

DISASTER INFORMATION SYSTEMS AND SEISMIC COUNTERMEASURES FOR FIELD FACILITIES IN NTT

by

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ABSTRACT

NTT has experienced various disasters as a telecommunications operator, and has worked to develop a complete range of countermeasures. Particular emphasis has been placed on strengthening the early recovery systems when disasters occur in order to improve the reliability of telecommunications services. However, it was extremely difficult to understand and convey disaster conditions in the aftermath of the Hyogo-ken Nanbu Earthquake, and this delayed the start of disaster recovery activities. Drawing upon this experience, NTT is developing and introducing various disaster information distribution systems and services, and is also taking measures to improve the seismic performance of the field facilities. Of these efforts, this paper presents (1) support systems for distributing and sharing information within NTT and the NTT corporate group when a disaster occurs, (2) various systems for estimating and understanding the damage conditions of field facilities, and (3) technology for improving the seismic performance of field facilities.

Key Words: Telecommunication Facilities, Disaster Information System, Hyogo-ken Nanbu Earthquake, Fiber Optic Sensing Technology

1. INTRODUCTION

The Hyogo-ken Nanbu Earthquake was a major earthquake with local severe tremors of degree VII (JMA seismic intensity scale), and produced large-scale liquefaction in coastal areas and reclaimed lands. For these reasons even NTT telecommunication facilities were unable to remain unscathed. In addition, understanding of disaster conditions and dissemination of this information was slow in the initial stages, and this delayed the start of disaster recovery activities. At the same time, calls flooded the circuits from all over the country to Kobe asking for information, creating congestion never before experienced and reaffirming once again the importance of information during disasters. Following the Hyogo-ken Nanbu Earthquake and in consideration of the importance of tele-

communication services in an information society, NTT took the lessons of this earthquake to heart and established the Committee for Severe Metropolitan Disaster Countermeasures as an in-house committee for reviewing both hardware and software aspects in order to strengthen disaster countermeasures. This committee is further divided into 7 special committees that have conducted wide ranging investigations¹⁾. This paper presents systems that have been investigated and introduced in this manner, or which are currently under development. Table 1 shows the relationship between the basic items investigated by these committees and the systems described in this paper.

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sign of trouble. Storage batteries and emergency generators (some locations) are also installed as countermeasures against possible commercial power stoppages.

Although the Hyogo-ken Nanbu Earthquake caused some loosening and breakage of the switchboard foundation bolts and ceiling fixtures, there was no particular effect on service. However, commercial power stoppage, battery damage or discharge, and reserve engine damage all occurred at the same time, so the switchboards stopped and up to 285,000 lines were temporarily disabled and unable to make or receive calls.

The biggest problem for node system facilities is congestion so great that the number of inquiry calls exceeds the switchboard processing capacity, rendering it impossible to make or receive calls. In the aftermath of the Hyogo-ken Nanbu Earthquake, the number of calls reached a maximum of approximately 50 times the normal peak traffic, making it difficult to connect for five days. This congestion is a characteristic trouble for telecommunications facilities that does not exist for other lifelines. (Fig. 2)

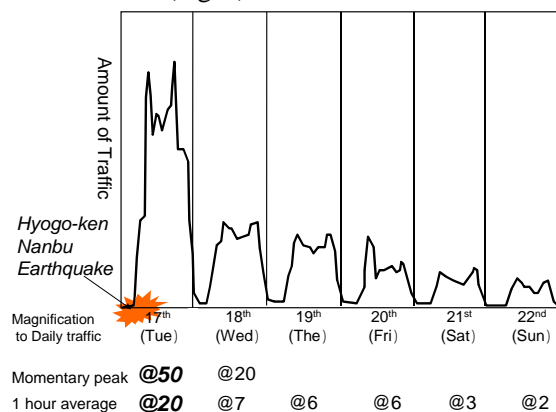


Fig. 2 Communications Congestion Immediately Following the Hyogo-ken Nanbu Earthquake

