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3D Tsunami Hazard Map and Models of Safe Shelters for Disaster Preparation

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ABSTRACT

In this paper, we describe a project to generate new tsunami hazard maps (for Hakui city in Japan) that change dynamically with the 3D landform and possible tsunami heights. We also generate 3D models of safe shelters in the city to help familiarize citizens with the facilities. Furthermore, we generated a website to enable the citizens to download the hazard maps and the shelters' images. The website is linked to the official website of Hakui city and it provides comprehensible and clear information to assist citizens in preparing for potential tsunamis.

Keyword: Disaster Preparation, CG, image processing, 3D Hazard map, 3D models

1. Introduction

On 11 March 2011, the most powerful earthquake to strike Japan occurred off the Pacific coast of Tohoku (Oskin B., 2011). The earthquake caused powerful tsunami waves that reached heights of up to *40.5* meters in some areas. The tsunami was far more destructive than people had expected, resulting in inconceivable damage. The existing tsunami walls of about *10m* high were considered sufficient barriers to block any tsunami. As such, many people did not move quickly to safe shelters because their houses were in high locations. Some buildings in low locations were assigned as safe shelters by the city office but these flooded.

The tragic experiences in Tohoku demonstrate that hazard maps (Fujiwara, H., 2006) that show detailed and accurate information about the city's landscape and safe shelters are essential for citizens to prepare for a disaster. A questionnaire survey (Sonpo and NRI, 2010) shows that *55%* of responders answered "No" to the question "Do you know the locations of safe shelters in the city?" For those who answered, "Yes," there was another question "Do you know the route from your home to the shelters?" *58%* of the people answered "No." This clearly shows that people are not prepared for disasters. To make a clear decision and act quickly in an emergency it is necessary for citizens to have sufficient information and to be prepared for possible natural disasters.

With the support of Hakui city government (Hakui city), we conducted a project to generate new tsunami hazard maps that dynamically change with the 3D landform of the city and possible tsunami heights. We applied three-dimensional computer graphics (3D CG) to represent the geomorphological features of the landform and developed a simple dynamic flowing model to estimate the areas with flooding risk. We also generated 3D models of safe shelters in the city to help citizens become familiar with them. Furthermore, we generated a website to enable the citizens to download the hazard maps and the shelters' images. The website is linked to the official website of Hakui city, and it provides comprehensible information to assist citizens in their preparation for the possible impact of a tsunami. In this paper, we describe our project in detail and present the visualized results.

2. Previous Hazard Map

Hazard maps show predicted inundation risk areas and illustrate information related to disaster prevention. Now almost all coastal cities in Japan have made their hazard maps available to citizens on the Internet. We looked at the hazard map links to websites, and classified them into 5 groups according to their visional techniques.

● Traditional 2D hazard maps

These are 2D maps with inundation areas shaded in different aposematic colors illustrating the flooding height of water (Fig. 1). Conventionally, 2D hazard maps are printed on paper and delivered to residents from city offices. On the paper map, there is also a list of phone numbers, information on safe shelters, and notices from governments. We can see such hazard maps also on the Internet, where you can click and zoom to see scaled maps with details. Although these maps are designed for ease of comprehension, users still need to learn how to read them since they have to mentally convert colors to flooding heights.

● "Marugoto Machigoto Hazard Map" project

This project presents a unique and effective way for people to evacuate from tsunami risks (Fujii, R., Morino, K., 2006). They installed tsunami-warning signboards to show the water levels during a previous flood disaster experience. These signboards of standardized design are installed in coordination with tsunami disaster management maps. Such signboards will be necessary for people to decide their route of evacuation and make quick decisions. They are helpful not only for local residents, but also for tourists who are not familiar with the town.

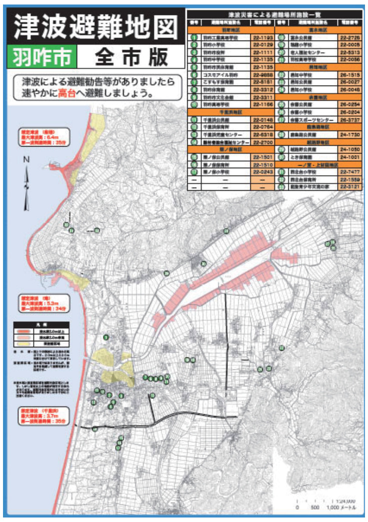


Figure 1. The 2D tsunami hazard map of Hakui city

● 3D model based hazard maps

For coastal cities with a large population and many buildings close to the beach, there are hazard maps of 3D CG showing the buildings and streets. By using 3D building models, it is possible to estimate tsunami wave pressure and fluid velocity. As shown in Fig. 2, the red bars indicate tsunami damage to buildings, and the damage expansion over time.

