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INTERPRETING GROUND CONDITIONS AND EARTHQUAKE DAMAGES BASED ON THE LAND USE AND ITS CHANGE

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SUMMARY

This paper describes a study in which maps in the old times have been compared with those in the present time, based on the hypothesis that topography has a strong relationship with ground conditions and that vegetation and land use were restricted by topography in the old times. It was found that the land use and its change are notable clues to draw a broad picture of the ground condition. Especially, former paddy fields have been found to coincide well with alluvial lowland thus implying the existence of soft soils. By examining damages due to earthquakes from the view point of topography and ground conditions, it was also found that this information can well explain those damages.

INTRODUCTION

The knowledge about the condition of the ground is crucial when considering earthquake disaster prevention and mitigation as well as planning to construct buildings and facilities. Especially, it is well known that the surface soil condition and the micro topography are influential to the seismic intensity of the ground and hence to the seismic damages. For example, damages to lifeline due to 1995 Hyogo-ken Nanbu earthquake clearly showed the importance of topography, although it is not apparent in the present time due to reclamation or filling [Isoyama et al., 1998]. The effect of topography on the surface ground motion has been discussed in detail in the field of seismic microzoning [AIJ, 1993]. However, collecting the information on the ground condition over a wide area is a fairly difficult task.

In order to overcome the difficulties, a number of studies have been reported. One of the effective approaches is to consult topographic maps of digital form and to estimate ground conditions from the type of micro landform [Matsuoka and Midorikawa, 1994]. However, since available topographic maps of digital form are of the grid type with the grid size of 1 kilometer, it is difficult to consider the micro landform of the order of 100 meters. An alternative is to use land condition maps, which unfortunately cover only a fractional portion of Japan. Another source of information for estimating the ground condition is the land use in the old times. Since the land use in the old times is considered to reflect the geological condition which has not been altered by human, it can be a clue to infer the landform and ground condition at that time, hence the soils beneath the surface layer in the present time [Nakai, et tal., 1998].

The objective of this paper is to investigate approaches to infer the ground condition of the present time and also to estimate earthquake damages based on the land use data found in the maps in the old times.

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2. GROUND CONDITION, TOPOGRAPHY AND LAND USE

Topography governs the distribution of soils in the landscape [Birkeland, 1984]. Many of the differences in soils that vary with topography are due to some combination of microclimate, pedogenesis, and geological surficial processes. Soil properties vary laterally with topography. One reason for this is the orientation of the hill slopes on which soils form; this affects the micro climate and the soil. Thus, topography, especially micro topography or relief, can provide a key to estimate such soil conditions as surface layer material and bearing capacity as well as groundwater level.

Another clue is vegetation or land use. It is clear that vegetation has strong influence on the soil. As a matter of fact, field sites can be found where vegetation is the most important variable producing differences in soil properties. In the old times, people tried to get along with the nature, meaning that they used the land on an as-is basis without altering it in a large scale. Thus, it is natural to assume that maps of old times reflect the original topography of the land. Based on the fact that land use also varies according to the soil condition and the micro topography, it is then said that the land use in the old times can be an index to the ground condition of the present time, at least for the soil underneath the current surface layer. In other words, a general principle of inferring topography and soil conditions can be given by the land use and its change.

3. METHOD OF ANALYSIS

3.1 Maps in the Old Times

Although old maps are useful, the older is not always the better because older maps are often inaccurate. Considering the fact that maps drawn up for Japan in the beginning of this century have enough accuracy, the authors adopted topographic maps drawn on a scale of 1 to 50,000 made in 1903. The areas of Chiba and Togane have been chosen for the study (Figure 1). From these maps, land use and vegetation are extracted and converted to a digital form by using an electronic digitizer. These digitized maps are then made a correction so that they can be directly compared to more recent digital maps. The correction process is done by applying the Affine transform associated with 15 of ground control points (GCP's) for each map.

3.2 Maps in the Present Time

Recent resources on topography include 1/25,000 land condition maps compiled by Geographical Survey Institute, Ministry of Construction, Japan, which unfortunately cover a fractional portion of Japan. As for the land use, latest information is available also from Geographical Survey Institute in a digital format. Since this information is given as grid data that consist of pixels with attributes, direct comparison with the above obtained 1903 data is not possible due to the difference of the data type. In order for this to be possible, the grid data are converted into the vector ones by making each pixel a polygon that has corresponding land use data as an attribute. In this study, 1/10 detailed digital land use information of the year 1989 is used and a conversion is made in this way.

