A local hazard map for the reduction of damage from earthquakes in Sendai, Japan

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Abstract: Since engineering geology deals with the subsurface, which is not visible, it appears to the general public that it is hardly needed for everyday life. Therefore, in order to let people understand the knowledge of the subsurface, a means of communication is greatly required. If knowledge of the character of local natural disasters, such as the relationship between geomorphology and geology and damage caused, has been acquired, it will be useful for reduction of damage from future natural hazards.

Sendai City has a population of 650,000 and is situated in northeast Japan. It has suffered damage from the Miyagi offshore earthquake in 1978. Nowadays, the residential area of Sendai City is extending into the surrounding areas of plains or the hilly land. New residential areas and public facilities are built on artificial foundations, such as soft ground and artificial fills, and new lifelines will also be built with artificial foundations. A future earthquake is predicted to occur almost certainly within 30 years and it will be expected that the damage will be greater than the past. Effective preparation for the natural disaster in the 21st century can be attained when people become more interested in the surrounding geomorphology and geology.

This paper will review the past damage of earthquakes and will describe the local hazard map of the area in which citizens live, in preparation for a future earthquake. The feature of the method used is that citizens have made a hazard map themselves, with engineering geologists advising on the geology. From the knowledge of engineering geology, it is considered that damage from a natural disaster, not only an earthquake but also flooding and landslides can be reduced.

Résumé: Comme la géologie de l'ingénieur traite de la sub-surface, par nature invisible, le grand public la considère comme peu utile au quotidien. C'est pourquoi, afin de rendre accessible au public la connaissance de la sub-surface, des moyens de communication s'avèrent nécessaires. Si la connaissance de la nature des catastrophes naturelles locales, telle que la relation entre la géomorphologie et la géologie et les dégâts causés, est acquise, elle sera utile à la réduction des dégâts issus des risques naturels à venir.

La ville de Sendai compte 650.000 habitants et est située au nord-est du Japon. Elle a subi des dégâts lors du séisme au large de Miyagi en 1978. Actuellement, la zone résidentielle de Sendai s'étend dans les zones environnantes de plaines ou de terrains montagneux. Des zones de nouvelles résidences et des aménagements publics sont bâtis sur des fondations artificielles, telles que des terrains tendres et des digues, et de nouvelles lignes de vie vont également être bâties sur des fondations artificielles. On prédit avec quasi-certitude un futur séisme dans les 30 prochaines années et les dégâts attendus devraient être plus graves que par le passé. Une préparation efficace de cette catastrophe naturelle du 21ième siècle sera possible lorsque les gens s'intéresseront davantage à la géomorphologie et géologie environnantes.

Ce document va examiner les dégâts des séismes passés et décrire la carte des risques locaux pour la zone habitée dans l'optique d'un futur séisme. La particularité de la méthode employée est que les habitants ont réalisé la carte des risques eux-mêmes, conseillés en géologie par des ingénieurs géologistes. A partir des connaissances en géologie de l'ingénieur, on considère que les dégâts causés par une catastrophe naturelle, non seulement un séisme mais également les inondations et glissements de terrain, peuvent être limités.

Keywords: education and training, engineering geology, earthquakes, mapping, urban geosciences

INTRODUCTION

Although Japan only occupies 1% of the world's area it has experienced 10% of the big earthquakes (seven or more In magnitude) that occurred in the world over the past 90 years. The cause of these earthquakes is attributed to the motion of the crustal plates near Japan. In Sendai, big earthquakes have a periodicity of 26 - 40 years in the past 200 years. The latest earthquake occurred on June 12, 1978. The damage from this earthquake was 27 dead, 7500 completely destroyed houses, and damaged water services, electricity, gas, roads, banks, etc.

The periodic cycle of an earthquake is predicted by the government's organizations. Consequently, the likelihood of a Miyagi offshore earthquake was predicted as 50% probability within ten years, and 99% probability within 30 years from now. For this reason, the Miyagi Prefecture and Sendai-City are making seismic intensity predictions and estimates of the consequent damage.

Although the seismic intensity prediction of an earthquake was conventionally performed based on a 500m grid in Sendai, the accuracy is too low for the prediction of a city area and seismic intensity prediction has been redone on a 250m grid. However, the accuracy of prediction is still too low to guide the design of the foundations for a residential section also based on a 250m grid.

