4. DEVELOPMENT OF THE PROCESSING SYSTEM OF THE MICROWAVE IMAGING RADAR DATA FOR THE PRACTICAL USE IN THE CONSTRUCTION FIELD

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Abstract: The objective of this study is to develop the processing and analysis system of the microwave imaging radar (SAR:Synthetic Aperture Radar) data for practical use in the construction field. As for the feature of SAR, the observation has been carried out in all weathers and day and night. But there are several problems in case of applying the SAR data to the construction field. For instance, SAR data contains geometric and radiometric distortion, such as the foreshortening, layover and shadow in mountainous areas. This system consists of the five characteristic systems, which is called "Format conversion system", "Preprocessing system", "Image analysis system", "Postprocessing system" and "Image display system". To evaluate the efficiency of the developed system, the liquefaction potential assessment integrating the SAR data and Geographical Information were executed. It should be confirmed that this system is very useful not only for an examination of the applicability of the SAR data but also for a presentation of the technical problems and requirements from the viewpoints of users in the construction field.

Key words: *synthetic aperture radar data (SAR data), image processing and analysis system, geographical information, data sets*

1. Introduction

Microwave remote sensors mounted on artificial satellites, designed for all-weather around-the-clock use, are effective in periodic measuring operations. The optical sensor is liable to be influenced by the weather on average, measuring at an interval of about 20 days can produce no more than two to three full scenes of fine weather data. This has long been discussed as an impediment to the use of satellite data for periodic surface observation. Microwave imaging radar systems, typified by the SAR (Synthetic Aperture Radar), are hard to be influenced by the atmosphere, as well as are capable of all-weather around-the-clock use. In the field of resource development, this type of radar has long been studied and has produced a wealth of results. However, there has been an unexpectedly small number of applications reported in the field of construction.

Since microwave imaging radar technology can be used to observe land use in a time series manner through periodic data observation, it is expected to be useful for land use plan. It would also be beneficial to compare and examine data observed before and after the occurrence of a natural disaster.

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While there have been reported a lot of research done for the use of data with focus on changes with respect to time. But little work has been reported as to making an algorithm that can make the most of microwave imaging radar data with respect to periodicity.

This is due primarily to the complexity of preprocessing. Data received by SLR (Side Looking Radar) systems in particular involve distortions attributable to topographic rising and falling[1]. SAR Images are useful for making out topographic features, land forms, etc. But data calibrated against the appropriate map coordinate system is needed for application in the field of construction. It is also necessary to eliminate or decrease speckle noise in SAR images.

The intensity of radar wave reflection is affected heavily by the dielectric and surface characteristics of the target to be observed. The surface of land is overlaid with diverse coverings. Active research is underway to shed light to how they bear on the scattering characteristics of microwaves[2].

There are plans to develop the multi-polarization and the multi-parametric radar in the near future. At present microwave imaging radar data is used to examine a photo-interpretation of topographical information. It is desired to build a system capable of analyzing and verifying the effectiveness of backscattering coefficients.

As an integrated system for the application of SAR data, the processing and analysis algorithms were developed in the field of construction.

2. Basic System Design

(1) Background of the system development

In recent years, diverse image processing and analysis software products have been developed and offered to handle remote sensing data and geographical information. There are great needs for using SAR data on a yearly, seasonal or monthly basis. It is no exaggeration to say that there exists no generally available system capable of speedily processing and analyzing SAR data. Development of a system, which is capable of accumulating and managing data including analysis results, is desired.

Table 1 gives a list of areas expected to benefit from periodically collected SAR data. In the area of construction, periodically observed data is expected to be used to analyze and monitor changes in cities and environments. The need is urgent to develop a system that can verify the effectiveness of SAR data for specific uses. In this study, a processing/analysis system to help establish effective SAR data utilization technology in the area of construction was developed.

(2)Requirements for the system

Three requirements for our system development were set as follows:

1)Making it easy to perform basic image processing and analysis, e.g., conversion to backscattering coefficients of SAR data and preparation of land cover classification images. The system should also be flexible enough to process and analyze data from multi-parametric radar expected to be developed in the near future.

2)Making it possible to efficiently store and manage a large volume of periodical observation data.

3)Allowing the user to concentrate on analysis work without concern for arranging data such as SAR data and geographical information.

