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DEVELOPMENT OF EARTHQUAKE-PROOF PERFORMANCE EVALUATION PROGRAM FOR UNDERGROUND TELECOMMUNICATION FACILITIES

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SUMMARY

During the Hyogo-ken Nanbu Earthquake, NTT's underground telecommunication facilities suffered only relatively light damage. However, because the underground telecommunication facilities are spread out over a large area, and because of the difficulty of visually checking the damage, a significant amount of time was required to check the facilities. Based on this experience, we have developed the Access Network Underground Route Earthquake-proof Performance Evaluation Application. This is a software application for MARIOS which is NTT's internal basic infrastructure planning management system. This application is a tool for evaluating the earthquake withstanding capability of underground telecommunication facilities based on various data pertaining to earthquakes before an earthquake occurs and it can also be used to predict macro-level damage following an earthquake. This application was introduced in a beta version in April 1998.

INTRODUCTION

Telecommunication facilities have become increasingly important as a basic infrastructure with the growth of computer networks in recent years. Thus it is very important that telecommunication facilities be kept safe and reliable. This need of society has increased rapidly after the Hyogo-ken Nanbu Earthquake.

The telecommunication facilities have been designed to have a certain level of aseismic capability, but ground conditions vary widely at installation sites. Thus there is a possibility that conduit will be subject to earthquake forces exceeding their design strength. If a major earthquake were to occur, a certain level of damage to facilities would be inevitable. Therefore, it is important to be able to determine the weak points in facilities before an earthquake, and to quickly determine the extent of damages immediately after an earthquake.

Immediately after the Hyogo-ken Nanbu Earthquake, it took a long time to determine the extent of damages because of a lack of information. This led to difficulties during the restoration phase. This report introduces the Access Network Underground Route Earthquake-proof Performance Evaluation Application (hereinafter referred to as "AP") which we have developed based on this experience. This AP is a tool for evaluating the earthquake withstanding capability of underground conduit facilities based on various data pertaining to earthquakes, ground, and facilities before an earthquake occurs. Fig.1 shows the role of this AP. Following an earthquake, it can be used to predict macro-level damage. Under normal conditions, we use this tool to conduct advance evaluations in relation to overall facility plans and renovation plans. When an earthquake occurs, we use it for purposes such as estimating restoration costs and resource introduction planning based on macro damage predictions.

FORMER TOOL

NTT previously developed the Telecommunication Seismic Accident Prediction Program (TEL-SAPP), a program which determines factors such as the reliability of conduits and underground cables during an

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earthquake, calling conditions on customer routes, and the extent of damages. This program was introduced in 1988 [1]. TEL-SAPP was developed for the same purpose as the new AP. TEL-SAPP made it possible to obtain highly precise evaluations with less work.

Unfortunately, TEL-SAPP had a number of problems, such as the following: 1) because it did not use the same data formats as existing DBs, it was necessary to manually enter all facilities data. 2) It was necessary to collect and enter a considerable amount of boring data in order to perform ground liquefaction judgments. 3) For the reasons presented above, an evaluation of the accommodation area of a single facilities center building required approximately three months and more than about 25 thousand US dollars. As a result, the program never gained widespread use.

Following the Hyogo-ken Nanbu Earthquake, there was a need to be able to evaluate the earthquake withstanding capability of all facilities at low cost and in a short period of time. As a result, it was decided to develop an AP on MARIOS (described below).

