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DISTRIBUTION OF SEISMIC INTENSITY AND DAMAGE IN KUSHIRO CITY CAUSED BY THE 1993 KUSHIRO-OKI EARTHQUAKE (M7.8).

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ABSTRACT

On 15th January 1993 an earthquake of magnitude 7.8 took place 30 km. off the shore line of Kushiro-oki that is located in Hokkaido Island.

The questionnaire data together with other basic data of Kushiro city such as its geology, environment and public service data were collated to construct a comprehensive Database System.

In this paper, various analyses were done by utilizing Geographic Information System (GIS) to reveal the characteristics of the earthquake and to evaluate the relation between shake and the destruction level.

KEYWORDS

Earthquake , Questionnaires , Database System , Geographic Information System (GIS) .

1. Introduction.

The Kushiro -oki Earthquake struck at 20:06 on January 15, 1993. It registered M7.8 and caused serious damage in the eastern region of Hokkaido. The epicenter of the earthquake was in the ocean approximately 10 km south of the city of Kushiro, 107 km deep. Casualties included 1 dead and 314 seriously injured. Property damage included 45 houses totally or partially collapsed and 108 houses partially damaged. There were also extensive damage to utilities such as power, gas, and water lines. It should be particularly noted that the Kushiro Observatory of the Japan Meteorological Agency, located on a plateau, recorded large maximum accelerations: 0.94G (NS), 0.83G (EW), and 0.48G (UD).

On the other hand, at lowland , maximum accelerations was recorded: 0.48G (NS), 0.35G (EW), and 0.39G (UD). Several other observatories also recorded large maximum accelerations. One remarkable characteristic of this earthquake is that the maximum accelerations were higher in high-altitude areas than in lowland areas. This led us to study its dynamic characteristics and the characteristics of local earthquake-intensity distribution, in conjunction with its generation mechanism and site topography and ground structure, as a major research project.

This report summarizes the results of our study on the distribution of the Kushiro -oki Earthquake intensities, which were calculated based upon a series of surveys in various areas inside the city of Kushiro, within the jurisdiction area of the administration branch office of Kushiro, and in Hokkaido. This is a preliminary study for to the research project stated above.

We constructed a database based on data obtained from a survey around the city of Kushiro in eastern Hokkaido, and various data on geology and the natural and social sciences. We then performed several analyses using the Geographic Information System (GIS), which was already in practical use, in order to comprehend the characteristics of the earthquake and the damage status. Based on these work, we attempted to investigate the relationship between the seismic intensity and conducted some damage estimation.

2. Ground , Environment , Social structure and Damage Database.

The database was divided in ground information, earthquake damage information, and information from questionnaires. The database for administrative purposes was called "relational data", geographical information showing the regional characteristics of Kushiro city and data arranged in layers were associated.

In this paper, the information described above was superposed rationalistic ally and graphically in the computer and analyzed using the Geographic Information System (GIS).

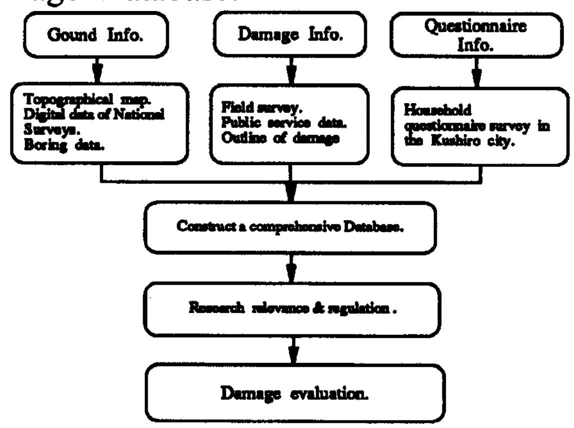

Fig-1. flowchart of investigation.

In order to use existent data, in this paper, the Digital National Land Information mesh size was adopted. Study area was divided approximately in meshes of 1,000 or 250 meters (the Digital National Land Information's base meshes), and its damage evaluated. The flow-chart of the entire study is shown in Figure 1.

The database consists of ground information, earthquake damage information and questionnaire's information. The data was collated from topographical maps sold at stores, the citizens register published by Hokkaido area , the national census, information from the Digital National Land Information of the Ministry of Construction's Geographical Survey Institute, the questionnaire survey's records, records of the on-field investigation after the earthquake, and information from private companies of the area.