● Photograph-based hazard maps

These maps use aerial photographs, high-resolution satellite photographs, or street views to represent people's living area, while using graphics or video to represent tsunami flooding. Photograph-based hazard maps give people such a strong impression of tsunamis that they will act quickly when an earthquake occurs and take suitable disaster prevention measures. The strong impression is due to the realism of the photos and the dynamic representation of water flooding. However, it is still difficult to change the perspective, i.e., movies and animations can be seen only from one specified direction.

Figure 2. The 3D model based hazard map for Pari city (Sinnakaudan K. S., Ghani A. A., Ahmad S. M., Zakaria A. N., 2003)

● Interactive hazard maps

Such hazard maps are an integration of the above described hazard maps with a GPS system. If you click a concurrent position on the map, possible evacuation routes to the nearest safe shelter will be shown interactively. Since the hazard map can be accessed by using a smart phone, it is useful for providing tsunami disaster management advice according to individual needs and minimizing damage in a self-help manner.

Many cities have been very conscious of tsunami-related issue and use hazard maps as non-structural countermeasures for minimizing damage. However, before 3.11, the existence of tsunami hazard maps was virtually unknown to residents, except for experts, researchers, civil engineers, and governments in charge of disaster prevention. After 3.11, tsunami hazard maps become popular among ordinary citizens, who realized that all coastal cities may be prone to tsunamis during an earthquake in submarine trenches, and measures have to be taken quickly to deal with them.

With a latitude of $36^o\ N$ and longitude of $136^o\ E$, Hakui city is on the Sea of Japan (East Sea) coast in the Noto peninsula. It covers an area of $82\ km^2$, and has a population of *23,675*. In 2006, the local government made a tsunami hazard map based on an expected earthquake of magnitude 7.8, originating 25 kilometers offshore from the Noto peninsula. The earthquake was expected to generate a 5.1m high tsunami that would travel inland towards Hakui city. The map showed the forecasted areas with flood risk and information about evacuation. The map was easy to understand, and quickly distributed to each household in the city. The map has been updated every year according to the increase in the number of safe shelters and the new simulation data. Figure 1 is the new version used from 2012.

The Hakui city local disaster prevention plan was also published in 2013. The number of safe shelters has increased. High buildings near the coast and open spaces on high land are particularly used for shelter in emergencies. In 2013, Hakui Coop discussed with other cities near Tokyo providing mutual help when a disaster occurs. It includes providing water, food, and other essentials, transporting these materials to the affected area, and providing human help. In other words, people of other cites may come and work here when a disaster occurs.

The experience of Tohoku has made us realize that more powerful earthquakes and higher tsunamis may occur anywhere in Japan. On the old hazard map of Hakui, the variation in the height of tsunami waves was not clearly illustrated. If a tsunami was much higher than 5.1m, a larger area would be flooded. Since Hakui has a 10*km* long coastline, the possibility of devastating floods is a concern. On a specified evacuation route, there would be danger spots due to lower land height. Although the city officials have identified tsunami risk as a high priority, it would be difficult to rely on the old hazard map to provide citizens with detailed and more accurate information.

The issue of how to select a safe shelter is rather complex. Which shelter would be more competent for evacuation in the event of a tsunami? Without advance preparations many people would be confused in an emergency. For example, there are two buildings with heights of *11.1m* and *12.0m*, which are about *900m* from the seashore. The city previously designated the two buildings as tsunami safe shelters. Based on the knowledge acquired from the Tohoku event, another building that is *1200m* away from the seashore but *14.4m* high is now given priority because building height is considered the most important factor for evacuating from a tsunami. It is necessary to inform the citizens not only of the location but also the height of every safe shelter. Such informed citizens are able to take quick and correct actions according to the individual situation, which in turn decreases the damage of a tsunami disaster.

Our project, therefore, focused on solving the above problems by applying 3D computer graphics (CG) to hazard map generation as well as building a website to provide clear and comprehensible information to citizens.

3. 3D Landscape Model and Tsunami Hazard Maps

To forecast flooding area patterns and generate tsunami hazard maps, we build firstly a three-dimensional (3D) landscape model. We used contour maps and LiDAR data provided by the city office as the base for constructing the landscape model.