Since seismic shaking at the surface is affected by its geological setting, the seismic shaking intensity of the earthquake needs to be predicted with due consideration of the near surface geology. However, it is rare for the residents who live in these areas to be interested in foundations. In order to raise awareness of this issue, social, cultural, racial and other factors should be considered. Important parts of such awareness are the geographical and geological environments.

In this paper, two examples of ways in which attempts were made towards reducing earthquake hazard are described. First, the creation of a map relating surface geology, the intensity of earthquake shaking, and the damage of the last earthquake related to foundations. Next, having created the local hazard map with regard to foundations it was presented at a residents' workshop to raise their awareness of earthquake disaster prevention.

1. COMPILATION OF A SURFACE GEOLOGIC MAP

The geologic map of the Sendai district was published at a scale of 1/50,000. Except for the earthquake foundations map made after the earthquake in 1978, it has not become public knowledge. The shaking of an earthquake is significantly controlled by a geologic distribution and geologic structure. Therefore, the map which distinguished the bedrock geology from the superficial geology on it is helpful in the prediction of damage due to an earthquake. Sendai is a city with a population of 1 million, concentrated in the central part that is surrounded by an agricultural area. The foundations map shown in Figure 1 shows the area in which the population is concentration at the present time.

The foundations map was compiled from the 1/25,000 topographical map of the Geographical Survey Institute and the 1/50,000 scale geological map. In this map, superficial natural deposits and artificial fills are distinguished from pre Pliocene bedrock. In recently developed housing estates, artificial fills present in residential areas are not represented on the geologic map. In this case, the height difference derived from the topographical map was read, and shown on the foundations map. The active faults were copied from the ‘Active fault map’ of the urban area of "Sendai”.

The surface foundations map required expansion of the 1/50,000 scale geological maps to 1/25,000, and needed correction due to the accuracy of the topographical map, and inaccuracies at the time of compilation. However, a distribution of terrace and landfill interpreted from the topographical map has been done towards this end. Since it is dependent on the original map, the actual accuracy of the map is 1/25,000. Accuracy will be improved by the addition of more detailed data in the future. It was processed electronically and scale expansion or reduction is possible for this map. This map enables the distribution of past damage and the relation with foundations to be easily understood.