(3)System configuration

Figure 1 shows the configuration of the system in this study. A variety of functions are required of each subsystem to handle SAR data. These function groups are given in Table 2.

a)Format conversion system

Converts distributed SAR data into a standard format capable of handling by the system.

b)Preprocessing system

Table 1 Expectation Field Applying SAR Data

Fields	Content
①vegetation	·monitoring of vegetation translation ·observation on biomass ·vegetation classification with seasonal variations ·environmental control and management
②Land use	·extraction of changed area ·monitoring of environment
③slope failure and landslide	·landslide interpretation with regular observation ·feature extraction before and after disaster
④liquefaction	·geomorgraph interpretation with regular observation ·feature extraction before and after disaster
⑤flood disaster	·observation on flood prome area
⑥volcanic activity	·topographic survey with interferometry
⑦earthquake	·urgent observation ·topographic survey with interferometry

To obtain SAR images requires performing special high-speed data processing including range compression, azimuth compression and multilook processing for level 0 data (raw data). At present, the Earth Observation Center, National Space Development Agency, supplies data after image reproduction processing (level 2.1 data). Usually, the user depends on data processed for image reproduction. But geometric and radiometric distortions are not completely eliminated from the data. This poses great inconvenience in combination with optical sensor data and geographical information.

These distortions are due mainly to the observation principle of SLR (Side Looking Radar). To provide correction processing, involves handling data between level 0 and level 2.1 image reproduction processing. Since currently available data is limited to level 0 and level 2.1, the user has no choice but to utilize either an appropriate image reproduction function or data with distortions contained[3].

Considering the limited availability to general users of processing and analysis systems and difficulty in obtaining a variety of technical information associated with image reproduction processing, it is essential for the system to provide a capability to DTM-based correction function, as well as the conventional GCP-based correction function. SAR data also contains speckle noise resulting from the coherency of radar waves. To eliminate or reduce the noise, various types of filtering have been developed. It is necessary to provide our system with different types of filters such as the median filter, the

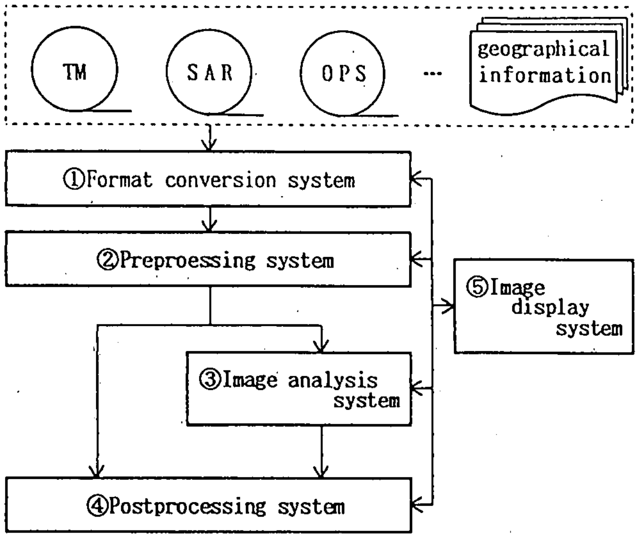

Fig.1 Configuration of the system

Lee filter, the edge preserving filter and the Kalman to examine data for quality and specific uses.

c)Image analysis system

Provides a variety of analytical functions to help use SAR data effectively in the field of construction. It is important to provide a variety of analytical functions to permit using SAR data alone and also in combination with geographical and other information. The seven major functions of this system are shown in Table 2.

d)Post-processing system

For practical use of SAR data, it is essential to provide functions to permit overlaying topographical maps with output images after analysis, preparing explanatory notes, etc.

e)Image display system

Analyzing SAR data requires displaying original data and backscattering coefficient images as well as analysis results and evaluation criteria. It is also important to provide a digital photograph output device or the like so that the user can carry output images.

3.Developing Processing and Analysis Algorithm

The system developed by ourselves has a good number of specialized functions. Because of limitation of space, the processing to correct geometric distortions and liquefaction potential assessment as typifying a preprocessing system and analysis system, were only explained respectively.

