STUDY ON TOPOGRAPHIC MODEL USING LIDAR FOR TSUNAMI SIMULATION

Y. Murashima [a, *], H. Takeuchi [a], F. Imamura [b], S. Koshimura [b], K. Fujiwara [a], T. Suzuki [a]

[a] Kokusai Kogyou Co., Ltd, 2-24-1 Harumi-cho, Fuchuu-shi, Tokyo, Japan - (yoichi_murashima, hitoshi_takeuchi, kenya_fujiwara, takayuki_suzuki)@kkc.co.jp
[b] Tohoku University, Disaster Control Research Center, 06 Aramaki-Aza-Aoba, Aoba-ku, Sendai-shi, Miyagi-ken, Japan - (imamura, koshimura)@tsunami2.civil.tohoku.ac.jp

Commission VIII, WG VIII/2

ABSTRACT:

This study discusses the creation method of topographic models from LIDAR data with the view of using them for tsunami simulation. Additionally, an examination regarding the improvement of simulation accuracy and topographic approximation of topographic models is carried out for the coastal region of Taro area of Miyako City in Iwate Prefecture in Japan using LIDAR data, comparing the simulation results of numerical analysis with different grid spacing from 5m to 40m. As for the differences due to changes in grid size, we can see that the modeling accuracy of sea walls and minute topography with a height of 1-2m is greatly affected by grid size. The tendency that the simulated inundation areas become smaller as grid sizes become smaller was observed in the urban areas behind embankments. The simulated inundation depths of the urban areas also became smaller in accordance with the decrease of grid size. This indicates that the detailed topographic model with smaller grids can interrupt the tsunami flow, because the smaller grids can express the minute ruggedness of the actual topography. Thus, it is important to use the smaller grid with precise height data in tsunami simulation in order to evaluate the hazard area adequately.

1. INTRODUCTION

Although the calculation method of tsunami simulation is improving to a useful level and the importance of topographic approximate precision is recognized, an in-depth investigation of accuracy and grid spacing has not yet been carried out. Recently, not only inundation area but also such things as inundation depth and flow distribution information is increasingly being supplied and the impact that using topographic data has on the results is a major issue.

Meanwhile, as can be seen from the tsunami which struck the Indian Ocean in 2004, it is recognized that one of the main causes of damage aggravation is peoples' lack of knowledge regarding tsunami hazards and the importance of things such as hazard maps is steadily increasing. At this time it is essential to provide detailed information, such as inundation area, extent of tsunami damage, evacuation centres and evacuation routes, to promote suitable evacuation procedures.

Under the Hazard Map Manual of Tsunami and High Tide supervised by the Cabinet Office (2004), accurate inundation prediction was carried out by topographic approximation according to grid spacing of 12.5m, in addition it is stated that elevation data (topographic data) with detailed precision of more than 1m in height is essential for predicted inundation areas. Consequently to utilize the latest 1/2,500 topographic maps is shown there. However, some of the 1/2,500 topographic maps are out of date. Their precision and density of contour lines and elevation values are inadequate for topographic models. Many local governments are not even maintaining them.

Furthermore, the 50m mesh elevation data, which we call '50m mesh data' in this paper, from the Geographical Survey Institute in Japan is developed nationally and sold at a very low price and it also well utilized in tsunami simulation. Because this data is created from 1/25,000 topographic maps and coastal data is provided by liner interpolation from the coastline (elevation 0m), measurement errors of several metres in height are found for areas which would be flooded by tsunamis and vulnerable coastlines. For this reason, this data is unsuitable for tsunami simulation to create the hazard maps with a scale of more than 1/10,000.

In recent years, airborne laser scanner (LIDAR, Light Detection and Ranging), which we call 'LIDAR' in this paper, has made it possible to measure elevation in an extensive area with sufficient precision for the production of detailed topographic maps. LIDAR has high measurement density and can measure minute topographical ruggedness which existing topographic maps could not display. Nowadays, detailed topographic models which are created from LIDAR data are also being used for such things as tsunami simulation (Imamura et al., 2004; Tsubaki et al., 2006; Iwate Prefecture, 2004).