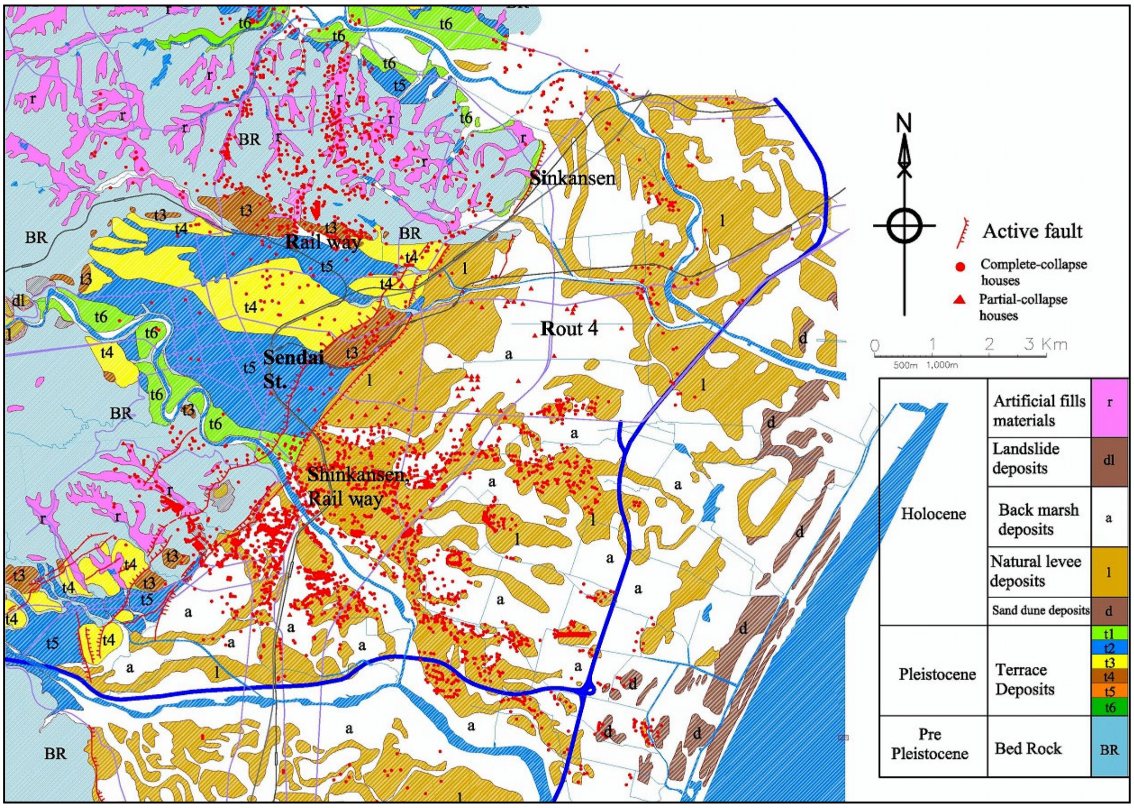

Figure1. Foundations Map of Sendai (Distributions of bedrock, superficial deposits and collapsed houses)

Similarly, emergency shelters, sites of emergency water resources, etc. can be overlain with the distribution of foundations. Figure 1 shows the distribution of houses destroyed by the Miyagi offshore earthquake in 1978. This map shows that the damage was concentrating in houses on, or near, a boundary of a natural levee and back marsh or in areas of artificial fill. Therefore, for future earthquakes, damage to buildings is predicted to occur mostly in areas of artificial fill or the on natural levees. It is also expected that damage to lifelines and infrastructure, such as the gas distribution system and the water distribution system will occur in the same areas. If evacuation routes, emergency shelters, hospitals, etc. are built on these areas they will experience greater shaking than if they were build in less vulnerable areas. . Therefore it is important to make a foundations map, based on past damage, to show where shaking was greatest. If this foundations map is used prior to the next earthquake disaster to guide the placing of important structures it will be possible to achieve a reduction in damage an aid recovery for earthquakes in the future.

2. MAKING THE LOCAL HAZARD MAP

2.1 The necessity of a delivery lecture

In each city in Japan, especially where earthquake damage is predicted, a disaster prevention map is prepared and supplied widely to the people living in the city. The position of emergency shelters, hospitals etc. are shown on this map of the city and its districts. However, there is little information that will be required by the survivors. That is, it shows the position of things that will be vulnerable at the time of an earthquake and the fine detail disaster prevention map needs to be made that shows temporary shelters, emergency water supplies and other necessary emergency supplies.

People's awareness of earthquake disaster prevention is low, and little preparation for an earthquake has been made. Earthquake preparation may be divided into three levels of activity. That is, the national government's agencies, the local community's council, and the family home. In the great Hanshin Awaji earthquake which occurred in 1995, 90 percent or more of the disaster victims were rescued by neighbouring residents. It is said that the volunteer activity of Japan was changed completely through this revival. various causes for the low level of concern about earthquake disaster prevention are mentioned. Social, historical, and local elements are among these causes, and they cannot easily be defined or discussed. We think that one of the factors contributing to this is a lack of education in science in the schools, especially earth science education. We think that the study of subjects which are unrelated to the taking of an examination are neglected. Moreover, we think the knowledge of previous earthquakes and the experiences of those who suffered damage has been lost by the change from the extended family to small-scale family units.

The Institution of Professional Engineers, Japan (IPEJ), Tohoku-Branch Applied Science Department, lecture series formed the starting point for activities promoting earthquake disaster prevention.

This lecture guided research work into earthquake related studies of the relation of foundations, and making of local hazard maps and to advance disaster prevention preparation before an earthquake.

2.2 Practice of a delivery lecture

2.2.1 1st Lecture

At the 1st lecture, a participant learns of the relationship of foundations and seismic hazard and learns the basic knowledge of earthquakes. This is achieved by the following activities.

1) The relationship between foundations and the earthquake disaster of Sendai during the 1978 Miyagi offshore earthquake.
2) The evolution and changes of foundations damage through the development of urbanization, and the change of in earthquake hazard
3) Seismic-intensity prediction and the composition of foundations.
4) Safe refuge from the view point of foundations (where are safest)
5) The production of a local hazard map. (Make a hazard map for my family and myself)
6) Questions and answers

1) Showed the foundations in Sendai, and the disaster of 1978 Miyagi offshore earthquake. As a consequently, it showed convincingly that the damage of an earthquake was more serious in some areas than others. For example on slopes of hills, on artificial fills in valleys and weak foundations on alluvial plains the damage of an earthquake was serious.