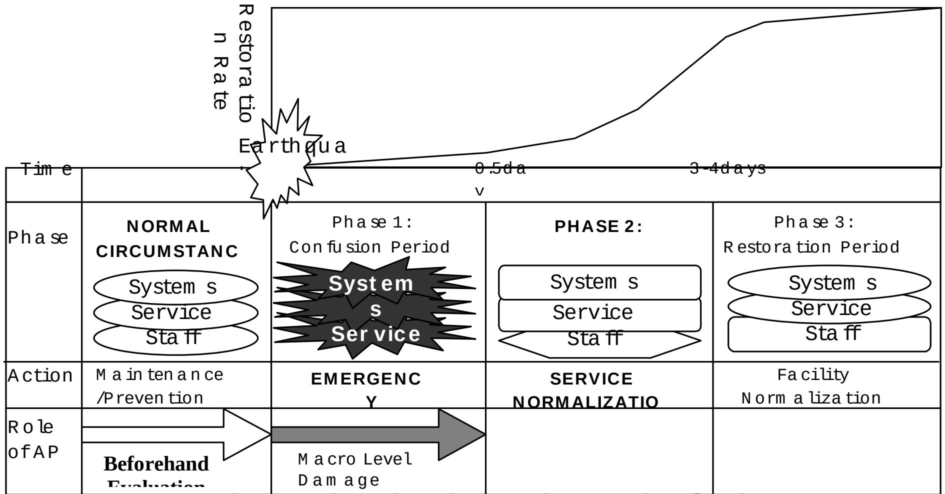
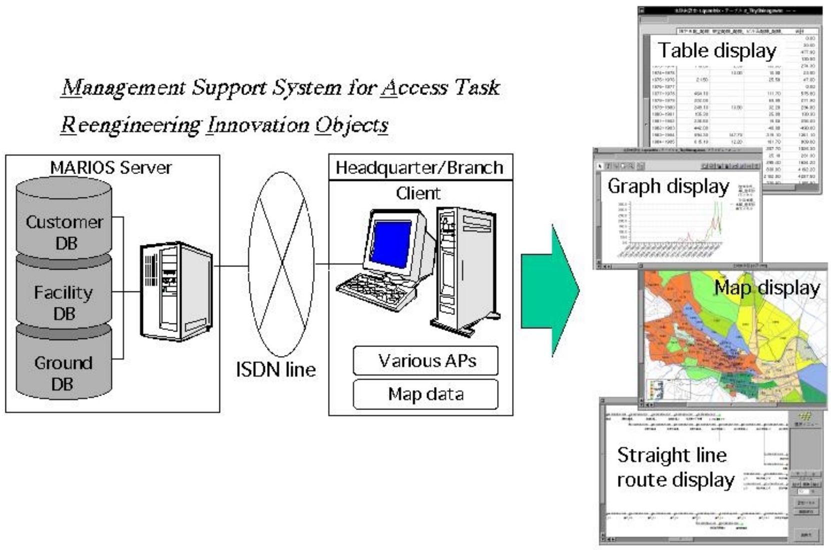


Fig.1 Earthquake Disaster Phase and Role of



OVERVIEW OF MARIOS

The Management Support System for Access Task Reengineering Innovation Objects, or MARIOS, is an information analysis system which supports management tasks such as determining the current condition of facilities, developing the overall design for basic infrastructure facilities and so on. An overview of MARIOS is shown in Fig.2. MARIOS can be used to process and work on various types of data, such as customer DBs, facility DBs, and map DBs, in an integrated and multifaceted manner. Processed data can then be displayed in a variety of forms, including distribution area maps, route diagrams, graphs, and tables. In addition, users can create and renovate applications since the operating system is based on object oriented programming. MARIOS is based on a client-server design, whereby clients situated at branch offices and outlets are linked with DB servers via digital public lines. Currently some 300-client terminals are installed throughout Japan and are used on a daily basis.

OVERVIEW OF EARTHQUAKE-PROOF PERFORMANCE EVALUATION APPLICATION

Developing an AP to run on MARIOS makes it possible to display maps and routes since these are basic functions in MARIOS. At the same time, because the facility DBs are already installed, the amount of work involved is much less than the requirements for TEL-SAPP. In addition, we decided to supplement the MARIOS DB group by developing and compiling an additional ground information DB, containing data such as boring data and soil test data. The compilation of this DB reduces the amount of work involved in collecting and registering ground data for earthquake withstanding capability evaluations. An overview of the AP is illustrated in Fig. 3.