In this study the characteristics of LIDAR data and the creation method of topographic models from LIDAR data will be described with the view of using them for tsunami simulation. In addition, an examination regarding the improvement of inundation prediction accuracy and topographic approximation of topographic models was carried out for the coastal region of the Taro area of Miyako city in Iwate prefecture in Japan using LIDAR data and the Geographical Survey Institute's 50m mesh data, comparing the inundation prediction results according to

---

* Corresponding author.

numerical analysis with a change of grid spacing 5m-40m. The adaptability and issues of LIDAR data will be described.

2. CHARACTERISTICS OF LIDAR

As shown in Figure 1, LIDAR is a system in which laser pulses are continuously emitted towards the land from fixed wing and rotary wing airborne laser scanner, and distance is measured from the return time by capturing the reflected light.
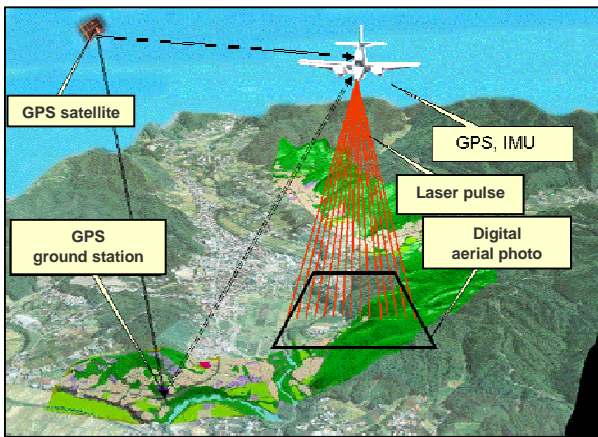

Figure 1. Schematic picture of Airborne laser (LIDAR) measurement

Laser pulses are cast at right angles from the aircraft's traveling direction and are emitted at a rate of 15,000-80,000 pulse/s. The ground point measurement density is approximately 0.5-2 points/m^2 and is remarkably high compared with existing topographic data. Location data (x,y,z) is calculated from the aircraft's location and relative positioning of the aircraft and the reflecting points. The former is measured by GPS and IMU (Inertial Measuring Unit) and the latter is measured from the distance and exposure angles between aircraft and reflecting points. Accuracy of point group data measured by LIDAR differs according to the conditions of such things as the regulating reference points and the aircraft's altitude at the time of measurement but they have the equivalent accuracy scope of ±30cm horizontally and ±15cm vertically for 1/1,000 topographic maps.

3. CREATION MEDHOD OF TOPOGRAPHIC MODEL FROM LIDAR DATA

The method of creating topographic models, used for tsunami simulation, from LIDAR data are described below. This study tried to maintain the positional accuracy and control and analysis by GIS from the processing of LIDAR data, numerical analysis and inundation prediction maps until the creation of CG.

3.1 Creation of DSM (Digital Surface Model)

After deletion of clutter included in the LIDAR data arising from diffused reflection which is caused by such as clouds, dust in the air and buildings, is performed, coordinate conversion and precision verification is carried out. This step data becomes DSM which is measuring the height of reflection