1) The map and the mesh partition

It is very important to define the basic map to arrange the database. If maps vary with the information, the data could not be pertinently organized and evaluated. For this reason, the 1/200,000 map of Hokkaido , 1/25,000 map of Kushiro city and the topographical map published by the Ministry of Construction;'s Geographical Survey Institute were adopted as basic maps and its information on the district/zones was used.

The total numbers of meshes covering all Kushiro city are 4,032, each one of around 250 x 250 meters, the information was organized based on these meshes.

The total numbers of meshes covering Hokaido are 103,612, each one of around 1,000 x 1,000 meters, the information was organized based on these meshes.

2) Ground information

Ground information was organized by items as shown in Figure 2(a). Data obtained was: superficial soil geology, land use, geological classification, etc., from the Digital National Land Information; the topographic map published by the Geographical Survey Institute; and boring column sections from Kushiro city's geology companies. From these basic data various types of new data were arranged.

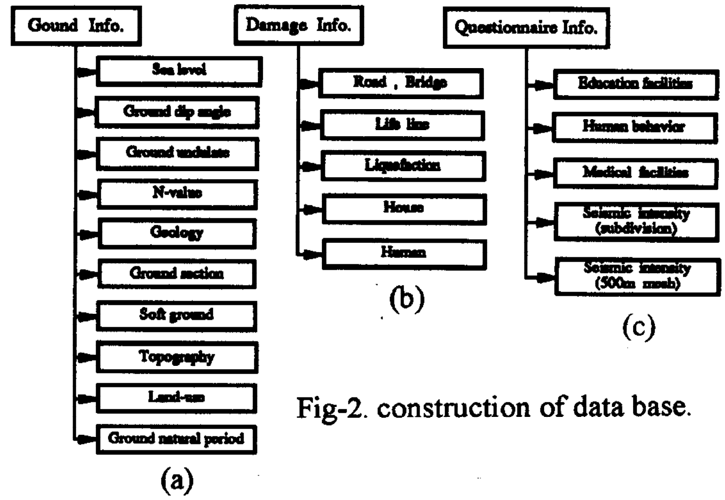

Fig-2. construction of data base.

3) Earthquake damage information

Earthquake damage information as shown by items of Figure 2(b) comprehends human and building structures damages as well as damage location and lifeline damage.

4) Questionnaire information

We adopted the questionnaires which had been used for many earthquake investigations. As for a seismic intensity distribution survey, handing out and collection of the questionnaires were carried out by staff members of cities, towns and villages with the cooperation of Hokkaido prefectural government. The number of the questionnaires handed out was fifty for each city and twenty-five for each town and village, and we collected the questionnaires from all cities, towns and villages. In regard to the high density survey of seismic intensity distribution for ten municipalities in Kushiro branch including Kushiro city, we requested the elementary schools through the Board of Education of each municipality to hand out the questionnaires to the homes of students. We also asked the elementary schools and the Boards of Education to collect the questionnaires and send them to us. The number of questionnaires handed out for the high density survey was 12,240 which is about half of the number of elementary school students in Kushiro branch. The number of collected questionnaires was 9,793 (80.0%) and the number of valid ones is 9,392 (76.7%).. This information according to the questionnaire survey cards was arranged by district zones and meshes units.

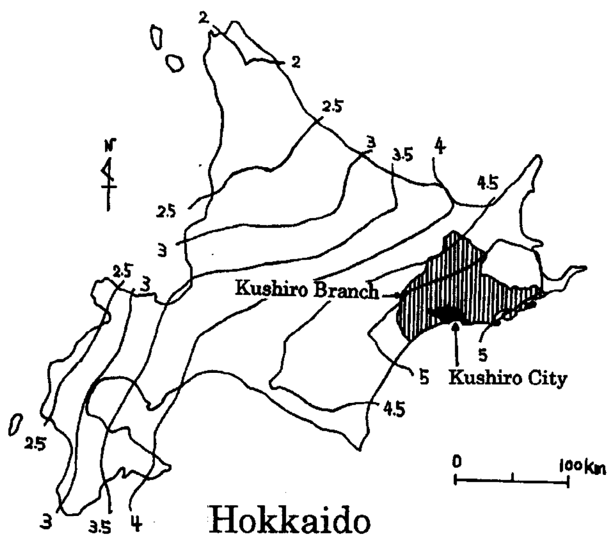

Fig-3. seismic intensity (JMA) contour map in Hokkaido Island.