(2) Link System Facilities

a) Trunk circuit network

The trunk circuit network is comprised of wired and/or wireless sections, and has a multi-route and double-route configuration. Thus, should service be interrupted over a section, the system still allows traffic to flow by switching to the reserve system of a different route. For example, NTT maintains separate routes between Tokyo and Nagoya along the Tokaido and Chuo Route in both wired and wireless for a total of six routes. Tunnel networks have also been constructed in the central areas of Tokyo, Nagoya and Osaka to create a network with high reliability as underground facilities.

b) Access system network

The access system network is comprised mainly of metallic cables. Most of these are aerial cables, and only 21% of the total are underground cables installed in conduits and other underground facilities. In addition, portable phone systems are spreading rapidly in recent years, with most customers using a combination of wired and wireless communications. The access system network generally adopts a star (spoke) configuration, and alternate routes are not secured with the exception of certain regions or important users.

The access system network covers a wide area, and includes vast amounts of facilities and diverse facility environments. Urban areas have high concentrations of older facilities, so localized damage occurs easily and it is not easy to estimate the damage conditions. Most disruption of service when an earthquake occurs is the result of damage to these access system facilities.

The Hyogo-ken Nanbu Earthquake caused building collapse and fires, which severed aerial and pull-in cables. In terms of conduits, manholes, underground cables and other underground facilities, underground cables suffered damage due to conduit breakage and disconnection and manhole duct sleeve damage, but damage leading to the disruption of service was much less than for aerial cables, thus confirming the high reliability of these facilities.

3. DISASTER INFORMATION SYSTEM CONCEPT

Possible disaster information system functions include detection of disaster occurrence, estimation and understanding of damage, support for recovery activities, and so on. As mentioned above, the greatest need in telecommunications is systems for understanding disaster conditions and assisting early recovery. Of these systems, online information systems in particular use the telecommunications network, and are differentiated from offline information systems that gather information directly from people at the disaster site through patrols, etc.

An overview of the online and offline information systems thought to be necessary for telecommunications is described below.

(1) Online Information Systems

The ideal online information system should constantly monitor the network to make sure that telecommunications service is provided properly, and be able to understand trouble occurrence in real time and perform network control to minimize any drop in service. In addition, it is considered important and effective to construct a system that would allow centralized control and sharing of damage and recovery information in order to promote a smooth recovery when a large-scale disaster occurs. As mentioned above, access system facilities are vast in number and span a wide area, so a system that could gather disaster information remotely with as little human assistance as possible would also be extremely effective for promoting early recovery.

(2) Offline Information Systems

When an earthquake occurs, it may be difficult to understand the damage conditions to telecommunications facilities using only the above-mentioned online information systems. In addition, online information systems are basically

used to estimate and understand whether damage has occurred, and it is difficult to understand the degree of damage. Furthermore, the damage conditions of conduits, utility poles, buildings and other structures must essentially be surveyed directly on-site by patrols. Therefore, offline information systems that use this type of human intervention are also necessary for recovery. However, these activities should proceed after careful selection of survey methods and priorities based on the estimation results of the online information system. In addition, systems and tools are also necessary for obtaining plant records and other on-site information needed to gather disaster and recovery information, and for compiling information gathered on-site into databases, etc.

4. CURRENT STATE OF DISASTER INFORMATION SYSTEMS RELATED TO SERVICE, OPERATIONS AND NETWORKS

(1) Network Monitoring and Control Systems

These systems were constructed by NTT prior to the Hyogo-ken Nanbu Earthquake. The systems were originally installed in prefectural units, but with the restructuring of NTT in January 1999 they were integrated into wide-area groups, with ten network operation centers and two network control centers currently located around the country (Fig. 3). The network control centers monitor and control the trunk circuit network in real time 24 hours per day using the following systems. 1) Overall Traffic Monitoring System which monitors and analyzes communications conditions in full detail, 2) Traffic Control System which detects and controls switchboard volumes as necessary when tolerable limits are exceeded, 3) Common channel signaling Network Monitoring and Control System which monitors and analyzes the signal network between switchboards, and 4) New Synchronous Network Control System which performs remote control of transmission routes.