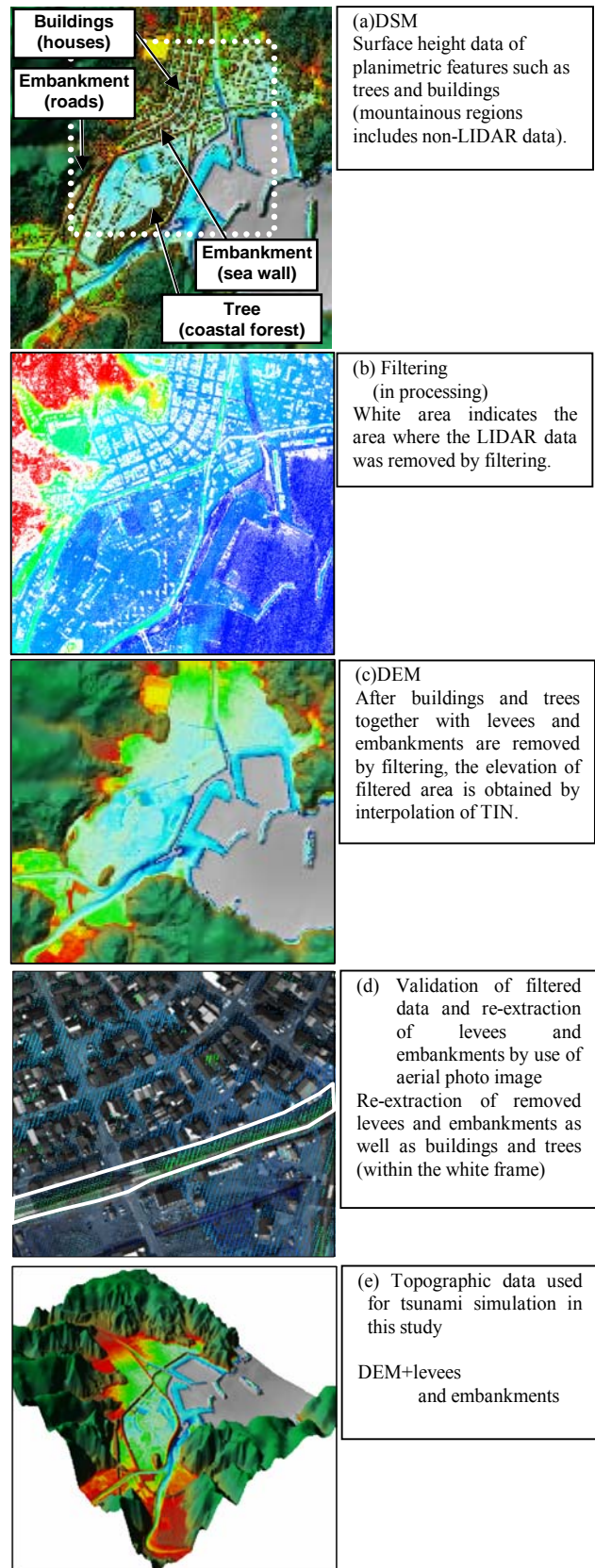points such as top of trees and buildings including ground surface (Figure 2(a)).

Figure 2. Flow of topographic model creation

3.2 Creation of DEM (Digital Elevation Model)

As shown in Figure 3, DSM includes the data reflecting at the surface of objects such as trees and buildings. From 1 round of LIDAR laser emission, several pulses such as trees and ground surface are obtained (Association of precise survey and applied technology, 2004). In addition, by using such things as high density points data and carrying out statistical filtering, to a certain extent, even for areas such as coastal forests bristled with trees, it can automatically make a distinction between reflection points which are trees and reflection points which are ground surface and it can extract the ground surface height.
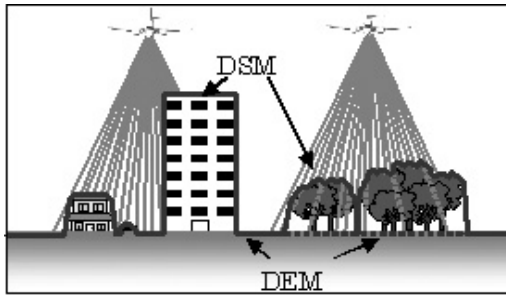

Figure 3. DSM and DEM

Figure 2(b) shows data after removal of surface data for planimetric features such as trees and buildings by filtering. Figure 2(c) shows the data (DEM) created by interpolating the surface height after filtering.
Figure 2(a) identifies planimetric features such as trees and buildings while in Figure 2(c) the contours of the planimetric features are reduced and the data reveals the ground surface.
This filtering process also removes levees and embankments.

3.3 Extraction of levees and embankments, meshing

Tsunami damage reduction facilities such as levees and consecutive planimetric features such as embankments have a great effect on the flooding behaviour of tsunamis. As these planimetric features cannot be distinguished by statistical filtering process alone, in this study the data was re-extracted by manual process by use of aerial photo images and town planning maps on GIS (Figure 2(d)).
In order to create elevation mesh data, DEM and re-extracted embankments and levees (Figure 2(e)) data are aligned, TIN (Triangulated Irregular Network) is created from those data, and the elevation of mesh is obtained as the height at the central point of mesh by interpolation of triangulated plane.