3.The seismic intensity distribution of the erathquake in Hokkaido and in the jurisdiction area of the administration branch office in Kushiro

1)The calculation results of the seismic intensity distribution.

Figure 3 shows our calculation result of the magnitude distribution of the Kushiro-oki Earthquake in various cities in Hokkaido. The seismic intensity scale ($I_{(JMA)}$) used in our survey correspond to the scale determined by Japan Meteorological Agent. Ombetsu area recorded the maximum $I_{(JMA)}$ and the estimated mean $I_{(JMA)}$ was 5.7, which is in agreement with the damage report and on-site investigation. We observed area in the northern region from the city of Kushiro where the $I_{(JMA)}$ was recorded above 5.5, which correspond to the intensity VI on the Japanese seismic scale. The area with the intensity V locates from Nemuro to Tokachi and partially extends to the Hidaka area.

Figure 4 shows the $I_{(JMA)}$ distribution in the jurisdiction area of the administration branch in Kushiro. We calculated the magnitude of the earthquake for 10 local towns and villages. These local places were close to the origin of the Kushiro -oki Earthquake and received serious damage. We attempted to observe a quasi-microscopic $I_{(JMA)}$ distribution in the jurisdiction area of the Kushiro administration branch in Figure 4, which is contrast to a macroscopic distribution in Hokkaido in Figure 3. The largest $I_{(JMA)}$ was recorded in Midori area in Ombestu area and it was estimated the $I_{(JMA)}$ 6.1.

2) Characteristics of the $I_{(JMA)}$ distribution

In Figure 3, which shows the macroscopic $I_{(JMA)}$ distribution in Hokkaido, we observe the mean $I_{(JMA)}$ 5.7 in Ombetsu area , 5.6 in Shibecha area 5.5 in Akan area and Tsurui area reapectively. It should be noticed that the places with larger $I_{(JMA)}$ are located in the jurisdiction area of Kurisho. The mean $I_{(JMA)}$ in the city of Kushiro was 5.2. The $I_{(JMA)}$ distribution extends from the east to the west near Kushiro and its contours are dense across Kitami and Abashiri, which indicates that the decay of the $I_{(JMA)}$ is more prominent to the north. The similar tendency was observed on the Ojika Peninsula where the magnitude decay spreads out to the west. The contour extends to the north in the low altitude are at the central Hokkaido, which represents the amplification effect of the ground.

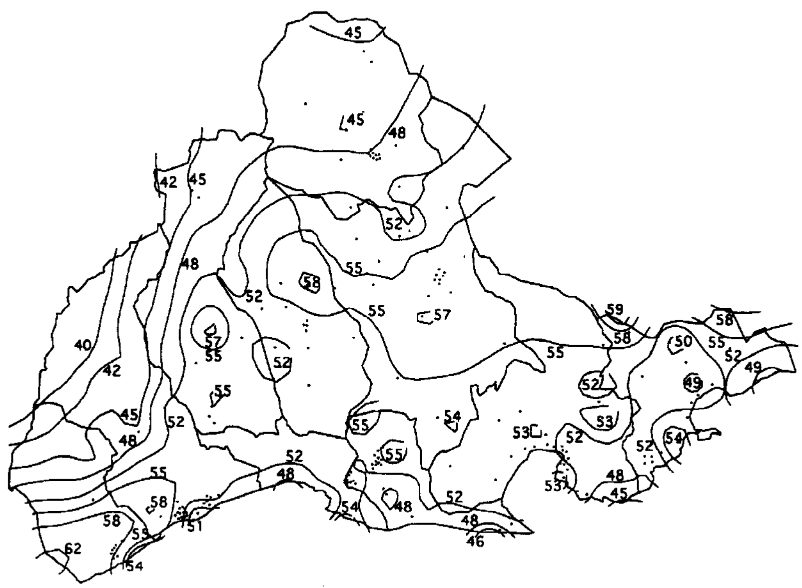

Fig-4. seismic intensity (JMA) contour map in Kushiro branch.

In Figure 4, which shows the quasi-microscopic magnitude distribution in the jurisdiction area of Kushiro, we have the matched tendency with the macroscopic magnitude distribution in the whole Hokkaido as shown in Figure 3. However, we can clearly notice that there is the $I_{(JMA)}$ distribution even in local places in the city of Kushiro.