Furthermore, the network operation centers monitor

and control the vast amount of telecommunications facilities including transmission facilities using the following systems. 1) Switchboard Maintenance Support System which monitors switchboard operating conditions and performs remote control and testing, 2) Control Measures Support System which monitors the overall communications facilities including switchboards, transmission units and wireless units, and 3) Transmission Monitoring Control System which monitors transmission unit operating conditions, determines breakdown locations, and switches to reserve transmission routes.

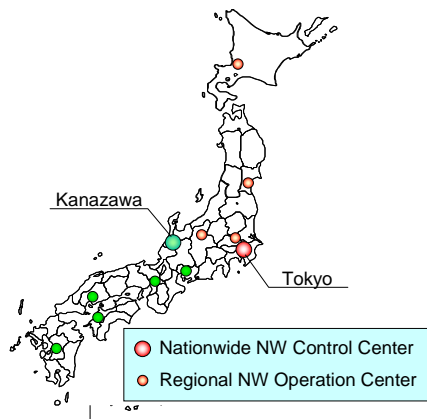


Fig. 3 NTT Network Monitoring and Operation System

(2) Disaster Information Transmission and Sharing Systems³⁾

a) Disaster information system

The disaster information system manages information such as the activity items of each NTT Disaster Countermeasures Headquarters team, damage conditions and recovery conditions using various databases when a disaster occurs. The system distributes this information and also displays it on a map. This client-server type system uses a LAN linking various corporate locations, and performs centralized management from the Disaster Countermeasures Headquarters server. The system uses commercially available Lotus Notes software that has been provided with group-ware functions.

When a disaster or accident occurs and disaster information is input from a client, the disaster location and area are displayed on a map. This disaster information can be easily referenced by simple point-and-click operations. Current facility conditions and other data can also be displayed during normal periods using the facility management database of this system.

The functions of this system are: 1) map display of disaster locations and areas, 2) display of disaster countermeasures system information, 3) display of various instruction and report information, 4) display of facility disaster recovery information, and 5) display of service call number "113" malfunction reception information. This information can be categorized and searched according to combinations of time, source/location, information type and other factors. In addition, various information required when disasters occur such as "Disaster Countermeasures Equipment List", "Disaster Countermeasures Goods List" and "Emergency Rations List" are compiled into databases.

b) Maintenance information network

The Maintenance Information NETwork (MI-NET) is an electronic bulletin board where information can be input and viewed in text format. This system can be accessed using web browser software from all PC terminals of the four NTT companies (NTT, NTT West, NTT East, NTT Communications) and specified PC terminals at each NTT Group company. This allows information sharing between all group organizations.

In April 1999 the entire NTT Group conducted a large-scale breakdown exercise that simulated a leased line accident with the aim of verifying the response during disasters. This system was used as an information linking tool during this exercise, and its practicality and effectiveness were confirmed. As a result, while there was some need for enhancement of functions, the system was confirmed to be effective overall at speeding up information transfer and information sharing.

(3) Disaster Emergency Message Dial⁴⁾

Disaster Emergency Message Dial is an information transmission system that makes full use of the nationwide telecommunication network to prevent the massive amount of communication following a disaster from causing congestion. This is a voice mail system for conveying personal safety and other information verbally using phone numbers within the disaster area as keys. To use this system, users dial "171" and follow voice guidance to register and playback messages. Unlike conventional voice mail, message registration and playback are dispersed throughout the country by distinguishing the telephone numbers for registering messages using the last three digits within the NTT network (Fig. 4). The main uses are: 1) to contact people who cannot answer calls due to evacuations, etc. and 2) to allow contact when residential phones cannot be used due to power failure or disasters. This system is expected to prevent congestion and reduce the effects on communication for disaster relief and recovery activities.