3.3 Satellite Photographs: Land Use in the Present Time

The potential of satellite photographs is well acknowledged in terms of monitoring the earth surface and has been discussed in a number of scientific discourses. Among others, they have been successfully used to show vegetation [Townshend and Justice, 1986]. Unlike airborne data, satellite records such as Landsat Thematic Mapper (TM) data are readily available for most of the world. Thus, it is theoretically possible to identify vegetation of any place in the world.

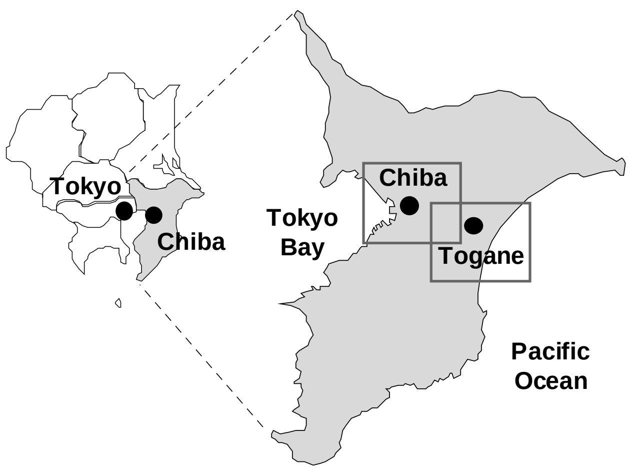

Figure 1 Target Areas

A vegetation index is a number that is generated by some combination of remote sensing bands and is considered to have some relationship to the amount or the characteristics of vegetation in a given pixel of satellite photographs. In this study, a Normalized Difference Vegetation Index (NDVI) is used to identify vegetation and land use of the ground. In the case of Landsat TM, NDVI can be computed by the following expression:

$$NDVI = \frac{Band\,4 - Band\,3}{Band\,4 + Band\,3} \qquad Band\,3 : \text{visible} \qquad Band\,4 : \text{near infrared} \tag{1}$$

In addition to NDVI, the seasonal difference of NDVI and Band 7 (short wave infrared) records have been used for performing land use classification. The seasonal difference is adopted to extract paddy fields and Band 7 is intended for identifying concrete materials.

As pointed out, vegetation indices are generally based on empirical evidence and not basic biology. This means that a good performance may not always be expected from this approach. Satellite images, however, have an advantage of reasonable spatial resolution (cell size of 30 meters by 30 meters in the case of Landsat TM) compared with above mentioned digital land information (100 meters to 1 kilometer).

3.4 Relationship Between Land Use and Topography

As mentioned earlier, land use, vegetation and topography are intertwined and have been investigated to a great extent [Suzuki, 1997]. Table 1 summarizes the rules (knowledge) that are used to infer the micro topography, hence the ground condition, from the change of land use/vegetation.

4. ANALYSIS RESULTS IN CHIBA AREA

4.1 Chiba Area

Chiba is a mid-sized city located about 40 kilometers east of Tokyo. The landscape of this area consists of a broad area of diluvial upland and a narrow band of alluvial lowland along the coast. A closer look at this area, however, reveals that this broad area of upland is a dissected plain with a dendritic pattern of narrow alluvial valleys called *Yatsuda* in the local expression. Thus, from the view point of micro landform, this area has a fairly complex topography.

4.2 Land Use and Landform

Figure 2 shows the land use and vegetation of Chiba area in 1903 extracted from the map at that time, while Figure 3 represents the data of the same area in 1989 found in 1/10 detailed digital land use information. From these figures, one can see that the building area grows drastically during this period and that, in response to the growth of the filled ground, the area of vegetation such as paddy fields and forests as well as tidal flats has decreased.