The local place where the largest $I_{(JMA)}$ was recorded is Ombetsu- area and the $I_{(JMA)}$ 6.1 was the maximum value recorded in Midori area in Ombetsu area . Even in Shiranika area adjacent to the east side of Ombetsu area , we observed several placed where the $I_{(JMA)}$ 5.8 was recorded. Thus, the area around Ombetsu-cho and Shirakaba-cho were the area of the largest magnitude for the Kushiro-oki Earthquake. We also observed the $I_{(JMA)}$ 5.7 - 5.8 in the Shibecha area area which locates in the north of the city of Kushiro. This area is the extended area of the northern upper stream of the Kushiro River which formed the Kushiro Moor. We believe that the large $I_{(JMA)}$ in this area can be attributed to the amplification effect on the earthquake by the topographical characteristics of that area. We also observed several places with the $I_{(JMA)}$ more than 5.5 in Akkeshi area and Hamanaka- area which located in the east of the city of Kushiro. However, the $I_{(JMA)}$ distribution in those places were smaller than that in local places in Ombetsu- area in the west of the city of Kushiro and Shibetsucha- area in the north of the city of Kushiro.

4. Geographical information on the magnitude distribution, the ground, and the damage

In our investigation on the $I_{(JMA)}$ distribution in the city of Kushiro, we conducted a detailed study for the $I_{(JMA)}$ distribution in order to obtain the difference in the distribution by the geographical shape in the city, the geological feature, and the structure of the ground .

In this chapter, we attempt to explain that the $I_{(JMA)}$ distribution abs the damage were affected by the complex geological shape and the ground structure in the city of Kushiro.

1) Intensity distribution

Within Kushiro city the ground movement was : at Kushiro Meteorological Observatory located on the plateau , the maximum acceleration registered was 919.4 gal; at the construction office of the port of Kushiro, in the lower region, the maximum acceleration recorded was 469.3 gal; also, at other places, large maximum accelerations were recorded.

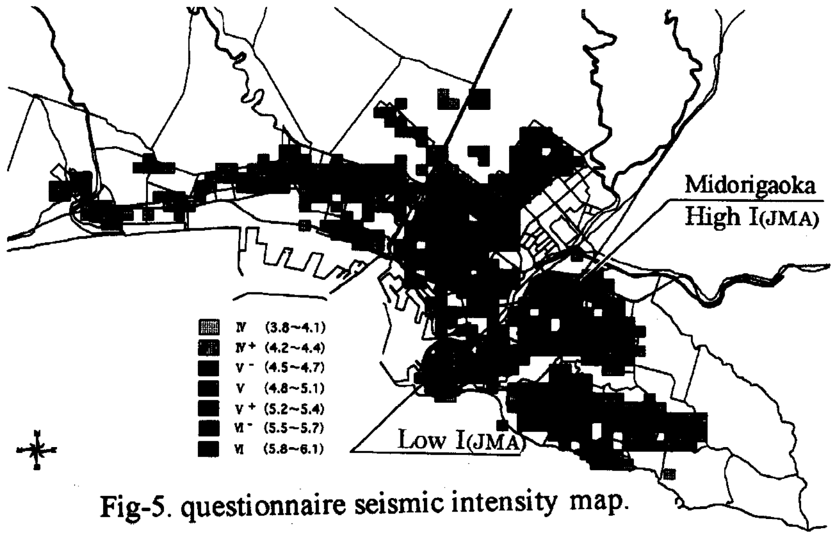

Fig-5. questionnaire seismic intensity map.

Figure5 shows intensity distribution for 250 meters meshes calculated from the questionnaire's survey. High intensities were recognized at the lowland region and at the plateau region, the west and east side of the old Kushiro river respectively. Regions with the highest intensity were Midorigaoka area, Zaimokucho and Kuroganecho with intensity 6. (the average intensity in Kushiro city was 5.2 . The highest intensity was on the plateau at Midorigaoka area with intensity 5.9). In special, in the neighborhood of Midorigaoka, housing totally collapsed, half collapsed and partially collapsed was largely observed, and also it is where more damage to pipelines occurred. At the plateau region, high and low intensities were observed, it could be due to different geological and topographical ground characteristics.

