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ANALYSIS OF SATELLITE IMAGES IN THE LIQUEFIED REGIONS

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ABSTRACT

Information on ground conditions specifically liquefaction potential obtained from analysis of infrared rays images from satellite remote sensing was compared with a liquefaction distribution map developed from behavior of ground in past earthquakes. Regions which correspond to a high liquefaction potential were extracted mainly by using the Band 7 image which is the infrared rays of Landsat TM sensor. Case studies were carried out around Noshiro City, Kushiro City, Kobe City and Shiribeshi-Toshibetsu River. Our investigation has shown that if Band 6 image is used together with Band 7, the analyzed image agrees reasonably well with the liquefaction distribution map. As a result, this technique is seen to be useful in regional assessments of liquefaction risk.

KEYWORDS

Liquefaction; Landsat; satellite image; infrared ray; 1983 Nihonkai-Cyubu Earthquake; 1993 Kushiro-Oki Earthquake; 1993 Hokkaido Nansei-Oki Earthquake; 1995 Hyogo-Ken Nanbu Earthquake

INTRODUCTION

Satellite images of earthquake damaged areas clearly reveal regions where sand boiling phenomena due to liquefaction has occurred, particularly if sand boiling appears over a large area. An effort has been made in this study to observe areas which are more susceptible to liquefaction prior to an earthquake and some parameters for such an observation are defined.

The study has focused on using ground information inferred from infrared images to assess liquefaction potential on a regional scale. The utility and characteristics of information that can be read using satellite image are clearly understood if we examine a case study. In this paper, we first outline an analytical technique to use remote sensing data for the estimation of liquefaction potential. This technique is then used to analyze images of ground where earthquakes have occurred in the past and for which the liquefaction distributions were known. The following regions were considered in this study: the surroundings of Noshiro City which experienced the 1983 Nihonkai-Cyubu Earthquake, Kushiro City which was hit by the 1993 Kushiro-Oki Earthquake, the area around the Shiribeshi-Toshibetsu River which was struck by the 1993 Hokkaido Nansei-Oki Earthquake and Kobe City hit by the 1995 Hyogo-Ken Nanbu Earthquake. These earthquakes had roughly the same Richter magnitude (M) of 7.2 to 7.8.

USE OF REMOTE SENSING DATA

Remote sensing data from satellites are obtained as images captured by sensors which receive electromagnetic waves that are reflected and radiated from the ground surface. A typical sensor is the TM (Thematic Mapper) sensor of the Landsat 5 satellite. Though the resolution of the TM sensor is 30 m it has sufficient accuracy for use in the field of construction, in any case the technique described in this paper is not sensitive to the resolution of the sensor.

There are 7 kinds of wavelength bands ranging from visible to infrared rays in the TM sensor images. Each image data is composed of a numerical value which is an indicator of the strength of reflection and radiation (described as the level value). Information on the ground such as type of ground surface, water content, etc. is included in remote sensing data. Therefore, use of this kind of data in the field of geology and engineering could prove to be very valuable (Research Committee on Using Remote Sensing to Soil Engineering, 1993). There are advantages to using satellite image data in delineating ground information as shown in Table 1 (Tomatsu 1994). However, there are also a few hurdles that must be overcome in order to make better use of satellite imagery data.

Table 1 Advantages and disadvantages of remote sensing data

Advantages
1. An image of a wide region can be obtained at one time at a relatively low price under the same standard conditions.
2. Surveying the same region repeatedly past information can be compared.
3. The information of infrared ray is obtained not only of optical ray.
4. Various analyses and visual presentation are possible through image processing.
Disadvantages
1. Lower resolution compared with ground surveys.
2. Cloudy sky hampers the ground information. (Microwave sensor is expected to solve this problem.)
3. Ground information is limited to shallow surface layers.
4. Information is obtained only from spectral intensity of reflected and radiated rays.