In developing the AP, we established the following performance requirements:

1) The ability to display color-coded damage probabilities for underground conduits in span increments on a map. 2) The ability to estimate the amount of damage to facilities and general restoration costs.

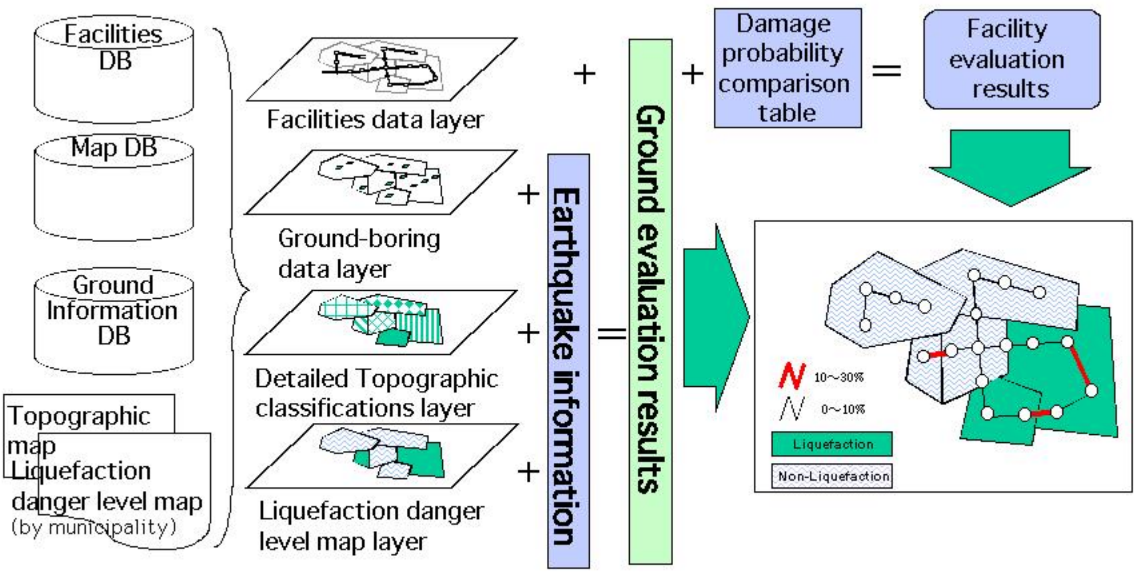


Fig.3 Overview of the AP

Evaluation Process Flow

Fig. 4 presents an overview of the evaluation process flow. An analysis of the emergency survey on underground conduit facilities conducted immediately after the Hyogo-ken Nanbu Earthquake showed that the main factors related to damage in underground conduit facilities are whether or not the ground liquefied, the earthquake scale, the pipe type, and passage years since the facilities were installed. Thus the AP is broadly split between a ground evaluation part and a facility evaluation part. The main features of the evaluation process flow with this AP are as follows:

1) The overall liquefaction judgment is made using detailed topographic classifications, boring data and liquefaction danger level maps prepared by municipalities. 2) Ground evaluations are made based on the fixed distribution areas that NTT uses in managing the communications network.

Details are presented in the following sections.

Initial Settings

In initial settings, the data to evaluate the ground are set or processed and registered.

Detailed topographic data

At an initial stage of development, we overlapped a fixed distribution area map for the facility building area and a topographic classification map to read and register detailed topographic classification data for each fixed distribution area. Because the operator had been doing this work by hand work, it took long time. Moreover, it was thought that the individual variation appeared in data. As a solution of this issue, we decided to use numerical geographic information data provided by the Geographical Survey Institute. Since this data is a mesh unit, and the geographical features of each mesh shows the overall tendency, it is not suitable to use them for liquefaction judgment as they are. So we converted this data in consideration of using it to judge liquefaction [3]. Refer to the bibliography for details.