Table 1 Inference Rules

Land Use in 1903	Land Use in 1989	Possible Landform
Paddy Field	Paddy Field	Lowland, Marsh
Paddy Field	Building, Road, Railroad	Fill
Sea, Tidal Flat	Other than Sea/Tidal Flat	Reclaimed Ground
Forest	Building, Road, Railroad	Leveled Ground
Forest	Forest	Other than Lowland
Field, Orchard	-	Local Relief, Hill
Building	-	Local Relief, Hill

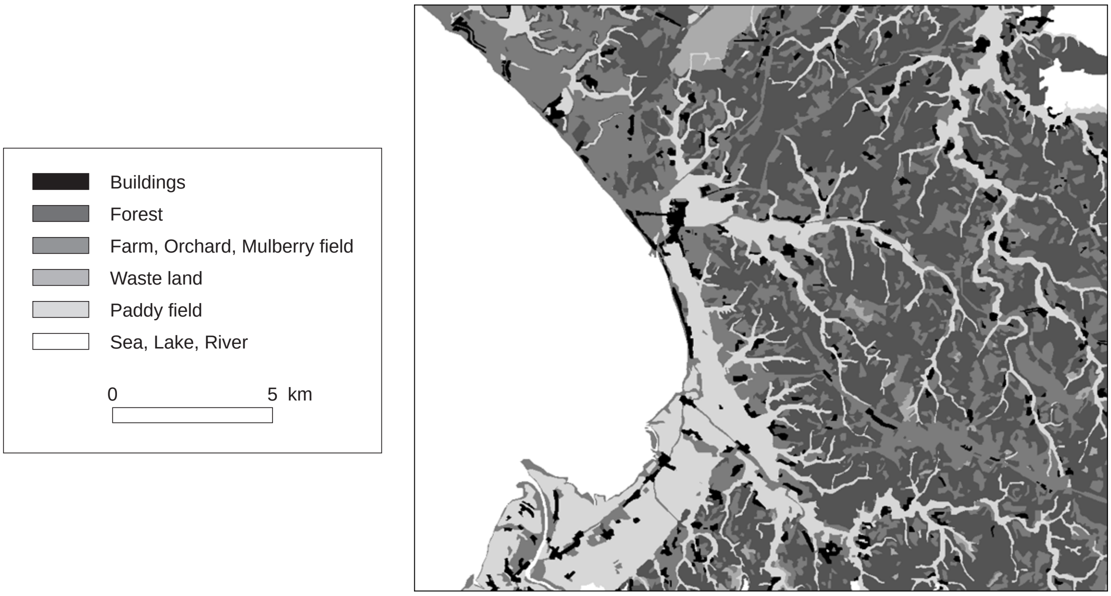

Figure 2 Land Use in Chiba Area in 1903

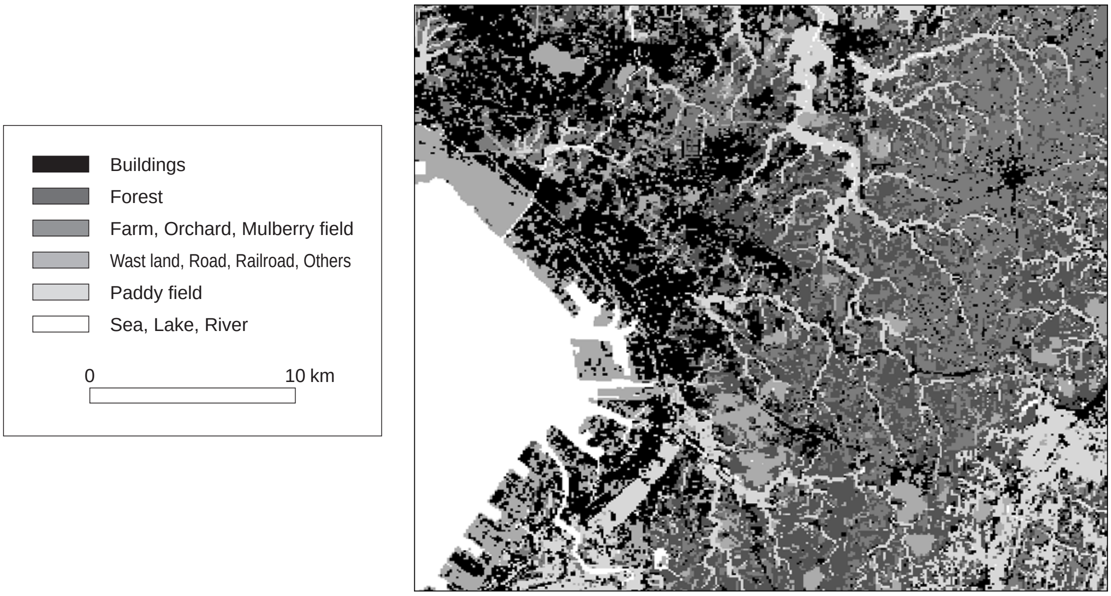

Figure 3 Land Use in Chiba Area in 1989

Figure 4 shows a landform classification map computed from the change of the land use between 1903 and 1989. It is pointed out from this map that, in Chiba area,