ANALYSIS OF LIQUEFACTION POTENTIAL USING REMOTE SENSING DATA

Up to now, the assessment of liquefaction potential of the ground over a large area has been chiefly based on using documentary evidence, field tests, and microzonation studies, etc. However, in many instances such information is insufficient and inadequate. In these cases, remote sensing data offers the potential of delineating ground information over a large area. Examples of such use are the analysis of remote sensing data in the liquefied areas of the 1983 Nihonkai-Cyubu Earthquake (Shima 1985, Goto 1986, and Kurita 1990).

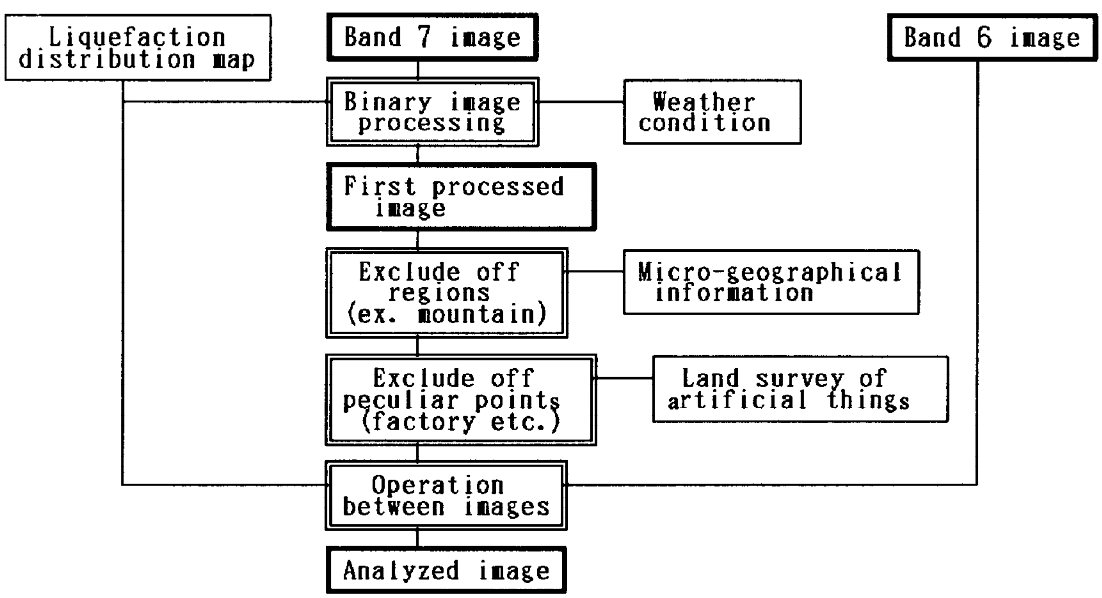

Fig.1 Schematic flow of image analysis

The procedure used in the analysis of remote sensing images in regions where liquefaction had been observed is shown in Fig. 1 (Tomatsu 1994). The analysis starts by selecting the image within the subject area. Wherever possible, the use of images with the following conditions is recommended:

1) Cloud: As few as possible,
2) Time: Images before and after an earthquake occurrence, and
3) Season: Image in a season with sparse greenery and minimum water in the paddy fields.

In the past image analysis has been done almost exclusively by using Band 7 images (2.08-2.35 μ m) of infrared rays. A threshold value is set to make this image binary which yields the first processed image. The image of the extracted regions looks very much like damage distribution maps of liquefaction. The extracted regions are compared with the liquefied regions and the differences among them can then be studied in more detail. The regions which are clearly not liquefied are excluded based on microzonation investigation. Some anomalous points caused by manmade sources of infrared rays discharge (factories etc.) are excluded. If Band 6 image (10.4-12.5 μ m) which takes into account the ground temperature is incorporated in the processing (see Fig. 1), the resulting image is better than the image obtained by using only Band 7.

Use of remote sensing data to obtain ground information in urban is limited to areas with exposed ground surface. However, residential areas have considerable open spaces where ground information can be obtained. Also, the ground condition can be indirectly identified even where thin pavement coats the ground. However, ground information obtained thus does not concern the depth of the liquefaction. The presence of underground water and soil permeability are inferred from information on temperature of the ground surface and the water content in the soil layers covering the liquefied layer is evaluated by indirect means. The validity of this approach is tested by insite investigations and by collecting evidences in the field.