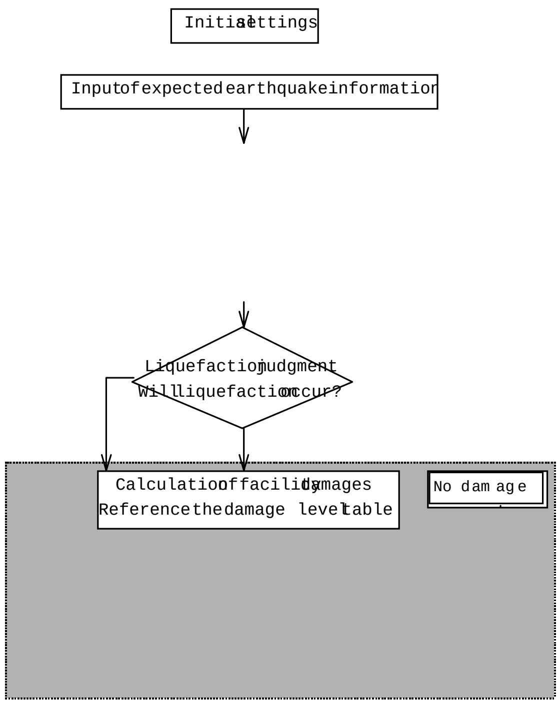


Fig.4 Overview of Evaluation Process

Boring data

The ground information DB is accessed to extract boring data for the facility building area in order to define the relationship between the fixed distribution areas and the boring data collected for them. Ground classifications are made using N values of boring data. It should be noted that this is the operation that does not involve manual tasks; the user simply clicks buttons with the mouse to process the data automatically.

Data provided by the municipalities

The fixed distribution area map is stacked together with a map containing earthquake intensity estimates and a map which classifies the liquefaction danger levels in two or three levels prepared by the municipality where the facility building is located. The operator then enters the liquefaction danger level and the estimated earthquake level for each fixed distribution area.

It is not necessary to enter all three types of data; just entering one type can make a liquefaction judgment.

Entry of Earthquake Information

The list of past large-scale earthquakes and assumption earthquakes that each municipality is examining are prepared in the program. When the earthquake to be evaluated is selected from this list, the earthquake name, epicenter position, epicenter depth, magnitude, and earthquake type are displayed. These items can be also input manually, so when estimating damages after an earthquake occurs, data released by the Meteorological Agency are entered. The earthquake data is registered in the database.

Earthquake Scale Estimation

The earthquake scales (PGA, PGV, instrumental seismic intensity) are presumed by the distance attenuation formula after the distance from epicenter position to each bore investigation position or fixed distribution position is calculated. We are using the formula shown below (Formula 1), which was presented in 1997 by

Yamazaki et al [5]. In the equation, “y” shows the earthquake scale, “r” shows the distance from epicenter, “h” shows the depth of epicenter and “M” shows the magnitude. “b_1”, “b_2”, “b_3” and “b_4” are parameters given by the earthquake type.

And “c” is a point coefficient given by the ground condition.

$$\log y = b_0 + b_1 M + b_2 r + b_3 \log r + b_4 h + c_i \qquad (1)$$

Liquefaction Judgement

In judgments made using liquefaction danger level maps, detailed topographic classifications and boring data with this AP, the overall liquefaction judgment falls onto the highest danger levels.

When liquefaction danger level maps are used, the results judged by the operator and entered for each fixed distribution area are used directly as judgment results.

When using detailed topographic classification data to make a judgment, “liquefaction” and “non-liquefaction” are judged by the combination of PGV and liquefaction level of each terrain type. Table 1 presents the relationship between terrain type and liquefaction level.

Table 1 Relationship Between Terrain Type and Liquefaction Level

Liquefaction level	Description (Liquefaction when)	Terrain type used in liquefaction predication
1	PGV 15kine	gradual slopes at edges of dunes, low ground between dunes, old canals,
2	PGV 25kine	sandbars, deltas, embankment, flood plain, etc.
3	PGV 35kine	Dunes, gradual alluvial fans
4	Low possibility	plateaus, terraces, alluvial fans, hills, etc.

When using boring data in the ground information DB to make a judgment, the necessity of providing a liquefaction judgment is determined. And then the FL value and PL value are calculated [2]. The liquefaction judgment is processed automatically.

