MANAGEMENT OF THE ROAD CAVE-IN RISK AFTER A LARGE EARTHQUAKE USING SUBSURFACE CAVITY SURVEY TECHNOLOGY

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ABSTRACT

Shortly after the earthquake that struck Niigata prefecture in Japan on October 23, 2004, the subsurface cavity survey on the national highways was carried out to manage the risk of cave-ins that could become a secondary disaster. The accumulated lane length of 814km was surveyed with the ground penetrating radar technology and more than 400 subsurface cavities were detected.
As a result of the study on this actual and rare data, the following knowledge that can be useful to manage one of the secondary disasters after large earthquakes was acquired.
- To minimize the cave-in risk the subsurface cavity survey should be carried out as soon as possible after an earthquake.
- The area where the seismic intensity is 5 or more should be covered by the survey.
- Great care should be taken at locations adjacent to subsurface structures.
- Even where the seismic intensity is less than 5, the survey is required if the ground condition is not very good.
- Hazard maps showing the degree of cave-in risk can be a risk management tool. It is utilized to make the most efficient and effective rehabilitation plan.

1. INTRODUCTION

The Earthquake that struck Niigata prefecture in Japan on October 23, 2004 caused serious damages mainly in the Niigata Chuetsu district. According to the report by the Japanese Fire and Disaster Management Agency, 65 people died and more than 4,800 people were injured. The road was heavily damaged as well and the traffic was obstructed in more than 2,300 locations. Since national highways are the linchpin of rescuing earthquake victims and restoration of the affected area, securing roads for emergency logistics was one of the top priorities.
Subsurface cavities that may result from an earthquake lead to cave-ins, which disrupt rescue and restoration activities. The Japanese Ministry of Land, Infrastructure and Transportation, therefore, carried out a subsurface cavity survey on the national highways soon after the earthquake to manage the cave-in risk. The ground penetrating radar (GPR) was applied as a primary technology for the survey in this case.
Furthermore, the monitoring survey in the representative area was carried out about a year later in order to evaluate the effect of the strong aftershocks happened after the data collection in the emergency survey and raising of water table due to the melting snow in this area.

2. SURVEY RESULTS

2.1. Survey Method

Nowadays, the GPR has become a standard technology to detect subsurface cavities effectively and efficiently in Japan. In case that it is required to survey wide range in a short period of time, the conventional survey method, using a portable GPR, could not be applied. The survey is, therefore, broken down into two phases, a primary survey and a secondary survey. [1] [2]

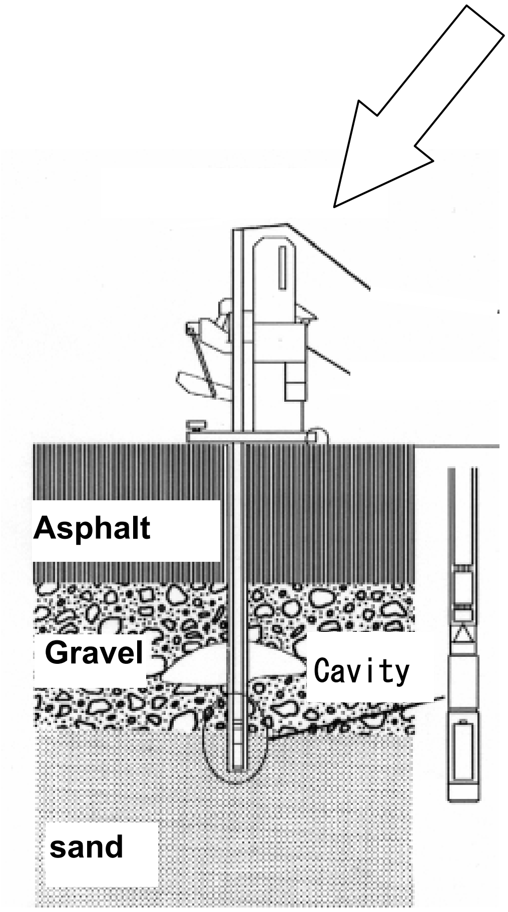
The survey vehicle, which is designed to detect cavities up to 1.5m from the surface of the ground, is used for a primary survey. This vehicle equipping with seven channel ground penetrating radars runs at a maximum speed of 45km/hr and covers 2.45m wide in one run. (Photograph 1) Therefore, speedy survey is achievable and influence upon the restoration activities can be minimized.