4. TSUNAMI SIMULATION

In order to compare the extents of the simulated inundation area depending on differences of grid spacing, tsunami simulation was carried out by numerical analysis of the following conditions.
For the tsunami source, according to Iwate Prefecture (2004), the parameters of the Meiji Sanriku Earthquake Tsunami were adopted. Numerical analysis is performed by using the nonlinear long wave equation as the basic formula, the leap-frog difference method and staggered grid. For overflow calculation the Honma's formula (Japan Society of Civil Engineers, 1999) was used.
The calculation areas were connected from the tsunami source region to the inundation area. The calculation grid spaces from the wave source to the coast were 3240m, 1080m, 360m, 120m and 40m.
For inundation areas, the 40m grid topographic model created from the Geographical Survey Institute's 50m mesh elevation data and the 40m, 20m, 10m and 5m grid topographic models created from LIDAR data were used as the minimum grid space.
In order to calculate the effectiveness of sea walls for each case in the same way, levee crown height (10.0m above mean sea level) is used as break-line data and incorporated in the topographic model.
The computation time interval for minimum grid space of 40m and 20m is 0.2 seconds, 10m is 0.1 seconds and 5m is 0.05 seconds, satisfies the stability conditions of a difference scheme and the computation period is the 40 minute period after an earthquake occurs, which includes the arrival of the first wave and is the period until before the arrival of the second wave.
The tide level is set to be equal to mean spring tide. The Manning's roughness coefficient n is set by classifying each land use on the 40m grid by use of the aerial photo images according to Table 1, with reference to Kotani et al. (1998).

Land Use Conditions	n
Oceans, Rivers	0.025
Arable Land (including waste land)	0.020
Woodland (including orchards, tide prevention forests)	0.030
Low Density Residential Areas (building density less than 20%)	0.040
Mid Density Residential Areas (building density 20-50%)	0.060
High Density Residential Areas (building density over 50%)	0.080

Table 1. Setting of Manning's roughness coefficient $n(s/m^{1/3})$

Figure 4 shows the tsunami water level changes at the arbitrary point within the minimum grid space from the results of each calculation. From the occurrence of the first wave until the end of the peak, the wave form is similar for any case. Thus, the tsunami conditions are almost equivalent when the inundation extent of the land areas of each case is compared each other.
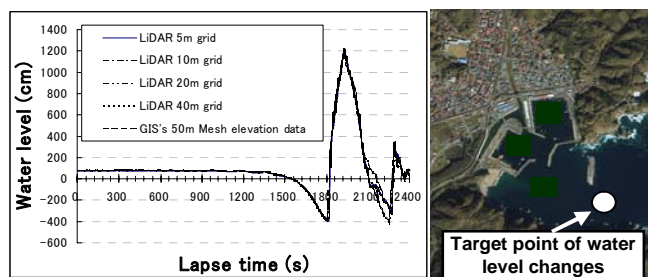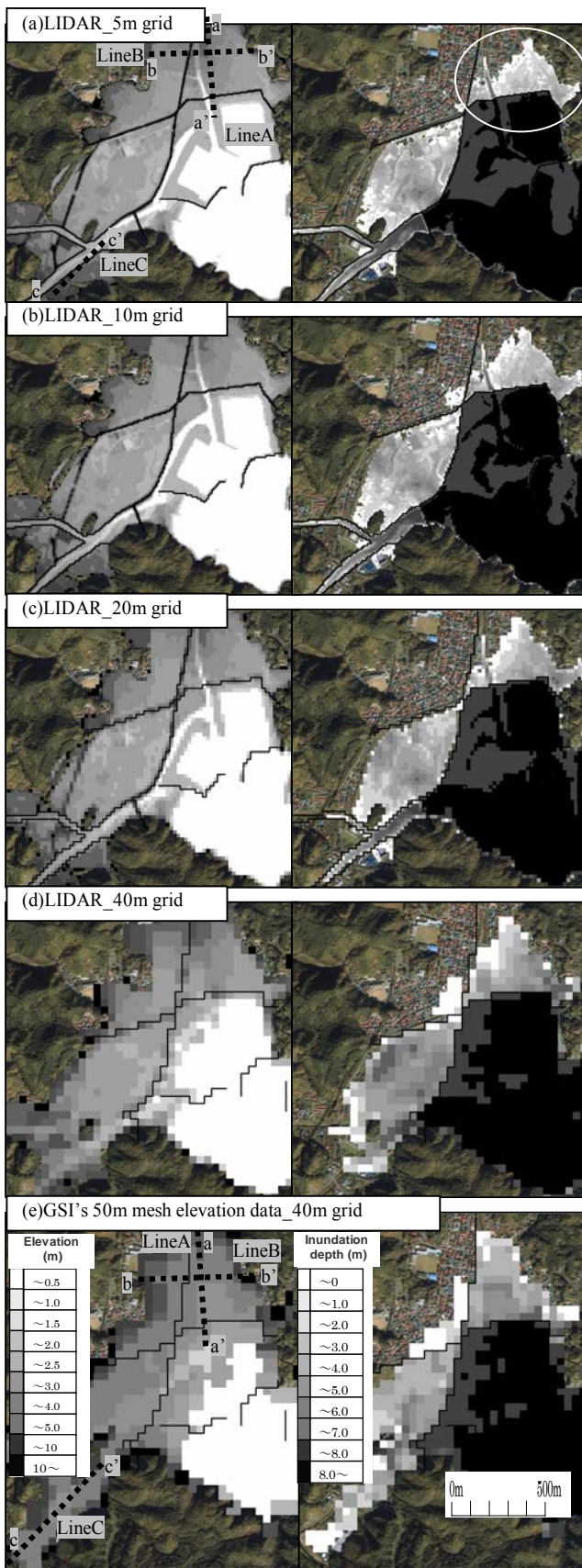