- A wide band of reclaimed ground is strung out along the coast.
- Inside the reclaimed ground is a narrower band of filled ground that used be paddy fields.
- Then comes a fairly broad area of diluvial upland with leveled grounds and narrow alluvial valleys.

In order to verify the hypothesis that land use can be an index of the ground condition, the computed landform classification is compared with 1/25,000 land condition maps. Figure 5 is one of such comparisons. In the figure, the area bordered by solid lines indicates paddy fields in 1903. The shaded areas represent landform that was extracted from a land condition map of 1969. It is found from this comparison that:

- Paddy fields in the past almost coincide with the lowland such as flood plains, river plains and coastal plains.
- Filled grounds identified from the change from paddy fields to building areas approximately correspond to those

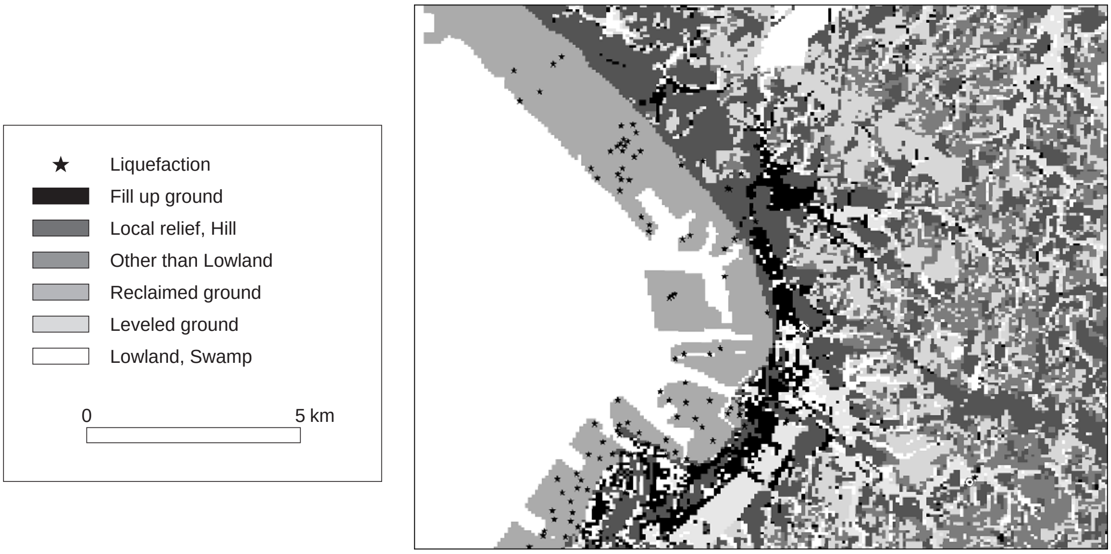

Figure 4 Computed Landform Classification in Chiba Area

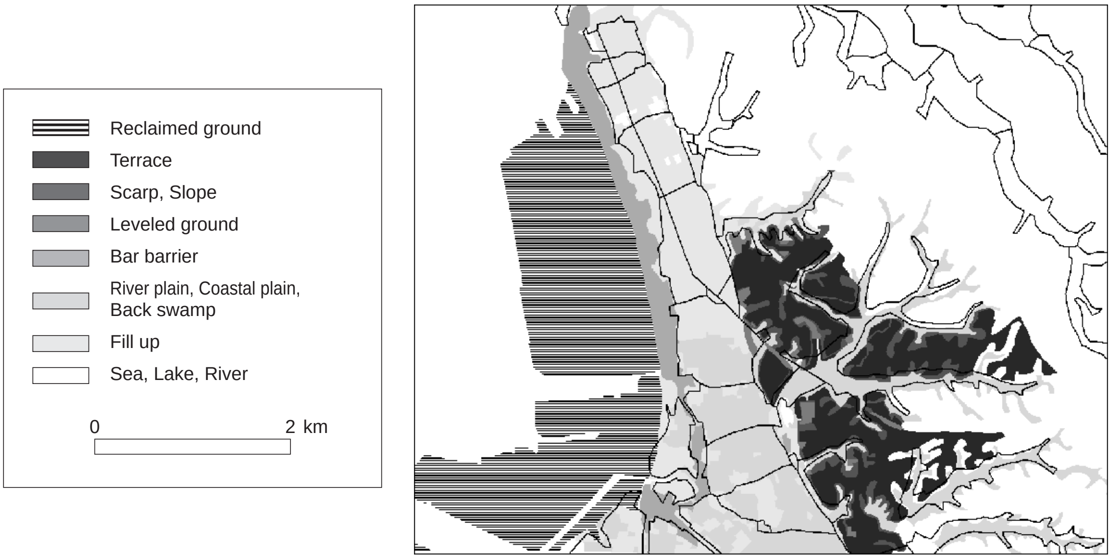

Figure 5 Comparison of Paddy Fields in 1903 with Landform Classification in 1969

in the land condition map.

- An accurate estimation of reclaimed ground is possible by this approach.
- It is difficult, however, to distinguish between local relief in the lowland and terrace only from the land use and vegetation information.

4.3 Damage Interpretation

Wakamatsu [1991] has conducted a thorough investigation of the sites that have undergone liquefaction during past earthquakes. According to this, reclaimed ground is one of the typical areas which most often experience liquefaction during earthquakes. In Figure 4, star symbols indicate the sites where liquefaction was observed during 1923 Kanto earthquake and 1987 Chibaken-Toho-Oki earthquake. The figure clearly shows that liquefaction has occurred in the reclaimed ground along the coast.

A certain amount of damage to buildings due to 1987 Chibaken-Toho-Oki earthquake has been reported (Joint Research Group, 1988). Among these, two sites were chosen for examination.

The first is a high school building which is built on a hill that is close to a lake. Damage details have been reported such that shear and bending cracks were found along the columns. However, no major damage to the foundation and the ground have been reported. According to the 1903 map, the land use of this site at that time was a field. This indicates that the site is classified as local relief or terrace, which suggests that the soil condition of the site is not bad because terrace in this area is normally diluvial upland covered with firm soils such as sand and gravel. The collected borehole data clearly support this estimation.

The second example is an elementary school building. It is reported that the superstructure of the building was not heavily damaged but that the foundation and its surrounding ground suffered a severe damage. In the playground, sand and water boil due to liquefaction was reported as well. In addition, this site had reportedly suffered ground subsidence before the earthquake. According to the 1903 map, this site was located on the boundary between paddy fields and forests which corresponds to the edge of a river plain. This can read that the present situation is that the site extends over a cut and a fill, causing a severe damage on a fill side. This reading is confirmed by the research report.