The contour maps are based on a long-term land survey in this area. They have been used to establish land maps and boundaries for ownership or governmental purposes. In contrast, airborne LiDAR (ArcGis resources: Light Detection and Ranging System) is a relatively recent technology for capturing data of the earth's topography. It is considered a feasible and practical technology due to the special attributes of lasers and the Global Positioning System (GPS). LiDAR data is produced by attaching a laser-scanner to an aircraft. A laser-beam is fired at the ground and measured when it is reflected back to the aircraft, which saves a great number of measurement points across the landscape. The LiDAR data we used is a dataset of points spaced between 25cm to 2m apart, with a vertical tolerance of up to 20cm.

To build a 3D landscape model of Hakui, we conducted a sequence of creative works using image processing and 3D modeling software:

(1) Overlay LiDAR data with the contour maps by using the image processing functions of Photoshop (Adobe Photoshop, 1986).
(2) Manually select the necessary feature points from LiDAR data, so as to generate a new contour map that has more detailed contours for the areas of high population density. Here, both Photoshop and Illustrator (Adobe Illustrator, 1986) software are used.
(3) Transform the new contour map into a net of triangular polygons, and save the coordinates of the three vertices for each polygon. Use an original program to calculate the slope angle and slope orientation for each polygon.
(4) Represent the net of triangular polygons by using a 3D software Shade (Shade 3D, 1986).

Figure 3 shows an image of the 3D landscape of Hakui. There are mountains on its northwest and southeast sides. In its center area there is a lake and a river that flows into the sea. The 3D model makes it easy to calculate and determine flooded areas and in turn to generate tsunami hazard maps (Fig. 4 and Fig. 5). When estimating water flooding areas, we have taken into account not only the height of the tsunami, but also the tsunami ascending up the river. Since a tsunami usually travels up along a river quickly, the areas near the river may be flooded even when the tsunami height is low.

Our hazard map belongs to the group of 3D CG based hazard maps. It has three advantages over previous hazard maps:

(1) It uses 3D topographical models to show three important and related factors, the height of the tsunami, the geographical features of the land, and the simulating result of flooding, in a single image with dynamic variation. Our hazard map provides a new method for communication with residents. It can be used as an educational tool to increase public

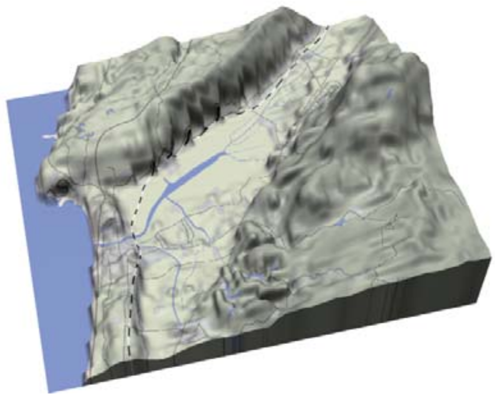


Figure 3. The 3D landscape model of Hakui city

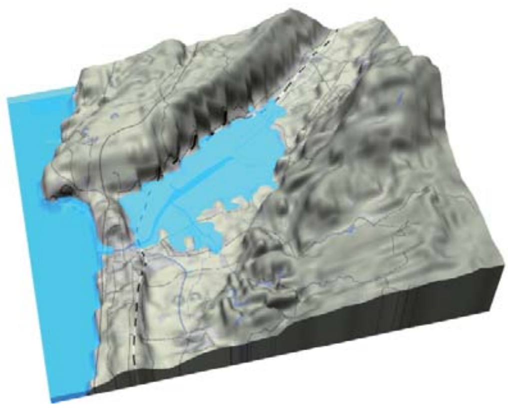


Figure 4. Simulated flooded areas according to possible tsunami height and tsunami ascending up the river.