Figure 4. Water level changes of tsunami numerical analysis

(a)LIDAR_5m grid

(b)LIDAR_10m grid

(c)LIDAR_20m grid

(d)LIDAR_40m grid

(e)GSI's 50m mesh elevation data_40m grid

Note: Black line in the figure shows the sea wall break line.
(Its height is 10m above mean sea level)

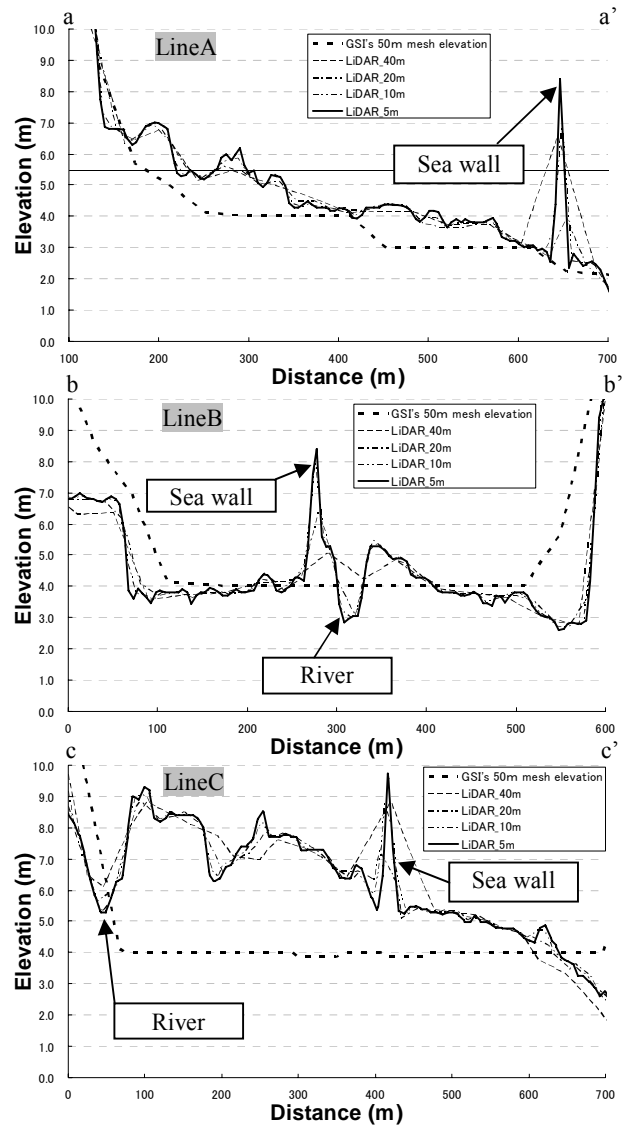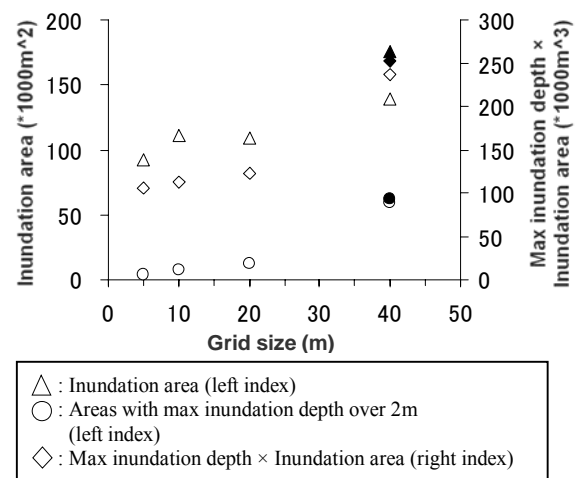Figure 5. Topographic Model (left) & Tsunami Flood Distribution by Numerical Analysis (right)