2) Geological and topographical distribution

The topography of Kushiro city is divided in: the lowland region, at the west side of the old Kushiro river (natural levee, delta lowland); and the plateau region at the east side of the river (loam plateau). The geology is formed by the lowland mud stone and river downstream that extends into the Kushiro marshy grasslands (flood plain sediment), and the reclaimed land and sand hills (mud stone, silt, clay, sand hills) of the seashore neighborhoods as shown in Figure 6. Also, at the plateau region, the Kussharo pumice sediment (weathered volcanic ash) a soft ground deposit, covers the Kushiro terrace formed by the Otanoshike Kushiro and Nemuro formations.

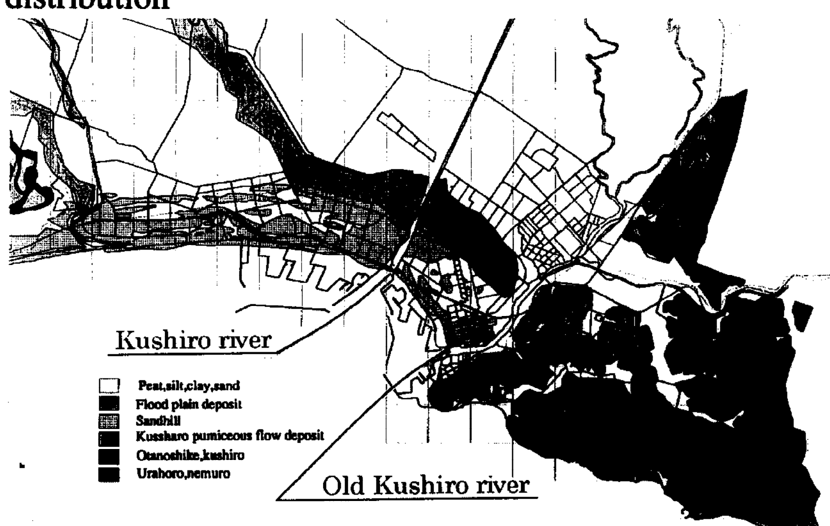

Fig-6. geological map.

3) Damage distribution

As an example of damage distribution, human damage occurrence locations are shown in Figure 7. These data were arranged by damage occurrence location, damage content, characteristics of the victims (sex, age), and as it is widely recognized, it could be confirmed that in the event of a night time earthquake in winter, a large number of victims would be distributed through as wide area of the city.

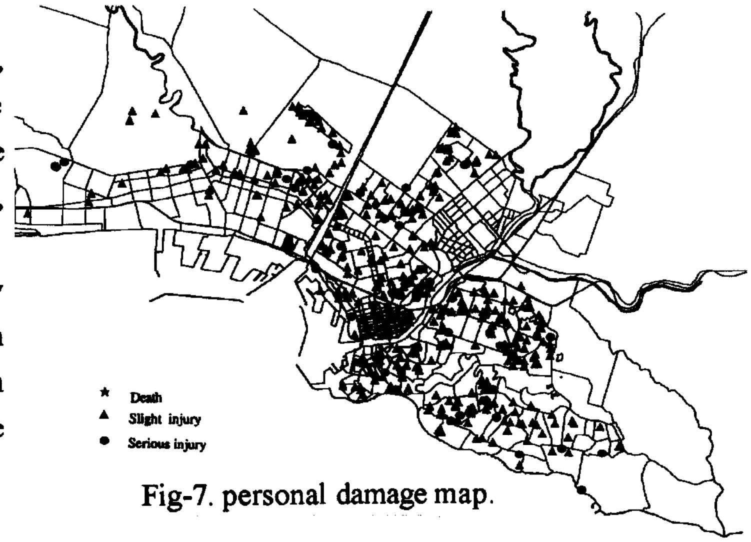

Fig-7. personal damage map.

5. Damage estimation method.

In this paper, questionnaire's detailed information and the information described above were arranged into each mesh, then the relation among intensity distribution, topography, geology, ground and damage distribution was analyzed and the damage evaluated.

1) Number of Damages and Intensity

As explained above each damaged location was plotted on GIS topographic map, and its attributes transformed in database. To study its relation with the intensity, it was necessary to organize the information on damage content and number of damages by mesh unit.

Therfore, from the relation between each damaged location coordinate and each mesh area location, the numbers of damages by mesh were summed up and classified by type of damage.