(1)Geometric distortion correcting algorithm

a)Problems on geometric distortion correction

Table 2 Functions of The System

System	Function
①Format conversion system	·typical format conversion
②Preproessing system	·image reproduction processing ·geometric distortion correction ·geometric distortion correction (used DTM) ·radiometric distortion ·removing / decreasing speckle noise ·backscattering coefficient calculation ·image quantization
③Image analytical system	·making land cover classification image ·multi-temporal analysis on the land cover change ·slope stability evaluation ·liquefaction potential assessment ·vegetation assessment ·dynamic flood assessment ·interferometry
④Postprocessing system	·overlaying map ·making introductory
⑤Image display system	·displaying of the analysis result ·displaying digital photograph

One of the most complicated preprocessing in using SAR data is the correction of geometric distortions. This involves two major factors, namely, the problem of GCP selection and the problem of interpolation.

Specifically, the former is attributable to the fact that there is no well-defined criteria for selecting GCP from images containing terrain distortions. The latter means the need for performing interpolation for areas in which foreshortening or layover occurred. In connection with areas for which no data was observed, there is a question whether or not it is appropriate to handle them in analysis after performing interpolation and rearrangement.

b)Geometric distortion correcting algorithm

Figure 2 shows DTM-based algorithm for correcting geometric distortions proposed in this study.

1)Selection of the test area: To select areas to use from a full scene and cut out the images concerned.

2)Identifying mountainous areas and flat areas: To classify the areas to use into flat areas and mountainous areas. In this algorithm, it applies conventional GCP-based correction processing to the former but DTM-based correction processing to the latter. It is known from experience that complex DTM-based correction is unnecessary for flat areas. In this paper, the conventional GCP-based correction processing is not explained.

3)Selection of GCP : In ordinary, geometric

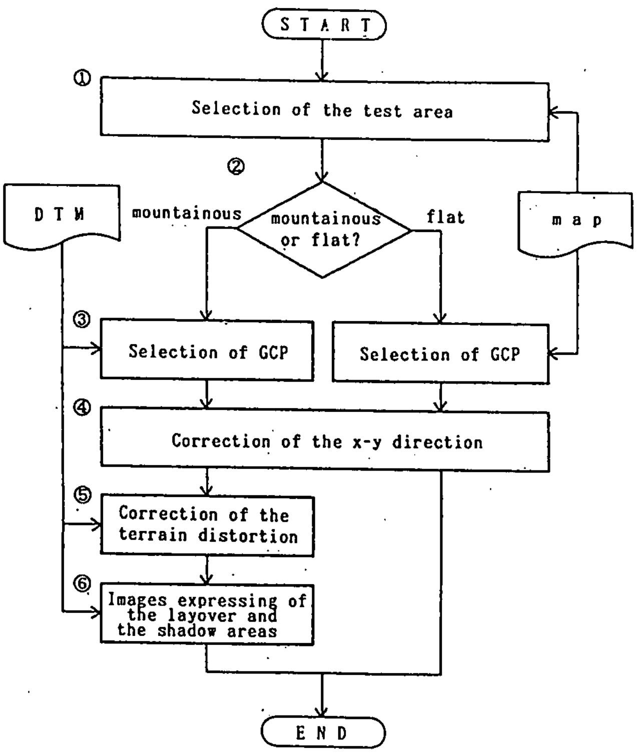

Fig.2 Procedure of the geometric correction

correction processing requires entering GCP coordinate values from the topographical map. With radar distortion correction, positioning with DTM needs to take place with high precision. This requires obtaining GCP coordinate values from a slant range image prepared from DTM.

4)Correction in x-y direction: For data before terrain distortions corrected, interpolation and rearrangements are made using coordinate conversion formulas as in the case of conventional geometric distortion correction processing.

5)Correction of the terrain distortion: Terrain distortions are corrected by calculating the displacement of data from DTM. Further, in the areas where layovers or shadows were generated due to differences in height, dummy data is placed to exclude the areas from analysis.

6)Expression of the layover and the shadow areas: Research has been done on radiometric correction to eliminate the influence of topography from backscattering coefficients[3]. It is important to show data lacking areas in handling the scattering characteristics of observation objects that do not depend on the local incident angle of a radar beam.

This system displays layover and shadow areas. At the same time, it prepares a terrain distortion image for the areas in which foreshortening arose with the magnitude of distortion shown in graduation.

(2)Liquefaction potential assessment algorithm

a)Problems on liquefaction potential assessments

There are three problems in applying SAR data to liquefaction potential assessment:

1)On Microwave scattering characteristics: The scattering characteristics of microwaves are influenced by the dielectric characteristics of objects, the roughness of landcover and other factors. In actual measurement, since individual pixels can contain a variety of land covering objects, data is used while analyzing relationships between backscattering coefficients and the features of land surface.