Figure 6. Topographic model profiles

△ : Inundation area (left index)
○ : Areas with max inundation depth over 2m
    (left index)
◇ : Max inundation depth × Inundation area (right index)

Note: Inundation area & depth in the area shown in white circle on the right diagram of Figure 5(a) (Solid mark indicates the results with the topographic model created from GSI's 50m mesh elevation data)

Figure 7. Comparison of extent of simulated inundation area according to different grid size

5. RESULTS

5.1 Change of Topographic Approximation Degree According to Grid Size

From Figure 5(a)-(e), the level of topographic approximation degree according to differences in grid size can be seen. Even 40m grid models seem to be able to express the approximate inundation area. However, grid model with spacing of less than 10m is necessary to express levees, embankments, and breakwaters.

As can be seen in Figure 6, representative cross-sections were selected and compared in order to quantitatively investigate the degree of topographic approximation depending on differences in grid size. From the cross-section view of the topographic model in Figure 6 one can see the topographic data differs more clearly. Firstly, comparing the topographic model from LIDAR data and the topographic model from the Geographical Survey Institute's 50m mesh data, areas with a difference in elevation level of over several meters have spread and the Geographic Survey Institute's 50m mesh data cannot express ruggedness with a height of several meters. Therefore, it is easy to imagine the huge effect it would have on inundation simulation results.

Following that, looking at the differences in the LIDAR data due to changes in grid size, one can see that the reproducibility of sea walls and minute ruggedness with a height of 1-2m is greatly affected by grid size. It can be seen that for topographic approximation of uneven lowland with a 25-100m width and skirts of mountains, a grid size of over 20m tends to lower reproducibility.

5.2 Tsunami Simulation Results

Comparing the inundation prediction results shown in Figure 5(a)-(e), one can see that in comparison with the topographic model from LIDAR data, the flood area is extensive in the topographic model from the Geographical Survey Institute's 50m mesh data and the differences in submerged land in urban areas is apparent. Besides precision in elevation values, the difference in reproducibility of topographic approximation for micro-topography emerges as differences in the extent of inundation area. In this way, in the area with lower reproducibility of topography, because of lower precision of inundation area, it is difficult to discuss adequate place of evacuation centres and evacuation routes for when tsunami's strike. In addition, when it is publicized by hazard maps, it is important to take heed that there may be errors in the level of risk.

Following that, the inundation prediction results for urban areas behind embankments were compared with the view of different grid size in Figure 7. It is found that simulated inundation areas become smaller as grid sizes become smaller. The inundation depth of the urban areas also becomes smaller as grid sizes become smaller. The rate of areas with maximum inundation depth of over 2m, which accounted for 30% (40m grid) of the entire inundation area, was greatly reduced to 4% in 5m grid (Figure 7). This is, as in the detailed topographic model, due to minute ruggedness inhibiting the flow of the tsunami flow and water being quickly accumulated in bog holes. On the other hand, in large grid sizes there is few ruggedness to inhibit tsunami flow and there is an apparent tendency for the extent of inundation area and maximum inundation depth to increase.

