low-lying areas without evacuation places, structural measures are effective. The structural measures can protect both of human lives and assets. Especially effective tsunami disaster mitigation is to make an integrated defense system which consists of the structural measures to reduce tsunami height and flow velocity and the non-structural measures to support evacuation. For structural countermeasures against tsunamis and storm surge, high structures are necessary, because it is hard to diminish the energy of tsunamis and storm surge by wave dissipation works.

5.1.2 Seawall

Seawalls are commonly used in Japan as the facilities to mitigate the disasters from tsunamis, storm surge and high waves. For high seawalls, on-land gates are additionally necessary to access coasts and harbors. In Male' Island, seawalls were effective to reduce tsunami flooding, because the tsunami above the astronomical tide at the moment which the tsunami came did not overtopped the seawalls badly. The tide level at the moment was around the mean sea level. Since the high tide level was 0.7m above the mean sea level, if the tsunami came at the moment of the high tide, the tsunami flooding may be more severe.

5.1.3 Coastal Rigid Building

Rigid houses and buildings are also effective to reduce tsunami damage behind them. They can work like breakwaters on the land. In the southwest of Sri Lanka, the tsunami trace height was 4.8m behind completely collapsed houses along the coast. On the other hand, it was 3.2m behind the houses with little damage. This is one example that rigid coastal houses contributed to reduction of the tsunami behind them.

Additionally, if the coastal rigid buildings are more than three stories, they can be available for evacuation places.

5.1.4 Evacuation Tower and Building

High buildings are available for evacuation places. Photo 5.1.1 shows an evacuation tower in Japan. This tower is 5 stories high and has about 220m^2 in area above the ground floor. It can admit 500 people. It is placed in the area difficult to evacuation by the existence of a river. It is also important to use existing high and rigid buildings for evacuation shelters.

Photo 5.1.1 Evacuation tower in Kisei-cho, Mie prefecture, Japan

5.1.5 Evacuation Terrace

Okushiri Island suffered severe damage by the 1993 Hokkaido Nansei-oki Earthquake Tsunami. The tsunami of 10m high attacked the south part of the island. After the tsunami, high seawalls were constructed along the coast to protect coastal low-lying areas. However, a fishery port was out of the seawalls to keep its fishery function. For evacuation of the persons working at the port from tsunamis, a new terrace was constructed as a tsunami shelter. The terrace was usually used for fishery activities.

Photo 5.1.2 Tsunami evacuation terrace

5.1.6 New-type Seawall

In the Maldives, high waves and storm surge are also natural hazards as well as tsunamis. The wave height can be reduced by wave dissipation works more easily than tsunamis and storm surge.

Photo 5.1.3 shows a new-type seawall constructed in Japan. This seawall has a buffer zone to prevent coastal inundation due to overtopping waves. The waves overtopped the front face of the seawall can permeate a buffer zone installed in front of the original seawall.

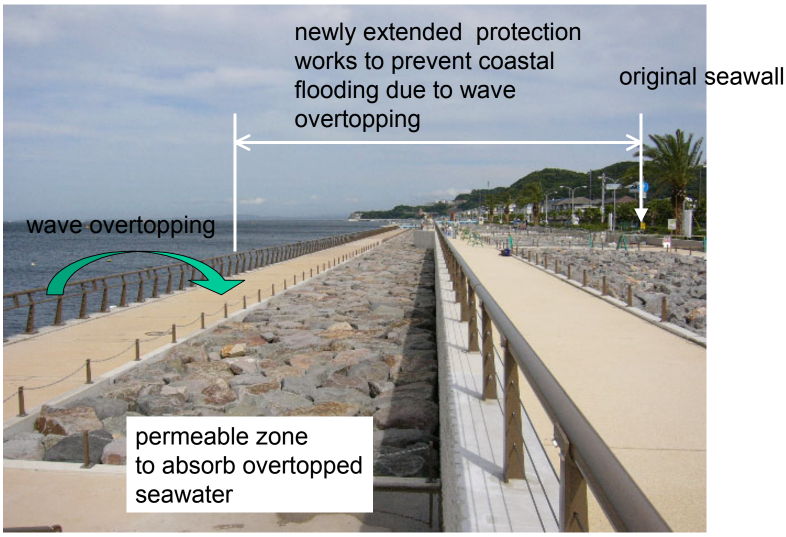

Photo 5.1.3 New-type seawall

5.1.7 Defense System

The structural measures can provide disaster prevention for specified hazards. However, for the hazards exceeding the specified level, which can happen in the future, the structural measures couldn't be necessarily effective in preventing damages. At that time, non-structural measures are needed to prevent the loss of human lives. Therefore, to prevent and mitigate the losses of human lives and assets, it is important to make an integral defense system which combines the structural and non-structural measures. In order to make the integrated defense system, we need to

- understand natural hazards in the target area with analyzing historic records, monitoring sea states and conducting numerical simulations, and
- understand the vulnerability of the community with evaluation of damage due to the natural hazards.