It also has three CCD video cameras mounted at the left, right and front of the vehicle to record position information in addition to a GPS. Thus, the following secondary survey can become efficient. The collected GPR data and position information are analyzed and anomalous locations of possible cavities are extracted from the data.

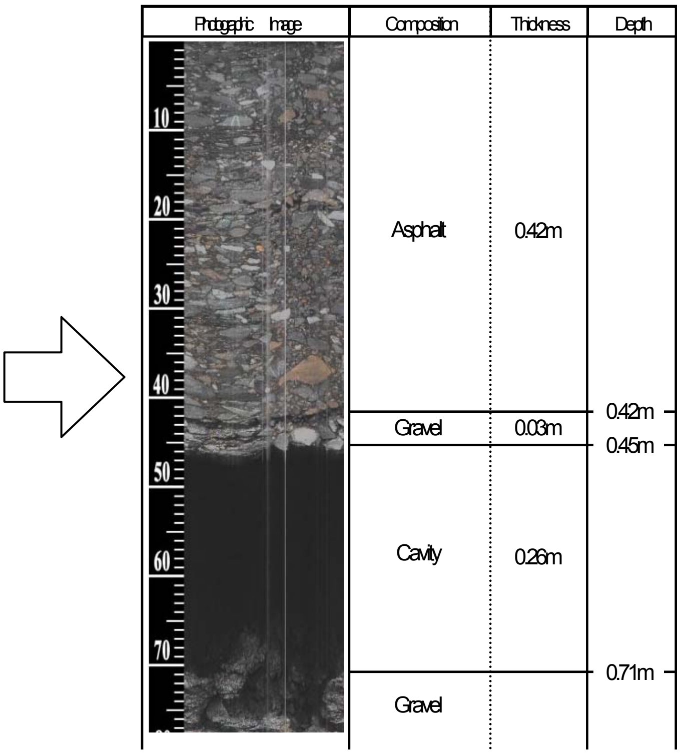
Photograph 1 – Primary Survey (Data Collection by Survey Vehicle)

A secondary survey is then carried out at anomalous locations. A portable single channel GPR is firstly used to pinpoint the anomalous locations. At the same time, the data collected by a portable single channel GPR is analyzed to determine the further possibility of cavity existence and its horizontal expansion. Then, a hole of 40mm diameter is drilled and a borehole camera prove is inserted in the hole to acquire a photographic image of the subsurface, called “Douro Scope Survey”. Finally, it is confirmed whether a cavity exists or not and what the subsurface condition is. (Figure 2)

Data collection with a potable GPR



Douro Scope Survey



Douro Scope Survey Result

Figure 2 – Flow of Secondary Survey

2.2. Survey Results

2.2.1. Emergency Survey

The emergency survey area was determined in terms of the followings.
- Area where the seismic intensity, shindo, (note1) of 5- or more was recorded.
- Area where the ground condition is not very good. For example, the area where the liquefaction due to the earthquake was likely was selected.

The figure 3 below shows the surveyed road.