2)On Seasonal changes: Users can examine the influence on microwaves of seasonal changes on the surface of land and determine the optimum season for SAR data observation for specific purposes.

3)On the utilization of SAR data: It is the generally employed analysis method to compare and interpret image data obtained through periodical observations. It is also important to use the data in combination with geographical information for comparison with analysis results of geometric features.

b)Liquefaction potential analysis algorithm

The algorithm to make the liquefaction potential map was shown in Figure 3 based on the Latency factor model(LF model)[4]. Table 3 gives its statistical indexes and outputs. The LF model of this algorithm employs a min-max distinguish method for use of training data based on the quantification theory[4]. In this LF model, the user uses not only geographical informations but also satellite data. The algorithm handles SAR data as one type of geographical information.

The algorithm is capable of preparing a subtracted image from more than one liquefaction potential maps obtained by applying the LF model. By preparing subtracted images using liquefaction potential maps prepared at different times of SAR data observation, it is possible to determine an optimal season for specific analysis.

In addition, using the data in combination with maps of historic liquefaction sites allows re-liquefaction related information to be extracted[5),6)]. The user can make reference to a subtracted image explanation table for each combination of liquefaction potential maps and historic liquefaction site maps.

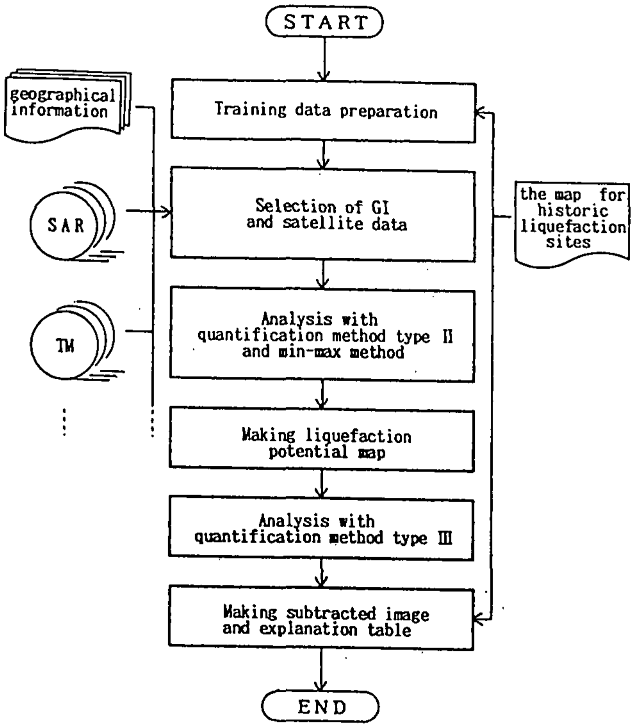

Fig.3 Algorithm of liquefaction potential analysis

4. Structure of Data Sets

In any field of data application, it is desirable for users to be able to concentrate in SAR data analysis without being bothered with troublesome data collection and processing work. The system developed in this study is flexible and expandable enough to permit accumulating and managing SAR data and numeric geographical information of observation areas as data sets each time they are processed and created[7].

As for the data set structure, two factors were examined as follows: 1) division of the data set, and 2) construction of the data set. This is summarized in Table 4 for liquefaction potential assessment as an example. Figure 4 illustrates the concept of the data set structure for easy understanding.

(1)Division of the data set

It is expected that data sets will be classified by prefecture and by assessment area. In this study, liquefaction analysis use two levels of classification, namely, 1) the prefecture level, and 2) the test field level. These are called division of the data set.

(2)Construction of the data set

In view of different types of information, data sets were classified into three as follows : 1) data sets on the relevant information (RI data sets), 2)data sets on the topographical information (GI data sets), and 3) data sets on the satellite observational information (SOI data sets).

a)RI data set: This category includes information associated with the analysis of liquefaction, including historical information of disasters recorded by individual prefectures and existing liquefaction potential maps. For test fields, support information for training data selection such as aerial photographs, historic liquefaction site maps, boring survey results and others will be accumulated for use in liquefaction analysis.

b)GI data set: This category includes geographical information to prepare liquefaction potential maps. Also included in this category are user-prepared information such as training data, liquefaction potential maps and subtracted images.

c)SOI data set: This category includes periodically observed SAR data factors and optical sensor data factors. The user can select data for the required observation timing and observation seasons. The listing of SAR specifications and periodically accumulated data is also stored as numeric and character information.