The artificial fills which filled the steep valley to a depth of about 20m is widely distributed over this area. Near the boundary of cut slope and an artificial fills, damage concentrated on a lifelines, such as a roads and a gas pipes, and houses. It was emphasized that it was important to make a disaster prevention map with consideration to foundations and to decrease the hazard caused by an earthquake.

2) Compared the situation of society in 1978, such as infrastructure maintenance, life style, regional society, means of communication, and earthquake-proof standards, with those of present day Sendai. Furthermore, the possibility that the quantity and the quality of a future disaster would be different due to changes of social environment. The drilling results of an investigation of an artificial fills in this area were shown, and it was pointed out that an increase in strength of an artificial fills was not expected to occur in 20 - 30 years. It is likely that buildings built before the revision of the Building Standard Law would still be liable to suffer damage at the time of a future earthquake.

3) The seismic intensity distribution map of the Miyagi offshore earthquake was derived from the result of an investigation of the damage of the third earthquake in the Miyagi Prefecture. In an earthquake (M7.6), it is predicted as little less than seismic intensity 6 on the hills of the east side of Sendai, and as seismic intensity 5 or a little more on the western plain. On the other hand, in an interlocked type earthquake (M8.0), the different response by foundations to the seismic intensity is lost. That is, the zone, which becomes seismic intensity 6 or so and a little less than 6, is in

the tendency, which spreads in the whole region mostly. However, a 250m grid seismic intensity distribution map is too coarse to be accurate, when the typical way of shaking in the area is expressed and it is aimed at a residential section. Therefore, it was emphasized that a more accurate hazard map needed to be created.

4) Introduces information shown by the disaster prevention map created at the department of Sendai. The map shows locations of important features for emergency planning, such as designated refuge areas, water hydrants, hospitals, regional refuge areas, emergency water tanks and wells Also natural disaster zones and tsunami risk zone. One of the problems illustrated by the disaster prevention maps was the example of the shelters sited on the artificial fills, which give weak foundations conditions, the valley, and near to the active faults. By informing people about the problem of placing a refuge or an evacuation route in advance, it emphasized the need to mitigate the effects of an earthquake.

5) After explaining various disaster prevention maps, the lack of detailed information about geographical features, geology information, and people and property at risk was pointed out. People were encouraged to produce a local hazard map with which the faults of the broader-based disaster prevention map are corrected. An advantage in making such a map is that the damage of an earthquake must be imagined. Everybody will benefit if the map created for a single family is shared regionally. It is emphasized that the local hazard map should be checked and updated at least once every year and preferably more frequently.

Table 1 shows the result of a questionnaire about this lecture. 140 persons attended the lecture and received the questionnaire and 81 persons responded. The participant's comprised 36 men and 27 ladies their age distribution was, 60 years old or more about 80% (64 persons), and 40 years old or less was only 2%.

Table1. The result of questionnaires of the 1st lecture

Question	Yes	No	Yes (%)	No (%)
Do you think that the contents of this lecture were intelligible?	41	13	75.9	24.1
Did your awareness of disaster prevention improve?	59	5	92.2	7.8
Do you think that a hazard map is required?	63	0	100.0	0.0
Activity about disaster prevention would be carried out availing of this?	66	6	91.7	8.3
Were you satisfied with this lecture?	41	27	60.3	39.7

2.2.2 2nd Lecture

In the 2nd lecture, it creates maps by examining an area with the participants. At this time, engineering geologist of IPEJ offers suitable advice. The workshop comprises two specialists and eight participants. Like a usual geology exercise, the participant locates hazard factors at the time of an earthquake, near to roads and houses and enters them on a map. At this time, a specialist explains the distribution of geographical features and geology. The weak superficial materials such as artificial fills, the natural levee deposits, the back marsh deposits etc. are entered on the local hazard map. Vulnerable structures such as concrete block wall and a glass window are indicated on the map that would represent hazards at the time of an earthquake, and Factors important for recovery after an earthquake, such as designated refuge areas, a hydrant, a hospital, regional refuge areas, etc are also indicated. The participant uses a digital camera to take photographs of significant, which are stuck on the map and annotated in order to make the map more intelligible. The member of IPEJ who guides a participant in their exercise prepares the basic information before the exercise and provides the base map for the exercise.