IMAGE ANALYSIS OF NOSHIRO CITY AND NEIGHBORING AREAS

Liquefaction occurred over a wide range by the 1993 Nihonkai-Cyubu Earthquake (M=7.7, May 26). Remote sensing data was obtained in the areas around Noshiro City (Tomatsu 1992) was analyzed and the extracted liquefied region were compared with actual liquefied region confirmed by site investigations. Figure 2 is a map of liquefaction distribution by Tohno (1985), the painted region is the actual liquefaction region confirmed by site investigations.

Fig. 2 Liquefaction distribution map in the vicinity of Noshiro City after the Nihonkai-Cyubu Earthquake

Fig. 3 Analyzed image of Noshiro City and neighboring areas [Band 7 >39 & Band 6 <170]

The TM sensor data taken on August 21 1989 (after the earthquake) is used for image processing. The liquefaction potential can be estimated from the image taken after the earthquake, if it is assumed that there is little change in ground conditions before and after the earthquake. Images obtained from each infrared ray band from 4 to 7 were compared with the liquefied region in Fig. 2. The Band 7 image was made binary using a threshold value and this image was seen to have a good correlation with the liquefied region. The binary image (First processed image on Fig.1) was then improved by using Band 6 data and the image using Band 7 and Band 6 together is shown in Fig. 3 which correlates well with Fig. 2.

IMAGE ANALYSIS OF KUSHIRO CITY AND NEIGHBORING AREAS

Extensive liquefaction damage was seen in Kushiro City and vicinity due to the January 15 1993 Kushiro-Oki Earthquake (M=7.8). Sand boiling in harbors and low marshes and the collapse and deformation of fills (reclaimed land, railway and road embankments, etc.) were remarkable. Cracks and differential ground movement were seen in a lot of wharves in Kushiro Port. Sand boiling by liquefaction was seen in many regions which surround Kushiro City; Mihara district and Kiba-Cho (where manholes coming up to the ground surface). There were also a lot of houses damaged around the plateau in the east bank of the Old-Kushiro River.

Remote sensing data from January 6 1993 before the earthquake was used from which many TM sensor images were obtained of Kushiro City and neighboring areas (Fig.4). The areas where a high level value of the Band 7 image was assumed to correlate with a high potential area of liquefaction showed an excellent relationship with areas identified as having liquefied by field surveys(Tomatsu 1993). However, places where correlation was seen to be inadequate were likely the result of the following factors:

1) The analysis of ground information was made difficult where ground was densely covered by buildings and the pavements, etc.
2) Places where manmade energy discharge activity was high (factory, etc.) had high level values reflected in the image.
3) Compared with images in other seasons, the level value in winter is low because of ground freezing.
4) Slope sites showed high level values because of abundant solar radiation in winter.

Fig. 4 Infrared rays image of Kushiro City region [1/6/93]

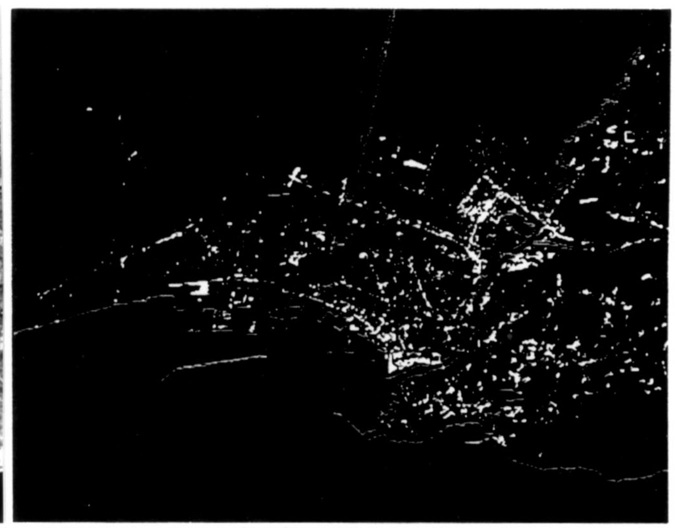

Fig. 5 Analyzed image of Kushiro City and neighboring areas [Band 7 >19 & Band 6 <60]