The above-mentioned data set structure will help facilitate the use of periodically observed data on the part of the user. It also makes easy to add new data and update existing data. The concept of object-oriented database management system is employed because managing data sets involves a large variety of information as classified by area, sensor, observation timing, etc.

Table 3 Indexes and Out put Maps

statistical index	output
① partial correlation coefficient	⑤ liquefaction potential map
② range	⑥ scatter diagram on the sample score
③ category score	⑦ scatter diagram on the category score
④ ratio of agreement	⑧ subtracted image and explanation table

5. Cases of Application

Cases of application of this system are listed in the function groups of the analysis system shown in Table 2. It is expected that cases of application will be added through the testing of SAR data for commercial use. In this paper, a case of liquefaction analysis is shown as follows:

(1)Preparing a liquefaction potential map

Table 4 Division of Data Sets

(a) RI data sets (data sets on the Relevant Information)

division of the data sets	image information	numerical value and text information
prefecture	·liquefaction potential map ·affected area map etc.	·reference data list (paper, report, etc.)
test field	·aerial photograph ·map for historic liquefaction sites etc.	·N value ·grain size distribution ·thickness of saturated sand etc.

(b) GI data sets (data sets on the Geographical Information)

division of the data sets	geographical information	user's information
test field	·geomorphological land classification ·soil ·subsurface geology ·slope classification ·elevation etc.	·training data ·liquefaction potential map ·evaluation (subtracted image, etc.)

(c) SOI data sets (data sets on the Satellite Observational Information)

division of the data sets	image information	numerical value and text information
test field	·backscattering coefficient image ·SAR image ·land cover classification map etc.	·sensor (radar) spec. ·data list

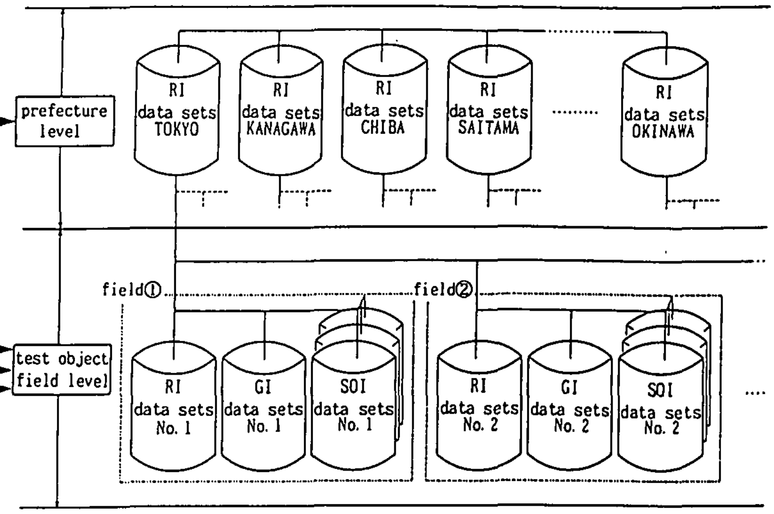

Fig.4 Concept of the management for data sets

a)Selecting data sets: As a test site, a downstream area of River Tone which suffered heavy damage including the collapse of houses due to liquefaction caused by the Chiba east offing quake in 1987 was selected.

b)Displaying geographical information: The user displayed the geographical information, stored and sorted in the system, on a CRT display terminal to check the distribution characteristics of the data.

c)Selecting training data: It is possible for the user to examine prepared historic liquefaction site maps as the result of site surveys and select training data from the areas where liquefaction occurred.

d)Selecting geographical information and SAR data: Various factors can be selected from basic survey data on the land classification, image information from actual vegetation maps and topographic information prepared from DTM.

e)Quantification method type II and min-max distinguish method: After factors are narrowed down through quantification method types II and III, a liquefaction potential map is prepared based on the results of quantification method type II and min-max distinguish method[8]. Further, the data structure is analyzed using quantification method type III.

f)Displaying the liquefaction potential map: The above-prepared liquefaction potential map is displayed on a display terminal. Figures 5 and 6 give sample maps displayed using geographical information alone (liquefaction potential map (a)) and using SAR data factors in addition to geographical information (liquefaction potential map (b)), respectively. Pressing the appropriate function key permits retrieving the statistical index or the result of data structure analysis shown in Table 3.

g)Preparing a subtracted image: There may be diverse combinations of images to prepare a subtracted image. Here, a sample system output for the following two cases of subtracted images is explained:

1)Comparison with liquefaction potential maps: By pressing the function key Subtracted Image shown in Figure 6, it is possible to prepare a subtracted image for liquefaction potential maps (a) and (b). This permits verifying the effect of application of SAR data factors in a liquefaction analysis.