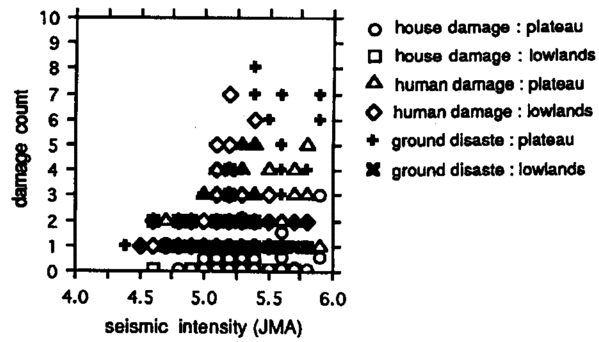

Fig-8. relation between distribution and seismic intensity.

The relation between number of damages and intensity with respect to housing damage, human damage and ground related damage is shown in Figure 8. The formula used to calculate the number of houses damaged was (totally collapsed+half collapsed x 0.5+partially damaged x 0.04)[2]. To calculate the ground related number of damages, water, gas, roads and liquefaction damage by mesh unit were summed up. According to this, along with the intensity increase the number of damages increased too, determining the number of damages occurred at the plateau region was larger than at the lowland region.

2) Ground and Intensity

To investigate the relation between ground natural period and intensity, the ground natural period from a past report was adopted, and using GIS to localize meshes with similar ground characteristics, the corresponding ground natural period was attributed to each mesh. The result is shown in Figure 9. Ground natural period observed at high intensity locations (0.25 to 0.35 seconds), and the relation observed between the number of houses damaged and the location where damages occurred are related to

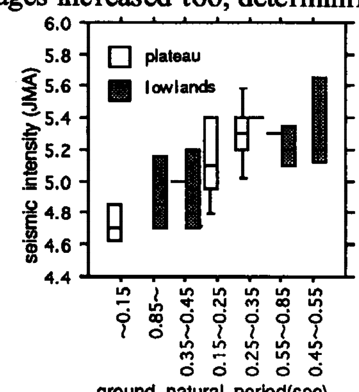

Fig-9. relation between seismic intensity and ground natural period.

the wooden houses natural period. Moreover, the horizontal line in the central part of the boxes in Figure 9 indicates the average value, the upper and lower part of the boxes shows the cumulative 50%. Also the external T to the boxes shows the 80% of the total.

Also, intensity is somewhat higher at the plateau region than at the lowlands. However, changes of intensity at the plateau region are extreme.

For this reason, it became necessary from a different point of view to add another attribute to the ground of the plateau region. Information on location and ground characteristics from boring column sections of Kushiro city were already on GIS map, so these attributes were transformed into mesh information, and the soft ground depth of each mesh was investigated, finally, the soft ground depth contours for the plateau region were made.

The lowland maximum soft ground depth, at the south edge of Otanoshike is 70 m.[3] at the plateau region, as shown in Figure 10, depth is among 0 and 20 meters because the ground has been man-modified (embankment, cut) by development of new residential zones.

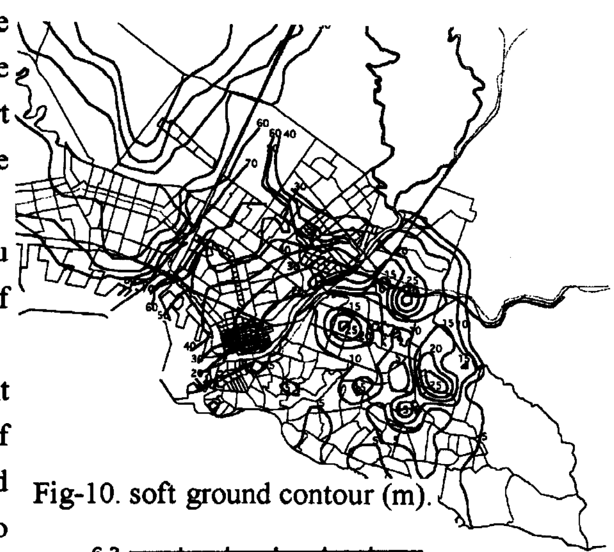

Fig-10. soft ground contour (m).

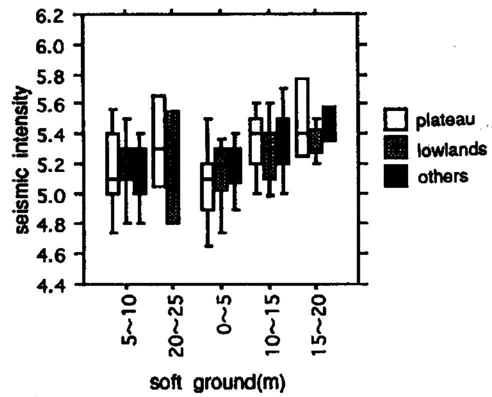

Fig-11. relation between seismic intensity and soft ground.