Facility Evaluation

Six types of facilities are evaluated: manholes, handholes, lead-in cable pipes, bridging facilities, trunk conduits, and distribution conduits. Individual facilities are divided into a number of classifications based on their structure type and the number of years since installation. The probability of damages can be estimated based on a combination of the earthquake intensity and whether or not there is liquefaction. Table 2 presents a comparison of damage probabilities in steel pipe trunk conduits. Damage probability is determined based on an analysis of damages in the Hyogo-ken Nanbu Earthquake. This figure represents an estimate of the number of pipes that will sustain damage in a given span between manholes, based on pipe type and installation year.

Table 2 Damage Probability Comparison (trunk conduits)

		Liquefaction	Non-liquefaction		
		80 PGA	400 PGA	250 PGA<400	80 PGA<250
Steel pipes	Y＜1953	0.50	0.45	0.35	0.25
	1954≦Y＜1981	0.30	0.20	0.15	0.10
	1982≦Y	0.10	0.00	0.00	0.00

A single span contains a mixture of new and old types of varying types. Thus after calculating the damage probabilities of the individual conduits, the average, maximum and minimum damage probabilities are calculated. These values are calculated automatically.

Displays

The map display function, which is a basic function in MARIOS, can be used to provide color-coded displays of fixed distribution areas in a building area based on liquefaction judgment results, earthquake intensity estimate results, and detailed topographic classification. In addition, it is possible to display a facility route diagram stacked on the liquefaction judgment results, and to display the color-coded damage probabilities for each span.

When a fixed distribution area is selected with the mouse, information such as the fixed distribution area number, liquefaction judgment results and earthquake intensity level is displayed in the window. When a span is selected with the mouse, information such as the facility name, facility distribution area, average, maximum and minimum damage probabilities is displayed in the window. A window containing detailed information such as the damage probabilities of the individual conduits, and the types of accommodated cables can also be displayed. Fig. 5 illustrates the image of evaluation results screen display.

Other Functions

The locations of major users in the facility building area can be displayed on a map. When any customer building is selected with the mouse, the conduit and manhole routes accommodating the cables installed between the facility center building and the customer building are displayed .

It is possible to calculate the approximate costs of emergency restoration and full restoration by calculating factors such as conduit repair costs, cable replacement costs and structure renovation costs based on the amount