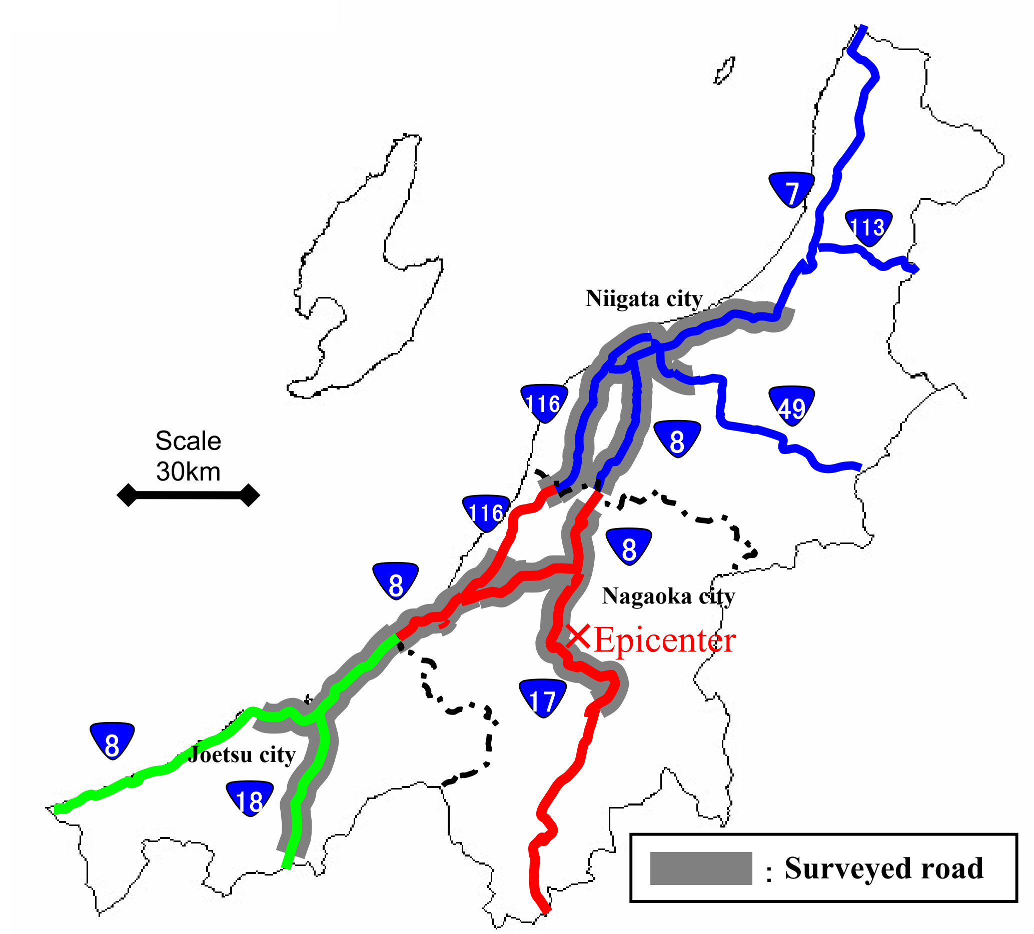


Figure 3 - Surveyed Area

(Note1) The Japan Meteorological Agency (JMA) seismic intensity scale (shindo) is a measure used in Japan and Taiwan to indicate the strength of an earthquake. The JMA scale describes the degree of shaking at a point on the Earth's surface. As a result, the measure of the earthquake varies from place to place. The JMA scale has 10 steps, 0, 1, 2, 3, 4, 5-, 5+, 6-, 6+ and 7, with 7 being the strongest. The seismic intensity (shindo) is calculated automatically from measurement of ground acceleration at many places. For example, the shindo 5+ is the seismic intensity that many people are considerably frightened and find it difficult to move.

The emergency survey started four days after the earthquake. 318km of national highway were surveyed. Since the purpose of the survey was to ascertain the safety of the road, every lane had to be detected. The accumulated lane length of 814 km was surveyed in total in this primary survey. As three survey vehicles were used simultaneously, it took only three days for the data collection.

As soon as the data was collected, analysis was started. 546 anomalous locations where there was the possibility that cavities would exist, were extracted.

Since the number of anomalous locations was very large, it was estimated that long period of time would be required to complete the secondary survey and the rehabilitation. Therefore, the hazard maps showing locations of possible cavities and degree of cave-in risk were prepared. (Figure 4) The degree of risk was set based on the primary survey results of the emergency survey. The degree was defined as follows;

- Degree I : Area of possible cavity is 2.25 square meters or more and cover to the surface is 0.3m or less.
- Degree II : Area of possible cavity is 2.25 square meters or cover to the surface is 0.3m, except “Degree I”.
- Degree III : Area of possible cavity is less than 2.25 square meters and cover to the surface is greater than 0.3m

The hazard maps were utilized not only for the daily road patrol activity but also for making the efficient and effective rehabilitation plan.