The ground temperature information contained in Band 6 image is used to remove the influence of (3)and (4). Figure 5 is an image of extracted regions where Band 6 is low and Band 7 is high. The extracted regions in Fig. 5 are expected to show a better match with high potential areas of liquefaction. This is confirmed by the extracted regions which correspond to Kushiro West Port, East Port, and Kiba-Cho, etc. where in all places liquefaction was verified by field surveys (Toki 1993). As a further investigation of the soil conditions samples were gathered at 21 points (some at liquefied points and some elsewhere). These samples were subjected to grain size distribution test to evaluate the liquefaction potential. Seven samples from paved areas were excluded and of the remaining 14 places the result of 9 which showed positive signs are located in areas which were identified to be liquefied regions as extracted from the remote sensing image.

IMAGE ANALYSIS AROUND THE SHIRIBESHI -TOSHIBETSU RIVER

A wide area around the Shiribeshi-Toshibetsu River valley suffered liquefaction damage by the 1993 Hokkaido-Nansei-Oki Earthquake (M=7.8, July 12). There was widespread liquefaction damage of embankments, one of which extended up to 7 km downstream from the Toyota Bridge (Kubo 1994). As in the other areas remote sensing data was analyzed, and the processed images compared with the distribution of the liquefaction damage from field surveys. In this region there are few manmade objects and the extent of the coating of ground surface is small though areas covered such as paddy fields and the river channel cannot be analyzed because of the high reflection from the water surface and must therefore be exempted from the analysis.

The image from the TM sensor of the Landsat 5 satellite was used for this analysis. The image at May 28, 1993 was selected as the pre-earthquake image showing in Fig.6. Figure 7 shows the analyzed Band 7 image of the surrounding area of the Shiribeshi-Toshibetsu River (Tomatsu 1995). White parts extracted in the image are interpreted to be places where water content in the soil is high and these regions are presumed to have a high liquefaction potential.

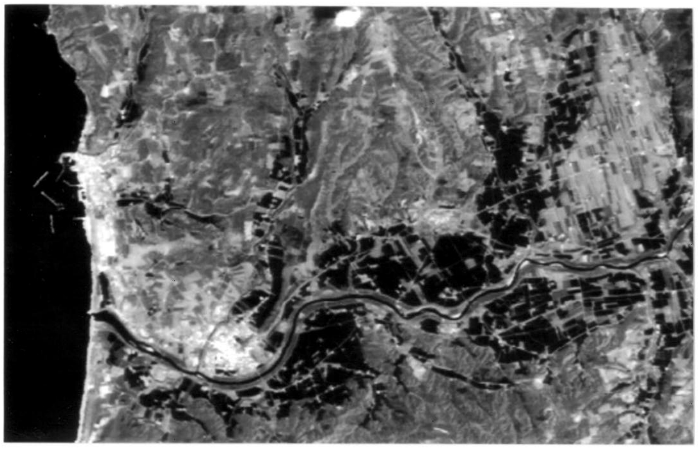

Fig. 6 Infrared rays image of Shiribeshi-Toshibetsu River [5/28/93]

Fig. 7 Analyzed image around the Shiribeshi-Toshibetsu River [Band 7 >35]

IMAGE ANALYSIS AROUND KOBE CITY

Liquefaction damage occurred widely around Kobe City by the 1995 Hyogo-Ken Nanbu Earthquake (M=7.2, January 17). Table 2 shows date and characteristics of the satellite images. In this paper the TM sensor image of the Landsat 5 satellite is analyzed paying attention as in the above cases to infrared rays. TM sensor image covering Kobe City area had been taken on January 24 after the earthquake. Figure 8 shows the Band 7 image taken after the earthquake. In Fig. 8 the urban area reflects like white, the mountain and the road is seen gray, and the river and the sea black. The image of Fig. 8 was made binary and areas of high level value were extracted and are shown in Fig. 9. The extracted region in Fig. 9 corresponding to the white area in Fig. 8 and included in it are Port Island, Rokko Island, Maya Wharf, and Wada Cape, etc. These extracted regions correspond reasonably well with a map of liquefaction distribution obtained from aerial photographs of the Kobe area.

