

Multiple defenses against tsunami

[Background]

The coastal areas of Sendai City suffered many casualties and severe property damage from the tsunami accompanying the Great East Japan Earthquake. The city had a certain degree of preparedness as it had coastal levees, but they were not sufficient to protect against a tsunami that was far more massive than was ever imagined. The experience showed that structural protection alone had its limits in the face of a massive tsunami.

[Response]

In response to the earthquake disaster, Sendai City formulated the Sendai City Earthquake Disaster Reconstruction Plan and embarked on implementing comprehensive tsunami countermeasures that combine “multiple defenses,” “evacuation” and “relocation” into a single plan. Based on the results of a tsunami simulation, coastal levees, coastal disaster prevention forests and elevated road were developed as multiple defense measures.

1 Basic concept

A vast area of Sendai City suffered many casualties and property damage from the tsunami accompanying the Great East Japan Earthquake, because the eastern coastal areas that were hit by the tsunami were flat land. Levees and coastal disaster prevention forests had been developed along the coast since before the Great East Japan Earthquake, but because the tsunami accompanying the Great East Japan Earthquake was of a colossal scale that occurs only once in a thousand years, they were not sufficient to prevent the devastating damage.

However, even in the coastal areas, local residents who evacuated to the rooftop of school buildings and other high places were saved. Additionally, the embankment highway that runs north-south along the coast of Sendai City (Sendai Tobu Highway) served as a defensive wall against the tsunami. Thus, most residents who fled to on top of this highway and residents who lived on the west side (inland side) of this highway were able to mitigate their damage.

Taking this into consideration, Sendai City embarked on the development of multiple defense facilities for protection against tsunamis based on the Sendai City Earthquake Disaster Reconstruction Plan formulated in 2011. In addition to reinforcing existing levees and disaster prevention forests, a road located farther to the east side (sea side) of the Sendai Tobu Highway was elevated to give it the added function as a levee.

Furthermore, evacuation facilities such as tsunami evacuation towers that provide vertical evacuation to residents and visitors were also developed, as multiple defenses alone have limits against massive tsunamis. At the same time, residents living in coastal areas were urged to relocate *en masse* to safer areas, and the implementation of comprehensive tsunami countermeasures were planned.

This case example focuses mainly on “multiple defenses” among the three countermeasures of “multiple defenses, evacuation and relocation.”



▲ Image of tsunami countermeasures

Bird's-eye view map



Photo taken in September 2015

- Coastal embankment, river embankment, etc.
- Elevated road
- Evacuation hills
- Evacuation facilities
- Coastal disaster prevention forest
- Disaster risk area (Inland relocation)
- Inland relocated residential area
- Evacuation roads
- Disaster prevention collective relocation movements
- Evacuation stairs



2 Coastal levees (Budget: approx.740 million yen)

Before the Great East Japan Earthquake, there had been T.P. +6.2m\* and T.P. +5.5m coastal levees along the coast of Sendai City. Of these levees, the 830m segment along the fishing coast was managed by Sendai City, and the remaining approximately 9km long segment was managed by Miyagi Prefecture. Over the entire area, the levees suffered serious damage, including partial collapses, scattering of wave dissipating blocks, outflow of the soil on the landside slope, and corrosion of the landside ground.

The national government and Miyagi Prefecture reviewed an appropriate new levee height based on a simulation of a tsunami that occurs only once every few decades to a hundred tens of years. As a result, T.P. +7.2m was judged to be the appropriate height for the Sendai City area.

To restore the coastal levees, Miyagi Prefecture requested the national government to exercise authority in implementing the necessary construction work on behalf of the prefecture. As per this request, it was decided that the national government would take charge of the restoration of the segment of the levees that were under the management of Miyagi Prefecture, and Sendai City would restore the 830m segment that was under its management. With respect to the portions of the levees undertaken by the national government, the restoration of levees that protect important facilities such as the Minami Gamo Wastewater Treatment Plant, where wastewater is treated, were completed by March 2013, and the rest of the levees were completed by March 2017.

Various improvement measures were applied to the new levees to ensure resilience even in the event of a tsunami overflow. For example, ground improvements were made to the foot of the levee slope on the landside, concrete blocks with sufficient thickness and weight were procured for the crown and slope, and the blocks on the landside slope were fit together so they do not loosen from the levee.

Additionally, debris from the earthquake disaster in Sendai City was used as embankment material for the new coastal levees. A total of some 200,000m³ of earthquake debris was

used, including approximately 140,000m³ of tsunami sediment and approximately 60,000m³ of concrete debris. Thus, roughly 70% of the embankment material required for the coastal levees in Sendai City were diverted from earthquake debris. To Sendai City, this helped reduce the amount of debris that it needed to dispose of, and to the national government, which was in charge of developing the coastal levees, it helped in securing the necessary embankment material and mitigating the traffic congestion that would have occurred by vehicles transporting embankment material.

Furthermore, the national government and Miyagi Prefecture also developed levees along the two rivers that flow into the Sendai City area on the Pacific coast that are respectively under their management, and made them the same height as the coastal levees.