2)Comparison with the historic liquefaction site maps: Figure 7 gives a display sample of a historic liquefaction sites map. Pressing the function key causes the system to generate subtracted image for the liquefaction potential maps shown in Figures 5 and 6.

h)Displaying a subtracted image and an explanation table: As shown in Table 5, the system outputs historic liquefaction site maps and an explanation table for the subtracted image generated from liquefaction potential maps (a) and (b). By using both subtracted image and explanation table, it is possible to make risk-side/safe-side assessment in the following manner:

Risk-side assessment means assessing places determined to have risk on liquefaction potential map(a) and have no risk on liquefaction potential map(b), and indicated as having liquefaction records on the historic liquefaction site map. These areas ought to have been regarded as having risk but were

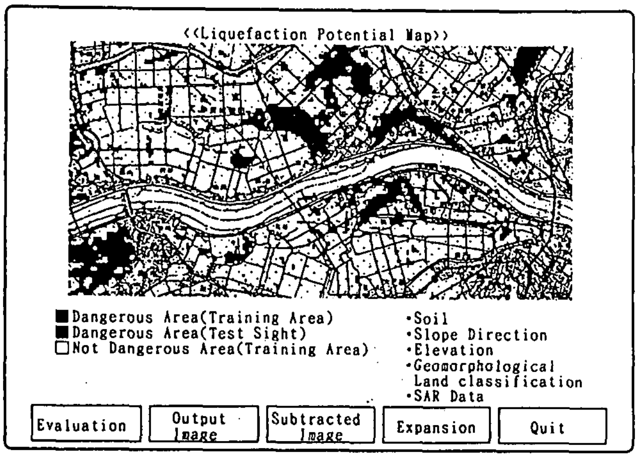

Fig.5 Example of liquefaction potential map(a)

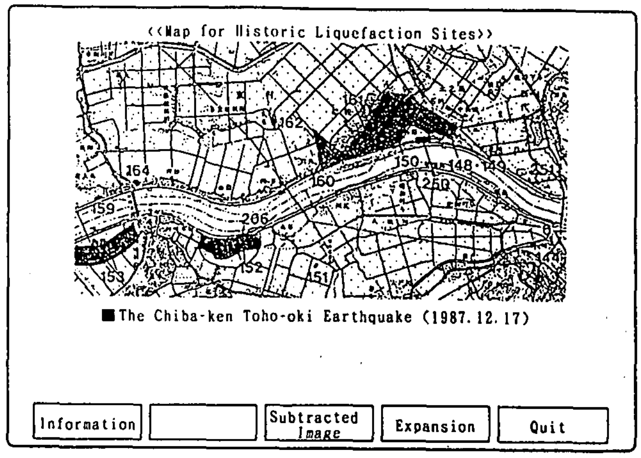

Fig.7 The historic liquefaction site map

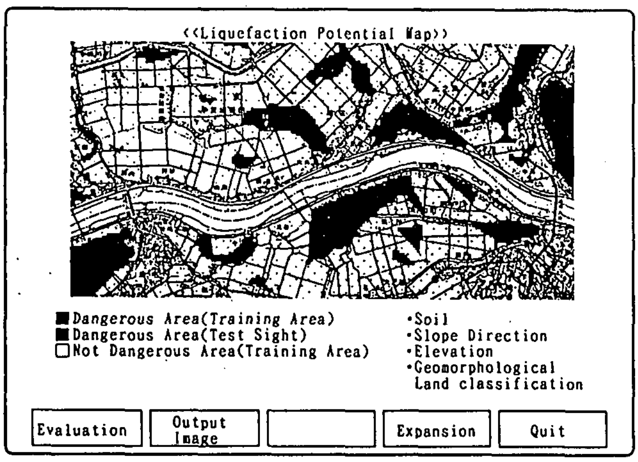

Fig.6 Example of liquefaction potential map(b)

actually determined to be not risky thanks to the use of SAR data factors. That is, SAR data contributed toward eliminating any risky place. This can be judged as risk-side assessment, providing support information that helps selecting areas for boring survey.