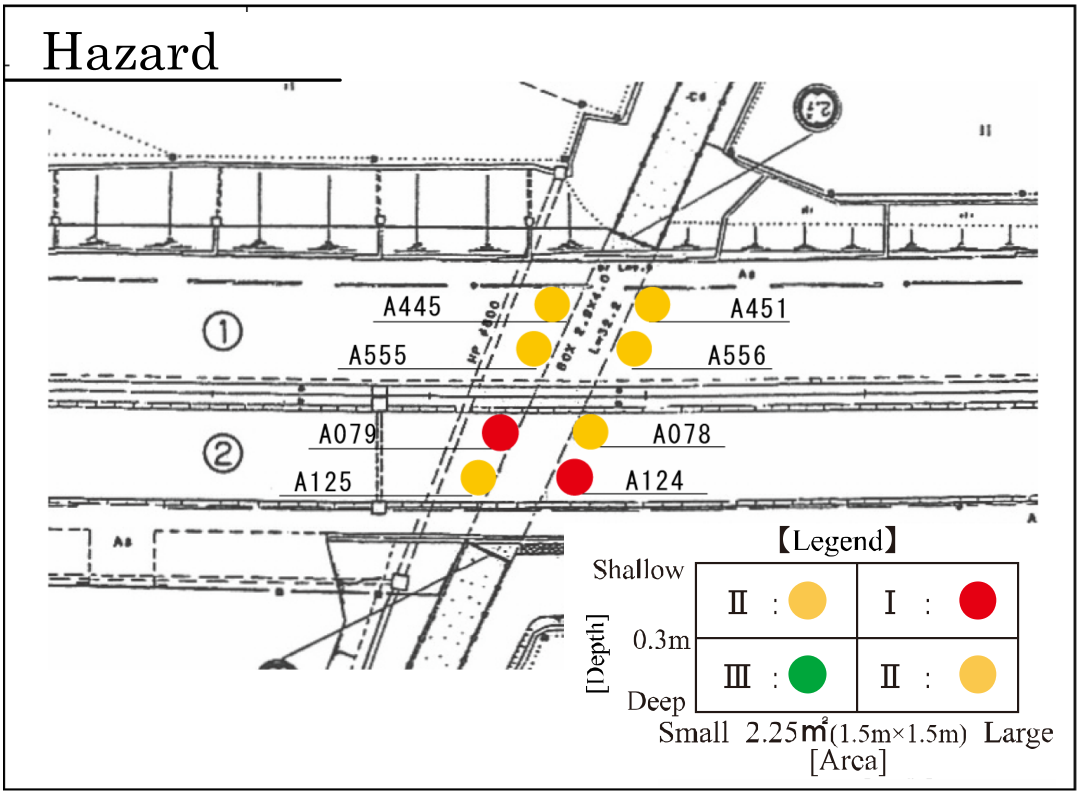


Figure 4 - Example of a Hazard Map

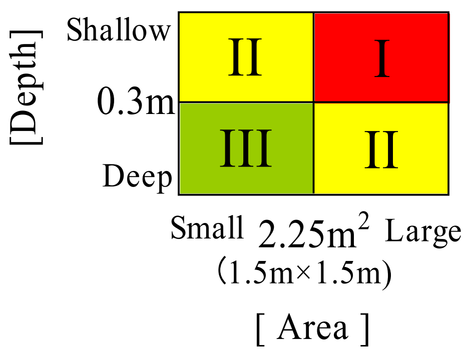


Figure 5 - Degree of Risk

The secondary survey was carried out at 393 anomalous locations out of 546. The rest was directly repaired during the other rehabilitation works without a secondary survey. As a result of the secondary survey, 310 locations were confirmed as cavities. That meant that about 80% of anomalous locations were confirmed as cavities. Considering this rate, 438 locations could be deemed to be cavities in total. Thus the number of 438 will be used for the later study.

The summary of the primary survey is as follows;
- The biggest cavity was expanded by 10.4m wide and 2.0m long.
- The thickest cavity was of 1.4m. (Figure 6)
- There was a cavity with very thin cover of only 0.12m to the surface of the ground.
- The typical location where cavities were generated was adjacent to a subsurface structure.