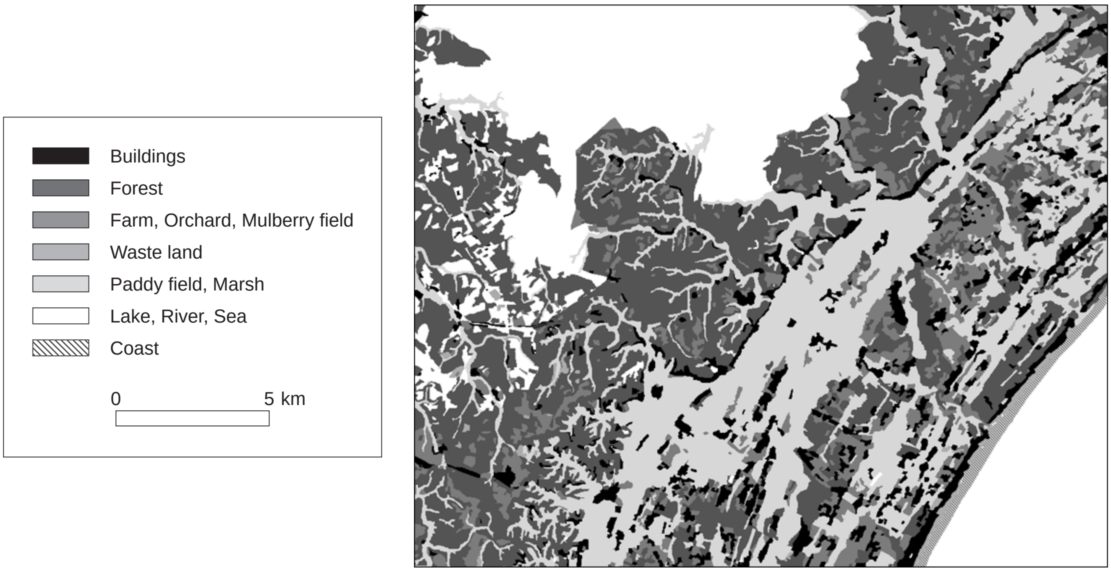

Figure 6 Land Use in Togane Area in 1903

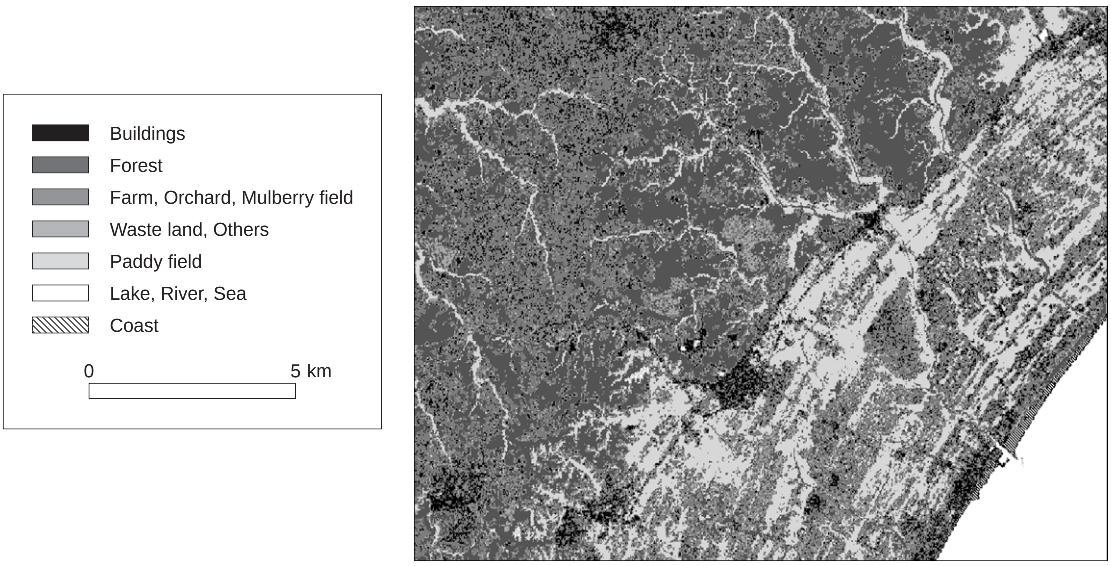

Figure 7 Land Use in Togane Area in 1987

5. ANALYSIS RESULTS IN TOGANE AREA

5.1 Togane Area

Togane is a small city just east of Chiba City. It is located at the west edge of a coastal plain which extends from southwest to northeast along the pacific coast. The city is also very close to the foot of the upland which is again a dissected plain with a dendritic pattern of narrow alluvial valleys.

5.2 Land Use and Landform

Figure 6 shows the land use and vegetation of Togane area in 1903, which have been extracted from a 1/50,000 topographic map. Instead of using 1/10 detailed digital land use information, satellite photographs were used to obtain land use in the present time in Togane area. Two scenes of June 6, 1987, and July 24, 1987, were used and a total of some 60 ground control points (GCP's) were selected to rectify the satellite data. Figure 7 represents thus obtained land use of Togane area in 1987.

As pointed out in 4.2, it is difficult to distinguish between local relief and terrace based only on the land use and vegetation. In order to distinguish between the two, altitude has been considered. Based on the observation of landform in this area, a threshold was set to 15 meters: below this level land is categorized as local relief, otherwise land is classified as upland (terrace). The digital elevation model (DEM) issued by Geographic Survey Institute was used for this analysis.