There were 35 participants in the production of maps of their area. The participants split into groups of about eight that were joined by 2-3 members of IPEJ. The participants investigated about 2km of round trips in 15 minutes per hour after guidance from the members of IPEJ. The resulting map was created on the basis of the Sendai City planning base map (S= 1:2,500), posted the near stratum boundary line from the foundations map, and also showed the position of the key point in prior exploration. In this area, it is the residential section, where artificial deposits filled the valley, in which damage caused by the earthquake in 1978 is concentrated. Part of damage done at this time remains in the form of damaged house foundations and cracks in concrete block walls. There is also a place where the boundary of an artificial fills is identified by a subtle change of geographical features. Inspection of old concrete block walls, hydrants, emergency water tanks etc. was also performed.

Since this was the first exercise of its kind, there was a participant who was unable to read a topographical map and it was necessary for a member of IPEJ to explain to them how to read, and place data on, a topographical map. The specialist's received various questions, such as composition of foundations, during the exercise. We consider that this is an important aspect of increasing their awareness. The result of the questionnaire of this mapping exercise is shown in Table 2.

Table 2 shows the following. Nearly 80% of the participants who had been guided in the production of a hazard had understood what they were being told and were enthusiastic about the production of such maps About half the participants had experienced the earthquake in 1978.

Table2. Result of the 2nd lecture (Mapping)

Question	Yes	Common	No	Yes (%)	Common (%)	No (%)
Was guidance of mapping intelligible for you?	14	13	0	51.9	48.1	0.0
Could you get interested in mapping?	16	2	1	84.2	10.5	5.3
Could you get interested in the production of a hazard map?	15	2	2	78.9	10.5	10.5
Have you experienced the Miyagi offshore earthquake in 1978?	8	-	7	53.3	-	46.7

2.2.3 3rd Delivery Lecture

In the 3rd lecture, the participants indicated the distribution of the past local damage on the local hazard map made during the mapping workshop. Based on this map, the foundations and the damage expected in the future were discussed, and also how to mitigate future damage. The participant discussed earthquake preparations, such as reservation of the water for emergencies, control and escape from fire, and preparation that could be made in the home.

The 3rd lecture was attended by 28 persons. Each of the maps was finished one week after the exercise. The participant's ages ranged from a schoolchild to a man in his 80's. This session involved speaking about experiences of the earthquake in 1978, and examined the damage caused by the earthquake. The contents were about the personal testimony of what people had experienced during an earthquake, what damage they suffered, whether or not they had been able to contact their family. On the basis of each of the hazard maps, the participants discussed various subjects. Such as special reserves of water for emergencies, fireproof shelters, escape routes, the direction of refuges, and domestic earthquake preparation.

Figure2. Local Hazard Map (by a fifth grader in an elementary school) Yellow line shows a boundary of artificial fills on the Foundation Map of Sendai. The scale of local hazard map is 1:1,000. He described a water reservoir for emergency and window glasses of buildings and dangerous concrete block walls etc.

The result of the questionnaire of the 3rd time of the lecture is shown in Table 3.

Table3. The questionnaire of the 3rd lecture

Question	Yes	Common	No	Yes (%)	Common (%)	No (%)
The history of a disaster	18	2	0	90.0	10.0	0.0
The disaster of house and office can be assumed.	17	2	1	85.0	10.0	5.0
How to make a hazard map	17		2	89.5	0.0	10.5
An useful information on earthquake disaster prevention	16		4	80.0	0.0	20.0

As a result of the questionnaire, 90% answered that the history of a disaster of an earthquake was useful, and 85% answered that the damage in a house and a company has been imagined. About 90% understood how to make a hazard map. Useful information introduced about the public auxiliary system of removal of a concrete block wall, and the seismic capacity evaluation of a house. It was answered that 80% was helpful.

As mentioned above, by the production of a map in the outdoors, it is thought that improvement in people's disaster prevention consciousness was achieved.

3. CONCLUSION

The preparation for and recovery from a disaster are two of the problems important for present-day cities. It is an important task for a city in a country with many earthquakes in the 21st century to make a foundations map and to use it to minimize damage. It is important to have information on engineering geology available before an earthquake so that people are able to understand the foundation conditions and design accordingly thus aiding in the preservation of life. In addition, it is important that we mitigate the hazard from natural disasters, such as a floods and landslides, by use of a foundations/hazard maps.

The foundations map in Sendai that has been created will be available to the public in the future. It is hoped that the basic data with which foundations maps are made and disasters alleviated will also be used in other areas and cities to create similar maps in the future.

We want to continue to develop lectures in the future and for use in the earthquake disaster prevention education in communities and schools as a grass-roots movement. Engineering geology gives us the background to enable us to work very effectively in this endeavour.

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