From this result, it was concluded man-modified ground (embankment, cut) is one of the reasons the plateau region shows a variety of intensities, and for these reason average sea level contours for the 250 meters meshes were read from a 1958 topographic map that shows sea level contours before ground changed due to urbanization[4] and compared with present sea level contours, where sea level contours were higher than the 1958 map it was considered as "embankment": and when lower as "cut" .

Figure 11 shows the relation between intensity, soft ground depth and man-modified ground at the plateau region.

From these results, it could be said that at the plateau region where soft ground depth is thickly accumulated and ground man-modified (embankment, cut) intensity was high, while at places where soft ground depth is only superficial intensity was low.

3) Intensity distribution, geology and topography

To transform in mesh data, geological and topographical c omplicated polygon partitions, the partition with the largest area was attributed as data to the mesh unit using GIS.

The relation among Kushiro's city intensity, geological and topographical classification, is shown in Figure 12, it could be seen that at the lowland sand hill's intensity was low, while at the plateau region in the Kushiro formation

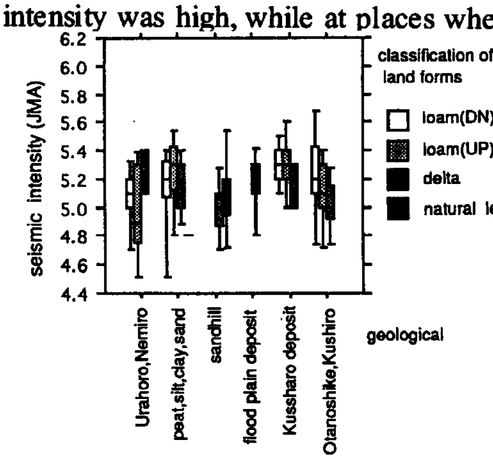

Fig-12. relation between seismic intensity, geological and classification of land forms.

and Kussharo pumice sediment intensity was high. In Figure 13, the relation between average N value for ground 1 0 meters below the superficial soil and geological classification is shown, ground average N value is approximately 30 (hard soil) at the sand hills in the lowlands.

In the other side, at the plateau region where intensity was high, ground average N value was 10 (soft ground).

Finally, it could be said soft ground depth and average N value influence the disparity observed in intensity.

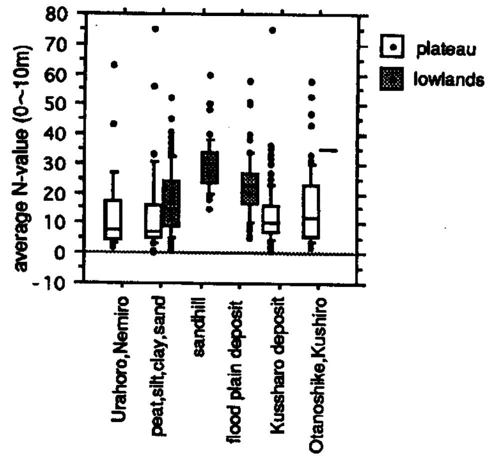

Fig-13. relation between geological and average N-value.

6. Conclusion.

Ground information, earthquake damage information, questionnaire information, etc., on the 1993 earthquake of Kushiro-oki, was transformed into database and analyzed using GIS to evaluate the damage. The use of GIS made possible evaluation of each information described above on each 250 meters mesh unit, and made possible an easier way to compare the relation among information while evaluating the damage.

As a result, at the lowland region, in special at places with geological conditions as mud stone, silt, sand and flood plain sediment intensity was high, while at the sand hill region due to the ground average N value (below 10 meters of the superficial soil) intensity tended to be lower. On the plateau region, intensity was low at the Paleocene and Cretaceous formations, however, at the Otashike Kushiro formation and at the Kussharo pumice sediment where soft ground is deeper (10 to 20 meters) intensity was higher, coinciding approximately to the registered at man-modified grounds.

Moreover, it could be seen at the plateau region, the relation between Kushiro city's damage distribution and intensity shows a clear tendency to high damage occurrence where intensity was high, it corresponds well to the observed intensity distribution. From now on, it is necessary to improve the database and GIS. Also, GIS is an effective tool for damage evaluation.

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