Figure 8 shows a landform classification map computed from the change of the land use between the 1903 and 1987. It is pointed out from this figure that:

- The landform of this area consists of an alluvial lowland in the east and a diluvial upland in the west.
- A fairly wide and intermittent range of local relief is strung out along the coast in the alluvial lowland. The elevation of this local relief relative to the surrounding marsh is very small.
- The diluvial upland is again a dissected plain with a dendritic pattern of alluvial valleys.

The computed landform classification has been tested against the 1/25,000 land condition maps. Figure 9 shows a part of the land condition map of Togane area issued in 1984. By comparing Figures 8 and 9, one can see that local relief in the alluvial lowland is clearly extracted by our method of analysis and is distinguished from the upland.

5.3 Damage Interpretation

During 1987 Chibaken-Toho-Oki earthquake, several school buildings were reportedly damaged (Joint Research

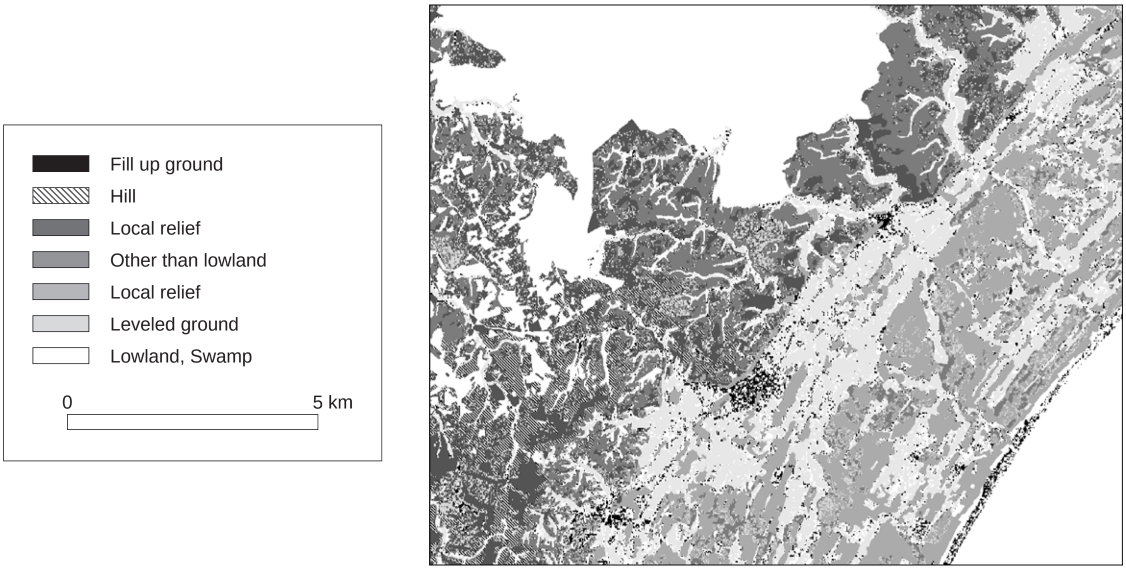

Figure 8 Computed Landform Classification in Chiba Area

Group, 1988). Among these, another two sites were chosen for examination.

The first is a high school building which is built on a narrow hill that lies between a coastal plain and a river plain. This topographic circumstances matches well with the computed results shown in Figure 8. It is reported that fairly large bending cracks were found on most of the main walls and columns. No major damage was detected on the foundation. Based on the topographic circumstance of this site, it is possible to suppose that ground motion amplification may come from this characteristic local landform.

The second example is an elementary school building. Only a minor damage, such as drop of finish materials and small cracks on the scarcement, is reported for this building. According to the computed landform classification and also to the land condition map, this site is located on a local relief in the middle of alluvial plain. This reading leads to a reasonable estimation of a fairly thick layer of sand deposit near the ground surface and implies a better soil condition when compared to the surrounding marsh. This corresponds to the observation.

Figure 9 Landform Classification of Togane Area in 1969

6. CONCLUSIONS

From the viewpoint that topography has a strong relationship with ground conditions and that vegetation and land use were restricted by topography especially in the old times, maps in the old times have been compared with those in the present time. It was found that the land use and its change are notable clues to draw a broad picture of the ground condition. Especially, former paddy fields almost coincide with alluvial lowland thus implying the existence of soft soils. Forests indicate such landforms as upland and local relief which can be distinguished by considering the altitude. These analyses have been found to agree well with the detailed earthquake damage reports.

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