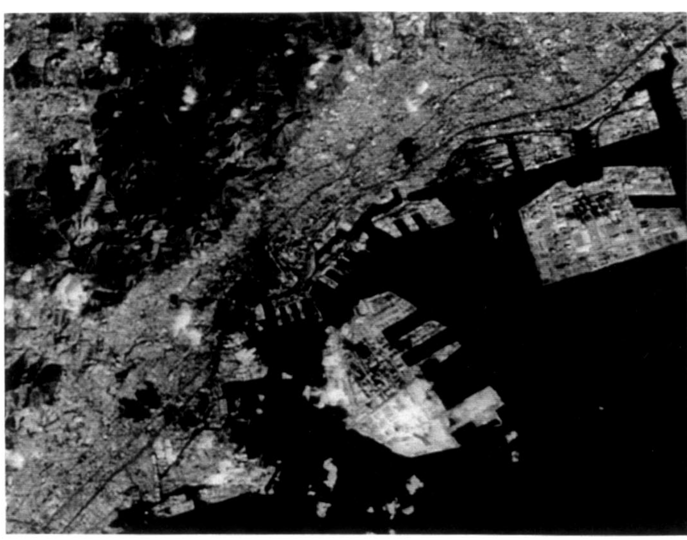

Fig. 8 Infrared rays image of Kobe City region after the earthquake [1/24/95]

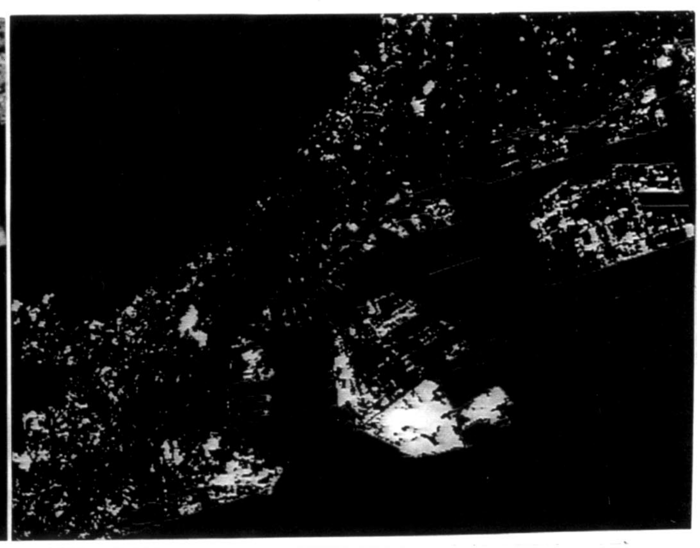

Fig. 9 Analyzed image of Kobe City and vicinity after the earthquake [Band 7 >27]

In the case of Kobe City it is also possible to compare the ground information before and after the earthquake by comparing the satellite images taken on March 23 1993 before the earthquake with those after the earthquake. The extracted region before the earthquake and after the earthquake, Fig. 9, are compared and the difference is shown in Fig. 10. There are three kinds of classifications in Fig. 10, the lightest color shows the extracted regions before the earthquake, the next deep color shows the extracted regions after the earthquake and the deepest color show the extracted regions

Table 1 Advantages and disadvantages of remote sensing data

Satellite	Sensor	Date	Resolution	Wave length	Advantages	Disadvantages
NOAA	AVHRR	1/18	1km	Visible ray	Taken every day	Low resolution
MOS-1	MESSR	1/19	50m	Visible, Infrared	Shot time delay	Low resolution
SPOT-2	XS	1/20	20m	Visible, Infrared	High resolution	Labor data prossesing
LANDSAT5	TM	1/24	30m	Visible, Infrared Thermal infrared	Wide wave band	Long time delay

common to before and after the earthquake. The extracted region where the level value rose after the earthquake lies in the deeper color part. The change is considerable in Port Island and Rokko Island which is probably a result of changes in the ground surface arising from the earthquake. However, in the southern part of Port Island the land was reclaimed two years ago and its image shows as light.