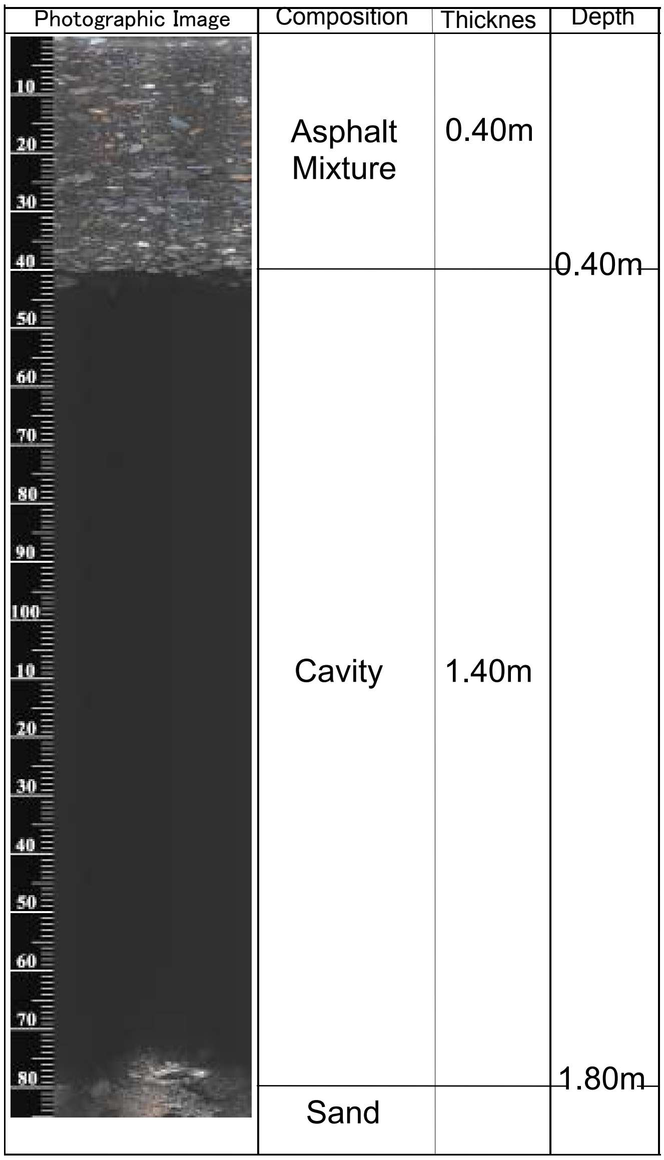


Figure 6 – “Douro Scope” Survey Result (The thickest cavity)

2.2.2. *Monitoring Survey*

The monitoring survey was carried out because there was a possibility that new cavities would be generated due to strong aftershocks after the emergency survey and rise of water table in this area in spring. Since the main purpose of this monitoring survey was to know the tendency of the above mentioned effects, it covered only a part of area where the emergency survey was carried out.
Although every lane of the road was surveyed in the emergency survey, only one representative lane of 48km was surveyed in this monitoring survey.
As a result, eight cavities were confirmed.