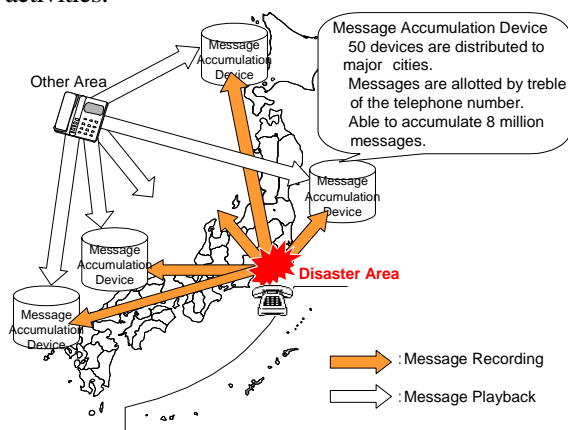


Fig. 4 Overview of Disaster Emergency Message Dial

Disaster Emergency Message Dial was operated during the heavy rains and flooding that occurred in Tochigi and Fukushima Prefectures in August 1998 and also during the Iwate-ken Shizukuishi Earthquake that occurred one week thereafter, and the system was accessed approximately 69,000

times including both registrations and playback. The system has also been used a number of times since, and is also operated on a trial basis during the annual Disaster Prevention Week. Through these operations, the service has been confirmed to be an effective tool for transmitting information and solving the problem of congestion when disasters occur. Recently, the service was accessed 200,000 times during the Tottori-ken Seibu Earthquake (October 6, 2000) and 87,000 times during the Geiyo Earthquake (March 24, 2001).

(4) Shared Map Database System⁵⁾

This system consists of a shared map information system for compiling map information databases and various map utilization systems that use this map information. The client-server system configuration has two dispersed databases: a map information management database and an attribute information management database. NTT had previously developed information systems that utilize map data, but these databases generally could be used only with the system in question. This system resolves this issue, allowing databases to be used by various systems. Map information position coordinate data can be supplied from figure data or attribute data, and figure data can be supplied in various formats.

Examples of applying the Shared Map Database System to disaster information systems include: 1) linking mobile technology with map information, 2) understanding damage conditions and searching damaged facility drawings, 3) searching damaged buildings and disaster prevention facilities, 4) arranging recovery work, 5) supporting on-site surveys, and 6) providing information on the web, etc. The ability to search and display these and other various types of information on maps is effective for sharing information.

5. CURRENT STATE OF DISASTER INFORMATION SYSTEMS RELATED TO FIELD SYSTEM FACILITIES

(1) Application for Evaluating the Seismic Performance of Access System Underground Routes⁶⁾

a) Overview of the Seismic Performance Evaluation AP

Damage to underground communications facilities caused by the Hyogo-ken Nanbu Earthquake was relatively minor. However, underground communications facilities span vast areas, and visual confirmation of damage conditions is difficult, so facility inspections take much time which posed a significant obstacle to recovery work. Drawing on this experience, NTT developed the Application for Evaluating the Seismic Performance of Access System Underground Routes (hereafter "Seismic Performance Evaluation AP"). This tool evaluates the seismic performance of underground conduit facilities based on earthquake, ground and facility information, and is used to estimate macro damage after earthquakes.

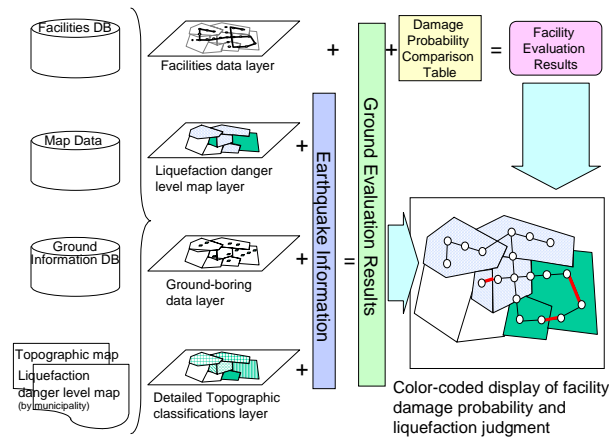


Fig. 5 Image of Application for Evaluating the Seismic Performance of Access System Underground Routes