Fig. 10 Comparison of analyzed images before and after earthquake

CONCLUSION

Ground information read from remote sensing data gathered by a satellite were processed to obtain images which were compared with maps of liquefaction distribution in past earthquakes. Regions with high liquefaction potential were extracted by using Band 7 image which corresponds to infrared rays of Landsat TM sensors. A threshold value was used to make a image binary for extracting the liquefied region. The threshold value was selected according to the place and the season. The processed images were seen to correlate well with many liquefied regions identified by field surveys. However, there are some areas which have a low correlation. In some cases, the correlation was seen to improve by using Band 6 image.

There are still a few problems with the use of remote sensing data and the limits of their use in image analysis are:

1. The threshold value to extract region changes from place to place and is therefore not uniformly provided for.
2. It is not possible to analyze liquefaction in regions where the ground is densely covered.
3. Ground information is obtained only on the shallow surface layers and liquefaction cannot be understood directly based on this information.

The analysis of the liquefaction potential using remote sensing data requires to be more accurate than present techniques. Also, more field surveys need to be made to provide more case studies to overcome the above mentioned problems.

REFERENCES

Goto,K., M.Sakamoto, Y.Sawazono and I.Tohno (1986). Characteristic of Landsat data of liquefied ground, *Japan National Conference on Soil Mechanics and Foundation Engineering*, JSSMFE, Vol.21, No.2–1, 831–832.

Kubo,K.[Chairman] (1994). *Annual Report on Study of Weak Soil and Lifeline to Earthquake*, Association for the Development of Earthquake Prediction, 39–92.

Kurita,T., H.Kishida and K.kitayama (1990). Characteristics of Landsat TM data band in liquefied region, *Japan National Conference on Soil Mechanics and Foundation Engineering*, JSSMFE, Vol.25, No.1, 119–120.

Research committee of using remote sensing to soil engineering (1993). *Symposium on Using remote sensing data in ground engineering*, Japanese Society of Soil Mechanics and Foundation Engineering(JSSMFE), pp.226.

Shima,H. (1985). Application of remote sensing technology to ground investigation, *Photographic Survey and Remote Sensing*, Vol.24, No.2, 15–25.

Tohno,I. (1985). Appendix – Liquefied map, *Investigation Report on 1983 Nihonkai Cyubu Earthquake disaster*, JSCE.

Toki,S., K.Miura and S.Yamashita (1993). Outline of damage by the 1993 Kushiro–Oki Earthquake, *Tuchi To Kiso*, JSSMFE, Vol.41, No.6, 5–10.

Tomatsu,Y., H.Koshiishi, Y.Sato and K.Hosokawa (1992). Basic research to estimating of liquefaction risk using by remote sensing data, *Annual Conference of Japan Society of Civil Engineers*, JSCE, Vol.47, No.1, 80–81.

Tomatsu,Y., Y.Sato, S.Takada, and M.Fukuda (1993). Distribution of Liquefaction and Ground Freezing Surrounding Kushiro–city at the Time of Kushiro–oki Earthquake –Risk analysis of Liquefaction use of remote sensing data–, *JSCE Earthquake Engineering Symposium*, JSCE, No.22, 407–410.

Tomatsu,Y. and Y.Sato (1994). Case studies on hazard estimation of liquefaction using remote sensing data, *9th Japan Earthquake Engineering Symposium*, Science Council of Japan, Vol.1, 127–132.

Tomatsu,Y. Y.Sato and T.Akashi (1995). Characteristics of the remote sensing images in the liquefied regions, *First International Conference on Earthquake Geotechnical Engineering*, Japanese Geotechnical Society, Vol.1, 25–30.