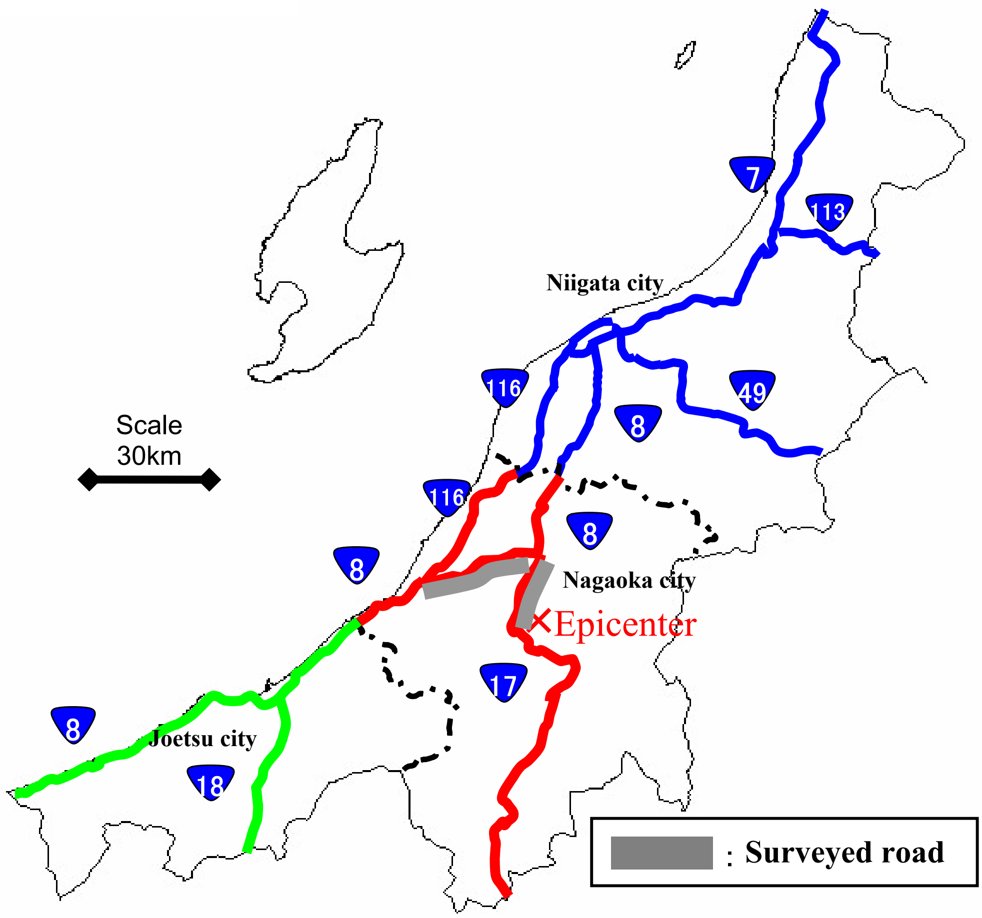
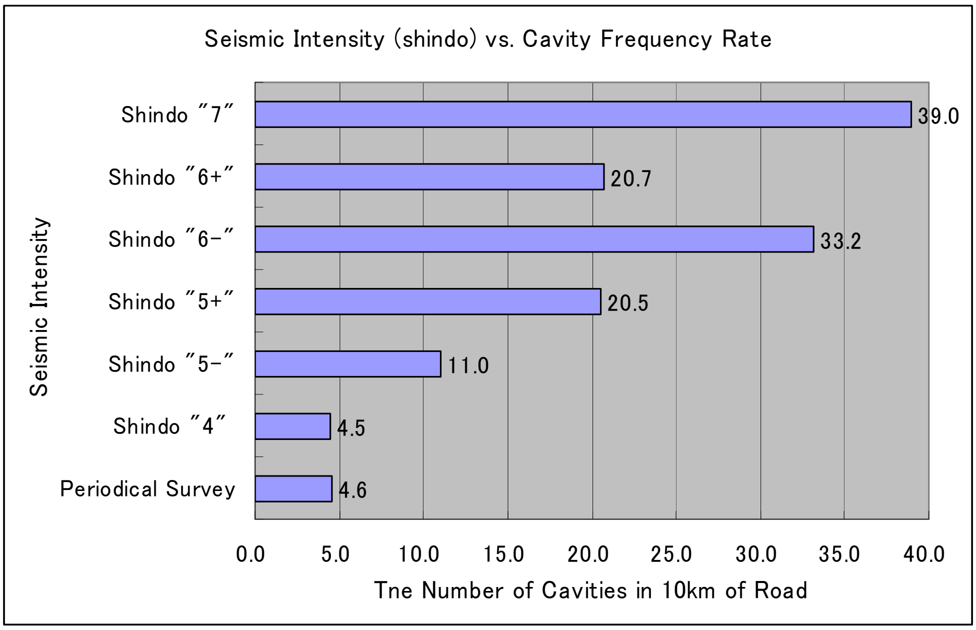


Figure 7 - Surveyed Area

3. STUDY ON SURVEY RESULTS

3.1. Seismic Intensity vs. Cavity Frequency Rate

The 438 cavities (note 2) were detected in the emergency survey. As the surveyed road length is about 318km, the number of cavities per 10km is 13.8 on the average. According to the periodical survey results in this area from 1991 to 2003, it is 4.6. Therefore, the cavity frequency rate after the earthquake become threefold compared with the ordinary situation. As shown in the figure 8, the cavity frequency rate increases as the seismic intensity increases in general. It can be understood that the cavity frequency rate increases rapidly in the area where the seismic intensity recorded 5- or more.