Fig. 5 shows an image of the AP. Advance evaluations conducted during normal periods are used to formulate overall plans and renewal plans, and macro damage estimations after earthquakes are

used to calculate recovery costs and formulate emergency inspection plans, etc. The databases required by this AP are the various in-house shared databases, which greatly reduces the database compilation and maintenance costs.

b) General evaluation flow

Fig. 6 shows the general AP evaluation flow.

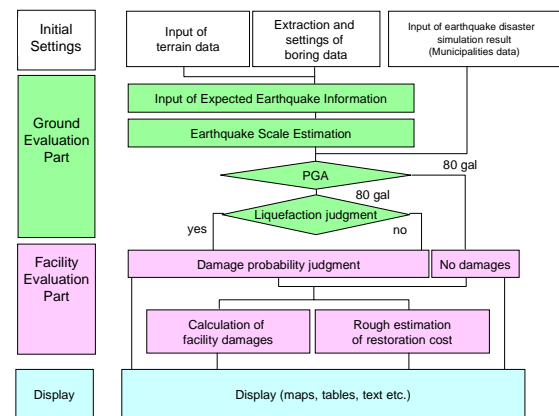


Fig. 6 General Evaluation Flow of Seismic Performance Evaluation AP

Analysis results of the emergency inspections of underground conduit facilities conducted immediately following the Hyogo-ken Nanbu Earthquake showed that underground conduit facility damage factors were broadly classified into liquefaction occurrence, the degree of seismic motion, the conduit type, and the year of construction. The AP can be broadly divided into a ground evaluation block and a facility evaluation block. The features of this AP evaluation flow are: 1) comprehensive liquefaction judgment using the micro-topography classification, boring data, and liquefaction risk factor maps issued by each municipality, and 2) ground evaluation in fixed distribution (FD) sections which are the unit sections used by NTT when managing the communications network. At the initial settings, topographical data and boring data are input and modified to evaluate the ground quality. Next, earthquake information is input and the seismic motion is estimated using a

distance attenuation formula. Then, the AP makes an overall liquefaction judgment based on this seismic motion and ground information.

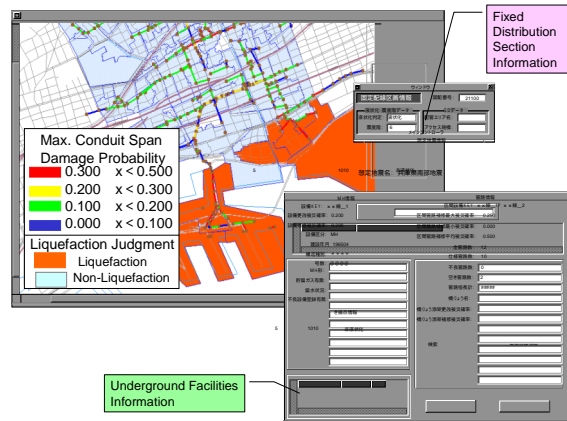


Fig. 7 Image of Evaluation Results Window Display

Facility evaluations target the six facility types of manholes, hand holes, building lead-in conduits, facilities attached to bridge girders, main line conduits, and distribution line conduits. Each facility is divided into a number of categories according to the structure type and year of construction, and the damage probability is estimated and evaluated according to the combination of liquefaction occurrence and the maximum ground surface acceleration (PGA).