Safe-side assessment means assessing places determined to have risk on liquefaction potential map(a) and have no risk on liquefaction potential map(b), and indicated as having no liquefaction records on the historic liquefaction site map. These areas ought to have been regarded as having no risk but were actually determined to be risky thanks to the use of SAR data factors. That is, SAR data contributed toward extracting any risky place. This can be judged as safe-side assessment, providing support information that helps selecting areas with the least possible risk potential for future land utilization.

Table 5 Interpretation on The Subtracted Image

	the map for historic liquefaction sites	discriminated results		color on the subtracted image	supporting information for liquefaction potential assessment	
		case(a)	case(b)		explanation	evaluation
training data	H	D	D	red	most dangerous area on "re-occurrence"	-
			N	sky blue	SAR data influences the result of no danger of "re-occurrence"	dangerous side
		N	D	brown	SAR data influences the result of danger of "re-occurrence"	safe side
			N	blue	SAR data influences the result of no danger of "re-occurrence"	dangerous side
test site data	H	D	D	green	dangerous area on "re-occurrence"	-
			N	yellow	SAR data influences the result of no danger of "re-occurrence"	dangerous side
		N	D	pink	SAR data influences the result of danger of "re-occurrence"	safe side
			N	gray	SAR data influences the result of no danger of "re-occurrence"	dangerous side
	NH	D	D	olive	SAR data influences the result of danger of "occurrence"	safe side
			N	orange	SAR data influences the result of no danger of "occurrence"	dangerous side
		N	D	purple	SAR data influences the result of danger of "occurrence"	safe side
			N	white	not dangerous area on occurrence	-

Notes 1)"H" : the area indicated as having liquefaction records.
2)"NH" : the area indicated as not having liquefaction records.
3)"D" : the extracted area in danger of liquefaction through the discriminated results.
4)"N" : the extracted area in no danger of liquefaction through the discriminated results.

6. Concluding Remarks

(1)Results of this study

The following three achievements were attained:

a)A variety of function groups were prepared for building an image processing and analysis system to use SAR data primarily in the area of construction.

Table 6 Technical Problems on The Application of SAR Data for Liquefaction Potential Assessment

(for liquefaction phenomena and liquefaction potential assessment)

items			problems	requirements
processing/analysis	preprocessing	geometric correction	·permitted accuracy on the flat areas and the mountainous areas	·systematization of the geometric correction
		noise reduction	·the choice of the method	·adoption of simple method and systematization
	analysis	backscattering coefficient	·the relation between test field condition and backscattering coefficient	·collection and accumulation of ground truth
sensor		①off-nadir angle	·influence on incidence angle ·dealing with foreshortening and layover area	·examination of 20~40 degree
		②frequency	·effect of the difference in frequency on the analysis accuracy	·examination using L. C. X band data
		③polarization	·effect of the difference of the like and cross polarization on the analysis accuracy	·examination using HH. HV. VH. VV data
		④swath width	·observation on wide area and narrow area	·about 20~100km
		⑤ground resolution	·speckle noise ·effect of the ground resolution on the analysis accuracy	·about 20~30m ·It's not necessary for liquefaction potential assessment to use very high resolution radar.
		⑥observation frequency	·periodic observation and variance observation	·periodic observation: 2 times per month ·variance observation: 1 time per day

Work is under way to further improve and add to the function groups for better utilization in the area of construction.

b)With this system, it is possible to verify SAR data for effectiveness in various fields of application. The algorithm developed for the system is expandable enough to handle multi-parametric radar data expected to become available in the near future.

c)Methods for data accumulation and management were prepared incorporating the concept of data set. This resulted in a practical system configuration that allows the user to benefit from SAR data obtained from around-the-clock all-weather periodic observations without concern for bothersome data processing work.

(2)Prospective on the use of SAR data

While making efforts to expand the scope of application of SAR data using this system, it is also recommended that users identify and submit observation requirements, issues associated with processing and analysis, etc[8]. Table 6 lists issues and requirements related to data utilization techniques identified through operating this system and verifying the effectiveness of SAR data. Issues and requirements are currently being added to the contents of Table 6. Through arranging issues and requirements as shown in Table 6, the system will be expected to further expansion. In the near future, this kind of approach should be expected to promote the spread of practical use of the SAR data in the construction field. Furthermore, the approach of this study should be a good guide line for the future development on a new sensor.

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