Fable 8 - Seismic Intensity (shindo) vs. Cavity Frequency Rate

(Note 2) Although the number of cavities confirmed was 310, additional 128 anomalous locations were deemed to be cavities based on the result of the secondary survey as mentioned in 2.2.1.

3.2. Ground Conditions vs. High Cavity Frequency Area

The figure 9 shows that the cavity distribution overlaid with the "Nationwide Map of Tremor" announced by the Japanese Cabinet Office in 2005. The height of bars in the figure shows the number of cavities at every one kilo meter of national highway.
It is easy to predict that there is an area of high cavity frequency rate near the epicentre. But, there are also areas of high cavity frequency rate away from it. These areas correspond with ones of shaky ground condition as shown in the figure 9. Most of the shaky area in this region consists of loose sand. As loose sand is likely to become liquefaction due to an earthquake, it is guessed that the liquefaction might be one of the reasons why many cavities were generated in these areas.

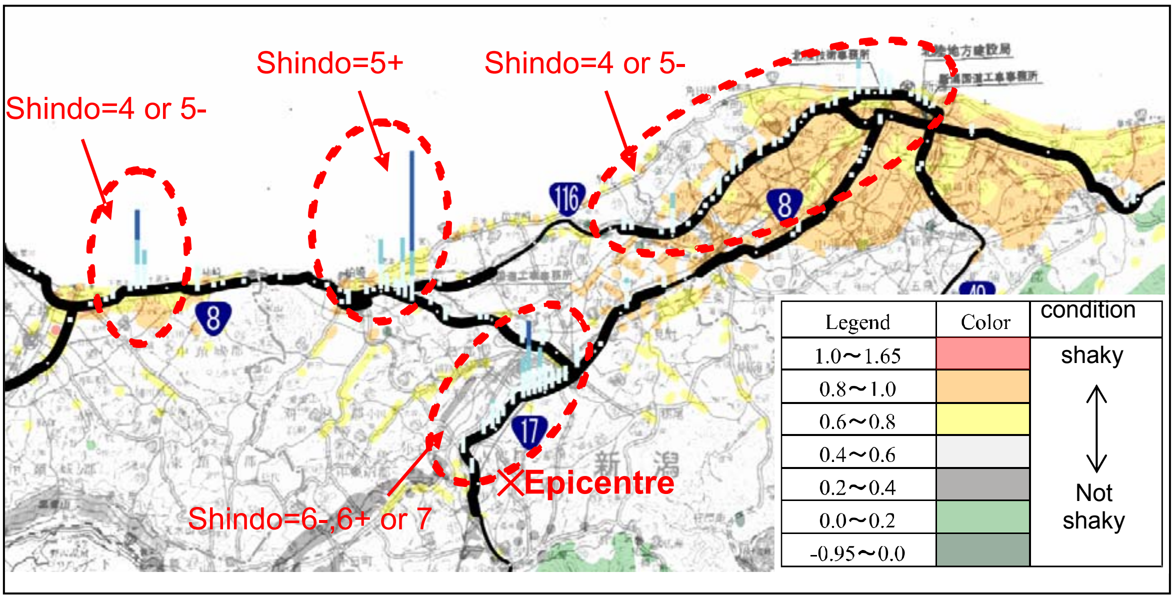


Figure 9 - Cavity distribution overlaid with the "Nationwide Map of Tremor"

3.3. Typical Location Cavity Found

The typical location where cavities were generated was adjacent to a subsurface structure in earth fill. About 60% of all cavities located close to subsurface structures crossing road. For example, culverts, underpasses and bridge abutments are typical subsurface structures.