The segment of levees managed by Sendai City was restored by Sendai City. The restoration work was completed in December 2015 at a total project cost of approximately 740 million yen, of which approximately 640 million yen was covered by subsidy from the national government.

※ T.P.(Tokyo Peil) refers to Tokyo Bay mean sea level, which is the reference point for level surveying in Japan.



▲ Coastal levee

3 Coastal disaster prevention forests (Budget: 30-40 million yen per year)

Verdant disaster prevention forests existed along the coastal area of Sendai City since 400 years ago and fulfilled the role of preventing disasters caused by strong winds, blown sands, sea breezes, high tides and thick fogs as coastal disaster prevention forests. However, most of the forests were swept away by the tsunami, and what trees remained dried up and died due to salt damage. A total area of 330ha of coastal disaster prevention forests in the Sendai City area that was owned both nationally and privately was affected by the tsunami. The restoration of these disaster prevention forests were decided to be undertaken as a project under the direct management of the national government.

One of the reasons why most of the trees were swept away by the tsunami is thought to be because they were not deeply rooted in the ground due to the high groundwater level. For this reason, it was decided that the ground would be raised by piling 2-3m of embankment material as necessary to improve the foundation. As with the coastal levees, recycled materials diverted from tsunami sediment were used as the embankment material. The restoration of the disaster prevention forests is slated to be completed by March 2021.

The restoration of disaster prevention forests not only involves the development of a growth foundation and the planting of trees, but

also the nurturing and conservation of the trees thereafter. Thus, Sendai City launched a project together with an NPO and private firms with the aim of regrowing the greenery, with an eye to its completion within 30 years of the earthquake disaster. Through implementation of regular tree planting and nurturing events, workshops and other such events, the project is providing opportunities for local residents to pass down their memories of the earthquake disaster from their respective standpoints and to hand down the green resources of the area to the next generation. The project costs 30 to 40 million yen per year.



▲ Coastal disaster prevention forests

4 Elevated road (Budget: approx.29.8 billion yen)

Sendai City decided to elevate the prefectural road that runs north-south along the coast by 6m to allow it to function as a means to decrease the strength of tsunamis that arrive at the coast. In doing so, a simulation was performed while listening to the requests of local residents of the region. As a result of the simulation, part of the road was deviated from its original course to correspond to the boundary of the designated disaster risk area (area with restrictions on the construction of residential housing).

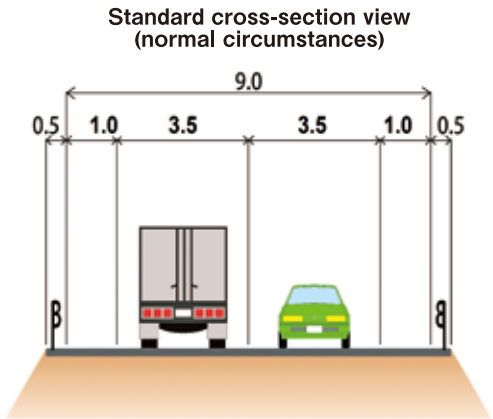
The road is a two-lane road with one lane in each direction, stretching a total distance of roughly 10km. The prefectural road segment that serves the largest amount of traffic is 9m wide. This is wide enough for three large vehicles, so that even if a vehicle is parked on the side of the road in an emergency, two lanes' worth of vehicles can still pass to the side of the parked vehicle. By raising the road by 6m, a height of T.P. +7.0m from sea level was secured. As with the levees and disaster prevention forests, earthquake disaster waste was recycled and used as embankment material, such that of the 1.6 million m³ of required embankment material, 400,000m³ were supplied by earthquake disaster waste.

Roads that run in the east-west direction intersect the elevated

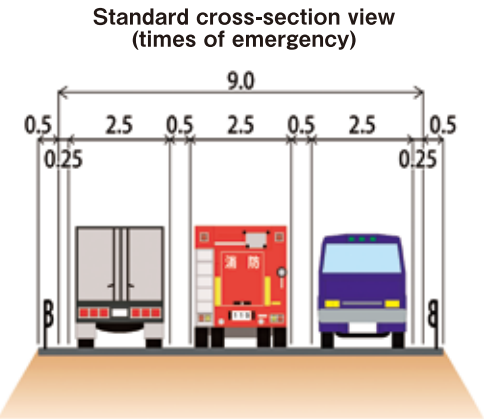
road in 14 locations. These intersections were constructed as level intersections, because an open structure like a tunnel might allow a tsunami to travel inland through these openings. Additionally, to secure the function of draining landside waters in normal times, openings were created in 27 locations where water channels intersect the elevated road, and flap gates (gates that block the opening) were built in all locations to prevent tsunami runups from these openings.

Rice paddies spread out on the east and west sides of the elevated road. Because the high embankment structure of the elevated road makes it difficult for farmers to use the road as a pathway, alternative roads were developed on the east and west sides as service roads. New service roads were constructed on the east side, and the existing prefectural road on the west side was kept so it could be used as a service road.

The elevated road was completed in November 2019. The total project cost was roughly 29.8 billion yen, but approximately 19.2 billion yen was funded by national government subsidy.



▲ Width of the elevated road (normal circumstances/times of emergency)



▲ Elevated road



▲ Intersection with an east-west road and a service road