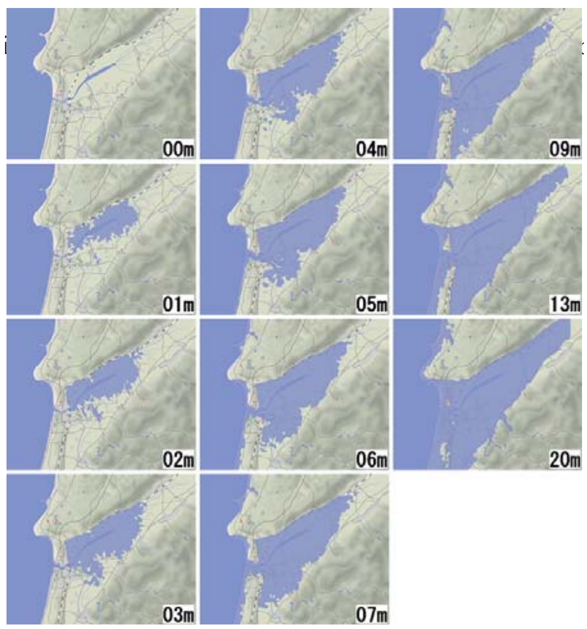


Figure 5. Hazard maps for tsunami of different heights

awareness of the topography in their living area. Even those who are familiar with their city do not know the features of the landform.

(2) Compared with photograph based hazard maps, our hazard map has the advantage that it is possible to provide vision from any direction at any location. This is a useful feature of 3D CG that should be employed in disaster prevention activities.

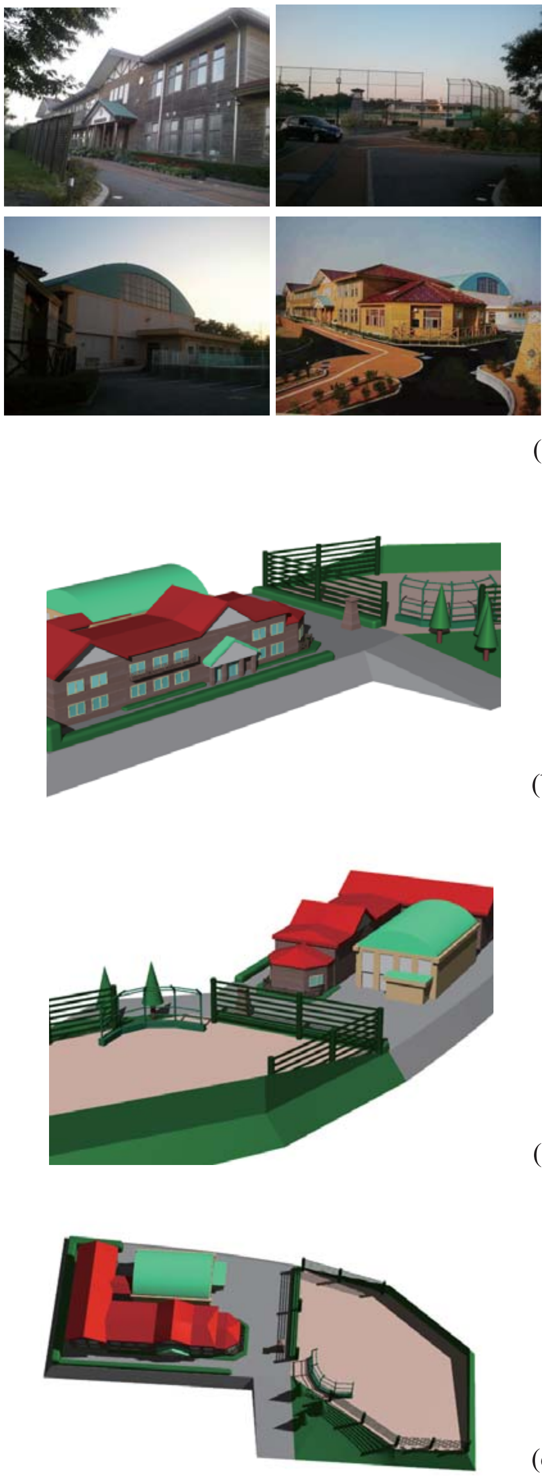
Compared to the traditional hazard map of Hakui city, our 3D hazard map simulates the low-chance worst case of flooding. For those residents living in high-risk areas, self and mutual-support activities for disaster prevention will be seen in a new light.

4. CG and Animations for Introducing the Safe Shelters

Another remarkable feature of our project is the digital models of safe shelters reconstructed using computer graphics. Compared with the photos of shelters, CG models have significant advantages: firstly, it is possible for the user to get a view of the shelter from multiple directions (Fig. 6); secondly, CG models place emphasis on representing the special features of the shelters so that citizens can remember them easily and distinguish them from common houses clearly. For example, the two shelters in Fig. 7 are both open spaces, but their surrounding environment and magnitude are different. Users can clearly understand these differences from the CG models.