For the damage evaluation, it is necessary to evaluate the defense performance of structural measures. If there is less performance to prevent damages in the structural measures, we need to extend the performance of the structural measures or have the non-structural measure to save human lives, i.e. a supporting system of evacuation.

The consideration of quick restoration is also important. Some infrastructures and facilities such as a power plant are indispensable for restoration and it is, therefore, necessary to avoid severe damages of them to do some countermeasures. For example, a power plant in an airport is one of the most significant facilities. If it is inundated and does not function, the airport cannot be reopened quickly. In this case, one of the defense measures for quick restoration is to set power generators up high or to make the power plant to watertight structure, depending on the situation of the airport. We need to select and combine suitable structural and non-structural measures to mitigate disasters.

5.2 Education and Evacuation

Even if some large facilities are constructed along the coastline, we cannot expect that the tsunami is always/perfectly blocked by the facilities. Evacuation of the residents and tourists is necessary to save their lives. The following countermeasures are required to make a safe evacuation.

(1) International warning system

The large earthquake perhaps may occur far from the Maldives. The department of meteorology in the Maldives has to receive the accurate information on the earthquake and the tsunami as soon as possible.

(2) National warning system

The residents and tourists in the Maldives may not feel the strong earthquake, because the epicenter of earthquake is distant from the Maldives. Thus, no one be cautious about the tsunami if they cannot receive the tsunami warning. The department of meteorology in the Maldives has to dissemble the information to the island offices, mass-media and all residents and tourists to urge them to evacuate. This is difficult but important and essential for tsunami hazard prevention.

(3) Adequate facility for evacuation

In the Maldives, there is no mountain. Thus, some refuge structure, e.g. solid building and artificial ground, is required for the evacuation. Note that a refuge structure should be constructed for not only the hazard prevention but also the ordinary activities of the residents or tourists, because the hazard is not occurred so frequently and the daily use of the facility is desirable for the maintenance. However, the aim of the facility should be written clearly on/near the structure not to forget the hazard risk.

It is also important to strengthen the houses and walls. In some islands, the mosque kept without damages, although many houses were washed away. This indicates that the solid structure is not destroyed by tsunami. If many houses near the coast are not destroyed and remain there, the tsunami flow inside the island becomes weak and the whole damage is expected to decrease.

(4) Disaster education

The residents have to evacuate onto a proper location by themselves. They should be educated in the following items.

1. Fundamental knowledge on earthquake and tsunami
    - earthquake distribution in the world, plate tectonics
    - probability of aftershocks
    - propagation speed of tsunami

- initial motion of tsunami (flood or ebb)
- wave number of tsunami
- the fact that tsunami height is strongly affected by the local topography

2. Fundamental knowledge on earthquake and tsunami for the Maldives
   - Great earthquake may occur on the subduction zone, the most active one near the Maldives locates at the west of Sumatra. In such case, tsunami arrival time at the Maldives may be 3 hours after the earthquake, then, the residents may have enough time to evacuate.
   - Of course, there is the exception. If the earthquake occurs near the Maldives, the tsunami arrival becomes rapid.
3. The appropriate evacuation route
   - to high land
   - to offshore (If they are on the sea, they should not return to the island.)

In addition, it should be emphasized that the most important countermeasure is not to forget the hazard risk. The hazard education should be carried out at not only school but also public space. In Hawaii and Papua New Guinea, the article on tsunami (when they should take care, how they should act under the tsunami warning) is published on a telephone book. A sign showing the evacuation route constructed in the United Sates and Japan plays not only the original role but also the role of the publication of the risk. A mass media has also important role to pass our experiences to the next generation.

The tsunami countermeasures are summarized as follows:

- Facility construction to prevent tsunami
- Facility construction to evacuate from tsunami
- Preparation of tsunami warning system
- Hazard education

The above measures should be combined, depending on the circumstances.

5.3 Future Plan

In the 26/12/2004 Indian Ocean Tsunami, the tsunami height was similar to the crown height of the quaywall of Male'. Then, the quaywall and seawall worked effectively and Male' city was saved from the heavy disaster by the dam-effect of quaywall and seawall. However, there were some lucky factors in this event.

1. The tide level was not high at the arrival time of tsunami, but approximately the mean level.
2. Because the incident direction of the tsunami was east and Male' Island is sheltered by Fulhule Island in the east direction, the tsunami height possibly decreased to some extent in Male'.
3. The tsunami arrived in the morning, so the residents maintained their composure.

Thus, the tsunami risk assessment is required to check the safety level of Male' against tsunami, by varying the time, the season, the location of tsunami source area and so on in the tsunami numerical simulations.

The 'Safe Islands Programme', future plan of the Maldives, seems very rational and effective. However, the location and the ground level of the safe island and the height of the quaywall should be carefully determined based on the risk assessment.

We cannot become perfectly safe against tsunami by any means, by any investments. The Maldives should determine the target safety-level and select the combinations of the countermeasures, considering the cost performance and the living comfortability. This decision should be conducted by the government of the Maldives. To support this decision of the government, the experts of coastal engineering and hazard prevention should be educated.