The estimation and evaluation results are displayed on a map by colors corresponding to the FD unit liquefaction judgment results and the damage probability for each facility. Selecting a FD section with the mouse opens a window displaying the FD number, liquefaction judgment results, measured seismic intensity and other data. Also, selecting a span with the mouse opens a window displaying the facility name, facility section, average, maximum and minimum damage probabilities, number of conduits and other information. Selecting the [Detailed Conduit Information] button in this window opens a window displaying detailed information such as the damage probability and type of cables housed for each conduit. Fig. 7 shows an image of the evaluation results window display.

(2) System for understanding Access System Damage Conditions

In contrast to the AP described above which is a tool for evaluating the seismic performance and predicting damage to underground conduit facilities that house cables, this system is a tool for testing cables to predict and understand the effects on service. This system is used for: 1) estimation of macro damage conditions in about half a day immediately after a disaster occurs, and 2) understanding damage conditions in the recovery period. Fig. 8 shows an overview of the system.

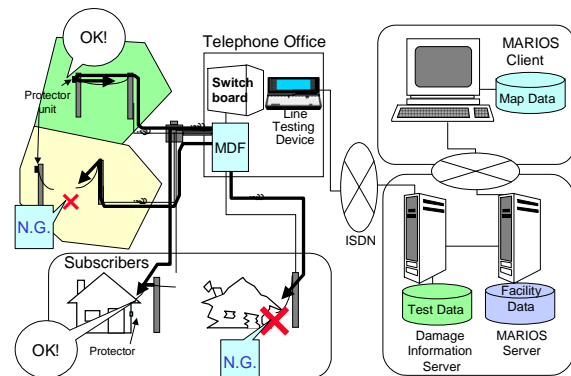


Fig. 8 Overview of System for Understanding Access System Damage Conditions

a) Estimation of macro damage conditions by order line tests

Communication cables include order lines for each fixed distribution section that are lines used for contact during work. When estimating macro damage conditions immediately after a disaster, first an order line G/NG judgment is made using order line testing units, and these results are sent to and registered in a database. Next, a macro estimation of damage conditions is made using the off-site facility management system (MARIOS), and these results are indicated on maps and in ledgers.

b) Understanding damage conditions by all-line tests

Disaster conditions in the recovery period are understood by testing all lines from the MDF (main distribution board) inside the facility center buildings using automatic line switching and monitoring units. The test results are sent to and registered on a server, and the damage conditions are indicated on maps and in ledgers.

c) Other functions and features

In addition to macro estimation immediately after a disaster and understanding damage conditions in the recovery period, transmission technology that supports multiple communication means such as public network, leased lines and portable phones has also been established to enable reliable data transfer even under disaster conditions.

(3) System for Monitoring Structure Degradation Using Fiber Optic Sensing Technology

NTT has researched and developed B-OTDR (optical pulse tester using Brillouin scattered light) based strain measurement technology as original fiber optic sensing technology.^{7,8)} NTT has applied this technology to develop a system for monitoring cracking and other degradation caused by earthquakes, superannuation, adjacent construction, etc., and has begun introduction to communications tunnels in metropolitan areas.

a) Measurement principle

Fig. 9 shows the principle of fiber optic strain measurement using the B-OTDR method. When pulsed light is input to an optical fiber, Brillouin scattered light having the frequency shifted in proportion to the strain generated in the optical fiber can be observed. The position at which the strain is occurring can be determined by measuring the time for the scattered light to return. Therefore, integrating structures and optical fiber makes it possible to continuously measure the strain generated in structures.

b) Overview of tunnel monitoring system⁹⁾

NTT has developed and started introduction of a system for constant remote monitoring of the strain produced in each section when cracking or other degradation occurs. This system uses optic fiber cables fixed at set intervals to the inner walls of communication tunnels as strain sensors. Fig.10 shows the system configuration, and Table 2 gives the performance. Tunnels within a radius of approximately 10 km can be monitored by a single B-OTDR using optical switches, and cracking on the concrete surface can be detected in 0.1 mm units for a fiber fixing interval of 2 m. This system makes it possible to quickly determine the presence of degraded locations after a major earthquake, and also monitors concrete cracking and peeling due to superannuation and other factors during normal periods. This is thought to help reduce maintenance costs by enabling quick detection and repair.