5.3 Application of Detailed Topographic Model for Evaluation of Tsunami Damage Reduction Facilities

Numerical analysis was carried out for a comparative verification of the results according to the conditions of flood gates and levee opening in the Taro area of Miyako city in Iwate Prefecture, and the results are shown in Figure 8. The 5m mesh topographic model was used because the width of the flood gates and levees range from several meters to 10m and the open conditions of the flood gates and levee were modelled by replacing the height of levees to the ground height. Consequently, the results show that the inundation area for open levees doubles for urban areas behind sea walls, compared with that for closed levees (as shown in Figure 5), which indicates the importance of flood gate closure before tsunami attack.
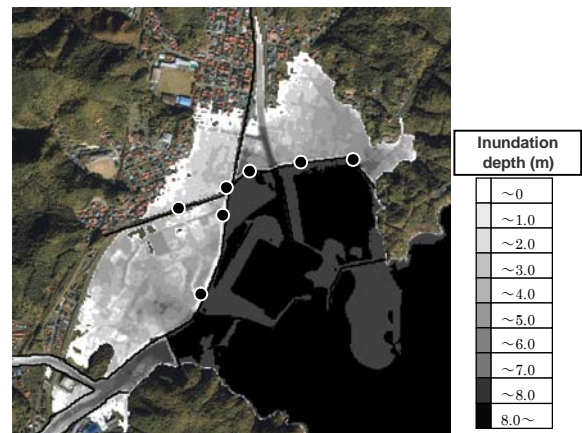

Figure 8. Tsunami inundation area for open condition of flood gates and levees
(Dots show levee points with open condition)

6. CONCLUSIONS

6.1 Adaptability of LIDAR Data Topographic Model

The advantages of using LIDAR data for creation of a topographic model for tsunami simulation are listed below.

- It has the sufficient precision and measurement density to express minute topographic features which will greatly affect the extent and depth of inundation by tsunami.
- It can extract topographic features (DEM) below trees and shrubs from a high density reflection data.

Meanwhile, in order to adequately evaluate tsunami counter-measure facilities and tsunami inundation prediction, it is important to create topographic model from LIDAR data, which has suitable grid size and precision for its purpose.

In addition, LIDAR has the following characteristics and it makes it possible to effectively create a high precision topographic model.

- It can carry out extensive measurement in a short time (high synchronism).
- Because LIDAR data is digitalized GIS data, automatic processing and visualization are easy (mass data processing).

6.2 Numerical Analysis using LIDAR data

From LIDAR data and using minute mesh, a topographic model which can express the minute ruggedness with height of several meters was created for the target areas.

It is ascertain that tsunami simulation with 5m mesh created from LIDAR data can adequately express the minute ruggedness in urban area and the effects of sea walls and embankments. Furthermore, it is effective for predicting inundation area and hazardous area, and investigating suitable evacuation centres.

Moreover, its effectiveness was ascertained for the investigation of the effectiveness of tsunami damage reduction facilities such as flood gates and levees. By using the detailed topographic model from LIDAR data, a comparative examination of these object facilities can be carried out from the numerical analysis incorporated in the topographic model.

REFERENCES

Association of precise survey and applied technology, 2004. Handbook on Light Detection and Ranging (in Japanese). 119p.

Imamura, F., Fujiwara, M., Shindo, K. and Ichimura, T., 2004. Development of the integrated simulation for tsunamis in coastal urban area (in Japanese). *Annual Journal of Coastal Engineering, JSCE*, 51(1), pp. 291-295.

Iwate Prefecture, 2004. Report on the simulation and damage estimation of tsunamis and earthquakes in Iwate Prefecture (In Japanese). 164p.

Japan Society of Civil Engineers, 1999. Hydraulics formulae (in Japanese). Maruzen, 133p.

Kotani, M., Imamura, F. and Shuto, N., 1998. Tsunami run-up simulation and damage estimation by using GIS (in Japanese). *Proceedings of Coastal Engineering, JSCE*, 45(1), pp. 356-360.

Cabinet office, government of Japan, Ministry of agriculture, forestry and fisheries, Ministry of land, infrastructure, transport and tourism, 2004. Hazard map manual of tsunami and high tide (in Japanese). 128p.

Tsubaki, R., Fujita, I. and Okabe, T., 2006. Unstructured grid generation using LiDAR measurement for inundation alalysis (in Japanese with English abstract), *Proceedings of JSCE(B)*, B62(1), pp. 41-52.