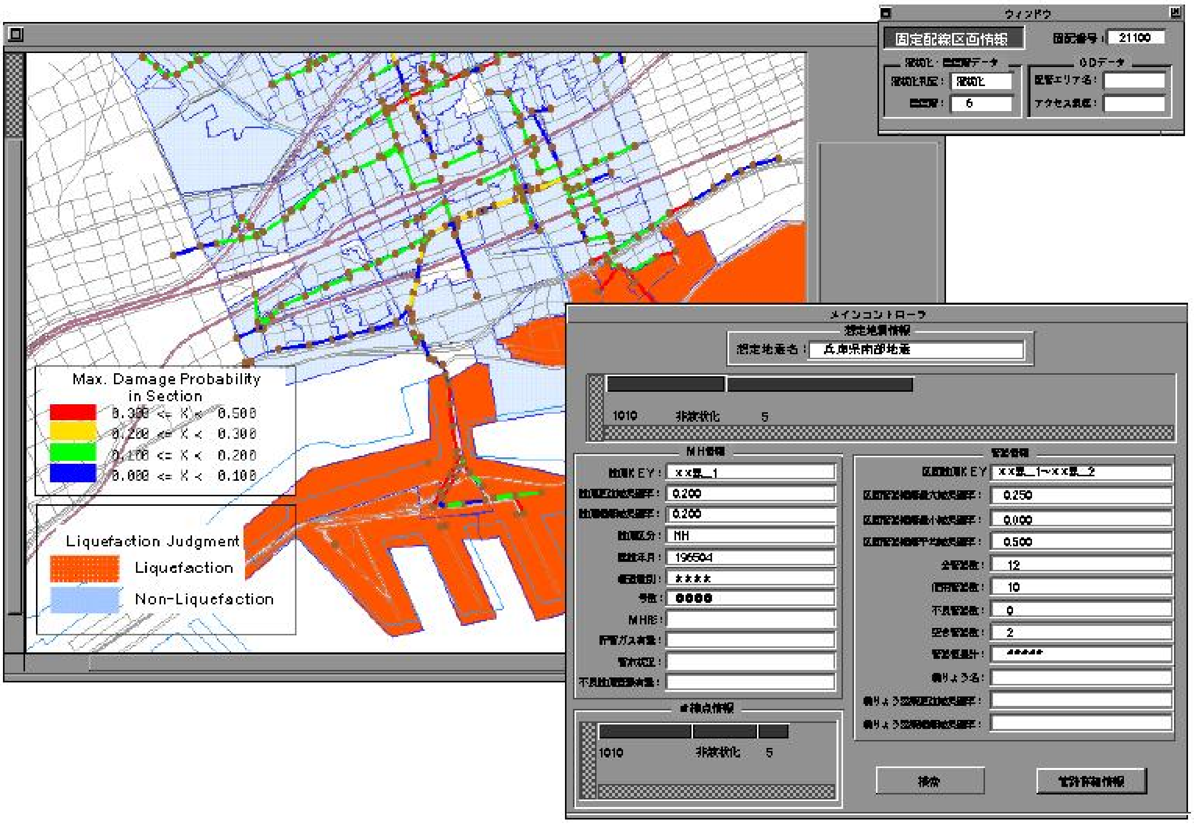


Fig. 5 Evaluation Results Screen Display

of cable and the amount of facilities predicted to have sustained damage in the building area.

FUNCTION VERIFICATION

We have not verified the evaluation and estimated accuracy enough because the earthquake of the scale that causes damage in facilities have not occurred since the development started.

Ground Evaluation

The verification result of both the earthquake scale evaluation and the liquefaction judgment functions is as follows.

Earthquake scale evaluation

Because the epicenter is set in the point, the earthquake scale evaluation becomes a result distributed in the concentric circular that centers on the epicenter. Thus, actual earthquake movement distribution and the estimated result become the a little different one when the fault that causes the earthquake is very near. It is an examination issue to input the fault as a line or plane and to evaluate the earthquake scale by using distance from the fault.

Liquefaction judgment

For liquefaction judgment verification, we compared the simulation result with liquefaction area distribution map based on investigation result by Hamada et al. In this comparison, the liquefaction area and non-liquefaction area can be evaluated by considerably high accuracy. There was a place where the evaluation result was not corresponding to an actual result in the vicinity in an old coastline. 90% or more of the liquefaction judgment was correct as a whole. The result of simulation in the Kobe city area assuming the Hyogo-ken Nanbu Earthquake is shown in Table 3, as an example.

Table 3 Comparison between actual liquefaction and liquefaction judgment in N facility center building accommodation area

		Liquefaction Judgment	
		Liquefaction	Non-Liquefaction
Actual liquefaction	100%	5	1
	50%	6	21
	0%	0	120

Facility Evaluation

The accuracy of facility evaluation has not been verified enough. The reasons are as follows: 1) the introduction of MARIOS has started in 1995. 2) The data base structure has changed several times since then. 3) The facility data has been updated several times a year. 4) The earthquake of the scale that causes damage in facilities has not occurred since the development started.

CLOSING

This report has presented an overview of the Access Network Underground Route Earthquake-proof Performance Evaluation Application, which was developed based on our experience with the Hyogo-ken Nanbu Earthquake. This AP was introduced in a beta version in April 1998. The time required to evaluate the earthquake withstanding capability of all facilities in the accommodation area of a single facility center building using this AP is approximately one month, including preparations and initial setup. The cost has also been reduced 50 to 60%. Once initial setup is completed and the ground DB is compiled, subsequent evaluations take only 30 to 40 minutes.

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