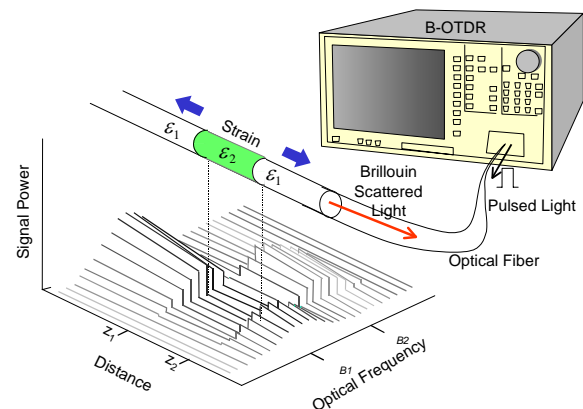


Fig. 9 Principle of Fiber Optic Strain Measurement Using the B-OTDR Method

c) Development of Optical Fiber Sensing Technology to a Wide-area Disaster Monitoring System

In addition to monitoring tunnel degradation, NTT is also working to apply fiber optic sensing technology to other R&D projects such as monitoring road

escarpment collapse and river embankment collapse. B-OTDR fiber optic sensing features the ability to continuously measure the longitudinal direction for long distances, and development to applications such as monitoring changes in large structures that cover a wide area and ground conditions can be expected in the future.

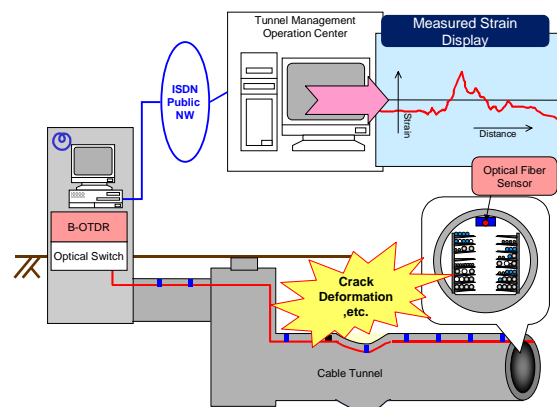


Fig.10 Tunnel Monitoring System Configuration

Table 2 Tunnel Monitoring System Performances

ITEM	System using B-OTDR	Present Systems using Electric Sensors
Measurement Object	Measurement of continuous section	Measurement at point
Measurement Distance	Up to 10km	Up to Several 100m
Strain Measurement Accuracy	50 μ Ability to detect crack of 0.1mm within 2m section	few μ
Electric Power Supply	Unnecessary. Thunder countermeasures are unnecessary.	Necessary for each sensor. Require thunder countermeasures.
Sensor Wiring/ Distribution	Single optical fiber. Regardless of measurement point.	Each sensor needs leading line. Becomes complex as measurement point increases.

6. Seismic Countermeasures for Field Facilities

The Hyogo-ken Nanbu Earthquake also caused great damage to telecommunications facilities. Comparing communication cable damage conditions for underground and aerial facilities shows a damage ratio of 1 to 9 at the service level and 1 to 30 at the

facility level. These figures confirmed once again that burying communication cables is an effective means of ensuring communications reliability.

However, weak points were also confirmed such as the connections between different structural systems, so technology was developed and introduced to improve the seismic performance of these portions.¹⁰⁾ Fig.11 shows an overview of these technologies. Priority issues were the three locations of expandable joints for open-cut tunnels, manhole ducts, and building lead-in portions. In addition, cracking and protrusion also occurred at the connections between shield tunnels and pits due to the lack of reinforcing bars, so expandable joints with superior waterproof performance were recently developed.