The followings are considered as the main causes of these cavities;
- As substructures in soft ground are supported by piles in general, they do not sink even when liquefaction due to earthquakes occurred around them. On the contrary, the filling material around them does sink. Meanwhile asphalt concrete layer does not settle as the ground does because it has relatively greater stiffness. Therefore, cavities are likely to be generated adjacent to subsurface structures. There is also another case that gap has been already created before an earthquake due to the long term consolidation effect and the gap is filled with sand around structure during the earthquake. (Figure 10)
- It was observed that the structural cross joints of box-culverts had been got opened by the earthquake and the back-filling material come out through the opennin. That might cause cavities around the box-culverts. (Figure 10)

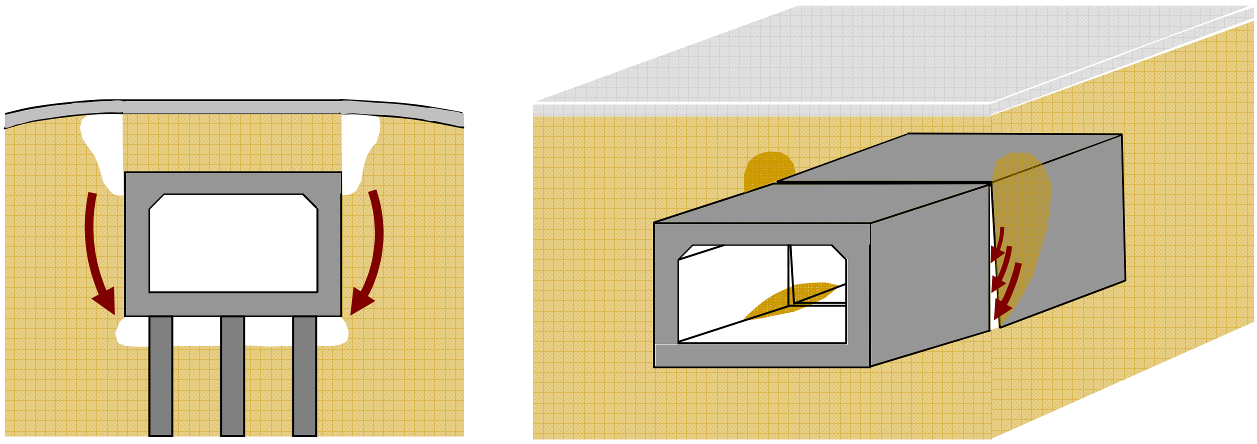


Figure 10 - Conceptual Sketch, Cavity adjacent to the substructure

3.4. Emergency survey vs. Monitoring survey

There were eight cavities detected in the monitoring survey of 48km. The cavity frequency rate of every ten kilo meters is 1.67. This figure can not compare directly with one of the emergency survey result. Because, only one lane was surveyed in the monitoring survey for the purpose of knowing the tendency although 2.56 lanes on the average were surveyed in the emergency survey. In order to compare both survey results correctly, adjustment of the monitoring survey result is required. In this case the adjusted cavity frequency rate is 4.3, 1.67 multiplied by 2.56. This figure is nearly the same as one of the periodical survey.
It can be said that most of cavities are generated by the main shock. Therefore, the subsurface cavity survey should be carried out as soon as possible after the main shock. However, the cavity frequency rate in the monitoring survey is not small enough to neglect. The periodical survey is still important as well.

4. CONCLUSION

It was probably the first time that the subsurface GPR data was collected on an enormous scale just after the large earthquake. As a result of the study on this actual and rare data, the following knowledge is acquired. And theses are useful to manage the cave-in risk that may be one of the secondary disasters after large earthquakes.

To minimize the cave-in risk the subsurface cavity survey must be carried out as soon as possible after an earthquake.
Regarding the emergency survey carried out soon after the earthquake, an average of 12.9 cavities was found in every 10km road. On the other hand, regarding the monitoring survey carried out about a year after the earthquake, the figure was 4.3. That means that most of the cavities were generated at the first shock.

The area where the seismic intensity is 5 or more should be covered by the survey.
The cavity frequency rate increased rapidly in the area where the seismic intensity of 5 or more was recorded.

Great care should be taken at locations adjacent to subsurface structures.
Typical cavity was generated adjacent to subsurface structures such as box-culverts, underpasses and bridge abutments where cavities are formed easily due to shaking.

Even where the seismic intensity is less than 5, the survey is required if the ground condition is not very good such as loose sand.

A hazard map showing the degree of cave-in risk can be a risk management tool. It is utilized not only for the daily road patrol but also making the most efficient and effective rehabilitation plan.

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