Compared with the pictures or street view that have been used in Hakui city's website for showing safe shelters, 3D CG models of shelters have the following merits:

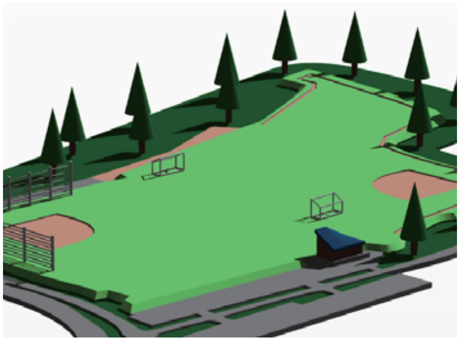
- Since 3D models emphasize the features of the building not only in form but also in color, it is useful for educating children, who will in turn take charge of disaster prevention. When these 3D images were displayed to children in Hakui, they showed great interest in finding the name and location of the shelters from the map. Children were attracted by the realistic 3D CG models that represent shelters in their own living areas.
- 3D shelter models can provide additional information when a street view is not available.



(a)
(b)
(c)
(d)

Figure 6. One of the safe shelters: Awanoho Primary school, (a) real pictures of the school; (b) 3D CG model viewed from the southeast; (c) 3D CG model viewed from the northwest; (d) an overview of the 3D CG model.

(a)



(b)

(c)

(d)

Figure 7. CG models of other safe shelters: (a) pictures of Bijoudaichi sports ground; (b) 3D CG model of the sports ground; (c) pictures of Closed Kashimaji Primary school; (d) 3D CG models of the closed Kashimaji Primary school, which is now being used as an open space for parking.

Only the center area of the city has a street view. Around the high areas, such as the shelters of Eikouji and the closed Kashimaji Primary School, where few people live, there is no street view. In a street view, a building can only be seen from the side facing the street. It is difficult to obtain information about a side if there is no street. The 3D CG model enables people to see a building from any direction.

- The street view may have privacy issues regarding the neighborhoods of safe shelters. Furthermore, shelters such as city hall may have a back door, center controlling room, or security spaces only known to staff. For security reasons it would be better not to put detailed information about these spaces on a website that everyone can access.

There is little such concern with 3D CG models since we can control the information provided by the models.

For providing more information on and stimulating citizens' interest in safe shelters, we created CG animations and characters that tell a story about every shelter. Figure 8 shows some images of the animations. The location, land height, distance from the seashore, and the manager of every shelter are reported in the animations.

Children and young people are particularly interested in these animations and characters. They can learn our information best when they enjoy these digital media. Using animation to provide information on disaster preparation is not only fun but also effective.

5. Website for Disaster Preparation

Hakui city has created a website for distributing hazard maps and a variety of related information (Hakui city). To meet the need of the devised methods to present inundation damage of the tsunami risk, our non-funded research was initiated. Since 2013, Hakui city has put our 3D hazard map on its website as additional information to the conventional hazard map. Citizens can see both types of hazard maps and are aware of the possible risk so they can communicate with others and take action when necessary.

We also generated a website for providing the images, hazard maps and animations to the citizens. The website equips disaster managers, planners, gov-

Figure 8. Animations and characters are created for informing citizens about the safe shelters

Figure 9. Acquire tsunami hazard maps for various possible scenarios

Figure 10. Search for possible shelters from area name, obtain information and see 3D CG models of shelters

ernments, and the general public with instant access to comprehensible and clear geospatial information to support risk assessment, early warning, response and other disaster management activities. Figure 9 and Fig. 10 show some pages of this website. Recently, this website has been linked to that of Hakui city.

6. Conclusion

Through the experience of the Tohoku earthquake and tsunami, many Japanese people learned about the importance of knowing their living environments, having the hazard maps of their city, and preparing measures to deal with possible natural disasters. Here, we explored the possibilities of using computer graphics and multi-media to help people. Through using our hazard maps, enjoying our animations, and accessing our website, the citizens in Hakui city will acquire more knowledge on which areas will be inundated, how to use safe shelters, and apply this knowledge in a practical situation. Our project is balanced between theoretical studies and practical illustrations, so citizens will get not only the WHY of dealing with measures, but also the HOW.

In future, we will release new versions of the hazard maps for Hakui city, which will be based on more accurate simulation of flooding inland. We will also continue the research on the application of LiDAR data and extend the 3D landscape model to represent the surrounding cities. Furthermore, we will create more animations for informing people about the history of disaster in this city, the communities, and the new technologies for disaster preparation.

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