(1) Flexible Tunnel Joints

The Hyogo-ken Nanbu Earthquake caused no damage whatsoever to cables housed in tunnels, indicating that the tunnels fulfilled their intended function to protect the cables. However, of the expandable joints of open-cut tunnels installed in the liquefied ground, grade differences of up to 18 cm in both the vertical and horizontal planes occurred at the connections between the tunnels and buildings or pits, resulting in leakage and flooding. Therefore, flexible joints were developed as seismic countermeasures for the joints of open-cut tunnels in ground subject to liquefaction. Workability was improved to allow execution with as little movement of cables as possible, and these flexible joints have been installed in 130 locations thus far. In addition, cracking and leakage were also found in three locations where shield tunnels connect to pits, so joints capable of withstanding water pressure up to 0.7 MPa and having expandable performance of ± 10 cm in the direction of the tunnel axis were also developed.¹¹⁾ (Photo. 1)

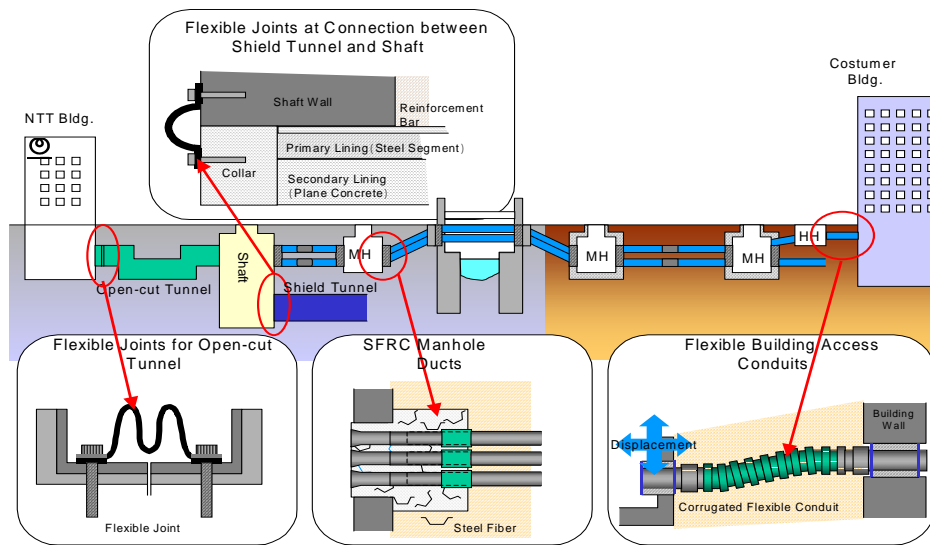


Fig.11 Overview of Seismic Countermeasures for Underground Structures
Following the Hyogo-ken Nanbu Earthquake



Photo 1 Flexible Joints Installed at the Connections
between Shield Tunnels and Pits

(2) SFRC Manhole Ducts

Manhole ducts are the connection points between the different structural systems of manholes and conduits, so ground deformation and other factors during earthquakes cause relative displacement between the two, applying large force to these portions. In areas with significant damage, there were cases where the damage did not stop at cracking, and concrete lumps also peeled away and

damaged the communication cables. Therefore, steel fiber reinforced concrete (SFRC) was adopted as a method of providing the duct concrete with sufficient load bearing strength after cracking occurs.

(3) Flexible Building Access Conduits

When ground subsidence and other factors during earthquakes caused comparatively large relative displacement between hand holes and customer buildings, the building access conduits were unable to absorb this variation and suffered damage such as conduit separation and breakage. As a countermeasure, a flexible joint structure capable of absorbing large displacement at the building end and joint portions was adopted.

7. Conclusion

Based on the experience of the Hyogo-ken Nanbu Earthquake and in addition to the various countermeasures for large-scale disasters that have been adopted thus far, NTT is pursuing new countermeasures aimed at realizing disaster-proof communications services. As the importance of data

communications increases in the future, NTT intends to construct even more reliable networks and develop various systems in order to fulfill its social obligations in times of emergency.

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