Experiment on Seismic Disaster Characteristics of Underground Cable

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ABSTRACT :

For protection from unexpected large-scale disasters, NTT Group has been tackling various measures based on the basic anti-disaster policies of "Enhancing communication network reliability," "Securing critical communication," and "Restoring service early." NTT's underground facilities have been improved and developed according to the results of facility damage analysis conducted at every great earthquake. After the Niigata Earthquake in 1964, conduit joints were improved with priority to measures against ground liquefaction. This improvement was proved effective by later great earthquakes.
According to past reports about underground cable damage, a conduit was fractured and disengaged by local shear due to land subsidence at a quick change of stratum or the crossing of the conduit over another buried item. This damaged a cable inside the conduit by side pressure or shearing force. At the Niigata chuetsu Earthquake in 2004 and Niigata Chuetsu-oki Earthquake in 2007, road surface collapses at banking sections produced tensile force on entire cables and caused optical transmission losses and the bracings of manholes cut cables.

We experimentally verified external force to work on a cable in a conduit after conduit damage by a ground change and the mechanism of damaging the cable. In the experiment, the standard conduit, manhole, and cable securing methods were modeled and the cable damage, optical transmission loss, and conductor strain after the forced disengagement of a conduit were checked. This paper introduces typical cases of disaster verified in this experiment.

As introduced here, we also experimentally confirmed the basic characteristics about faults on the communication service level when the assumed seismic conduit-damaging tensile force and bending were applied to an optical fiber cable.

KEYWORDS: Optical fiber cable , Telecommunication , communication service , manhole , Conduit

1. Introduction

As an important subject to support the reliability of the future broadband ubiquitous service, NTT is tackling the construction of a highly reliable network resistant against an earthquake. In particular, cable tunnels, conduits, and other underground communication facilities have been improved and developed by analyzing actual seismic facility damage because they accommodate and protect high-speed broadband cables. Figure 1 shows the configuration of underground communication facilities from an NTT building to a customer building. The underground conduits and manhole joints have elasticity in the axial direction to withstand earthquakes. For cable tunnels and also access conduits to customer buildings, flexible structures have been adopted to improve reliability since the Great Hanshin-Awaji Earthquake in 1995.

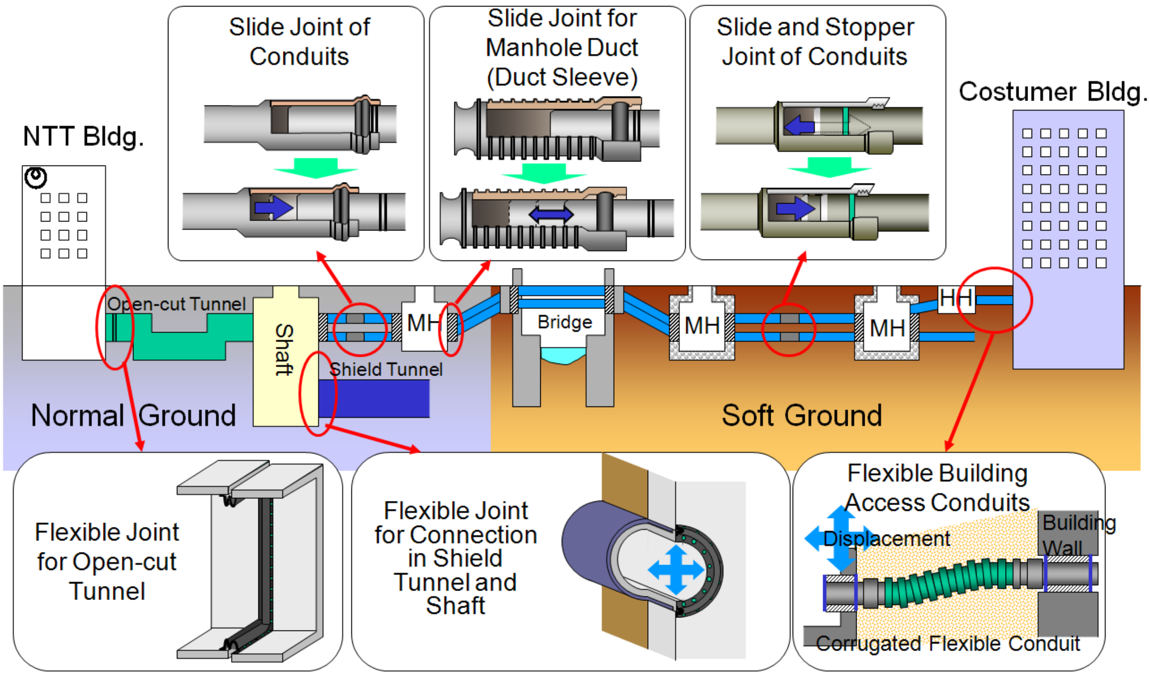

Figure l Configuration of underground communication facilities

In many cases so far reported about seismic underground cable damage, a conduit was fractured and disengaged under local shear by land subsidence at a quick change of stratum or the crossing of the conduit over another buried item. This damaged a cable inside the conduit by drastic bending or shearing. Therefore, conduit joints and manhole connections have been made flexible to improve the anti-seismic performance.

Cable damage by conduit fracture
Kushiro Earthquake

Cable cut in manhole The Niigata
Chuetsu Earthquake

Cable displacement in manhole
Niigata Chuetsu-oki Earthquake

Figure 2 Cases of seismic cable disaster

At the Niigata Chuetsu Earthquake in 2004 and Niigata Chuetsu-oki Earthquake in 2007 when many optical communication cables were already laid, cables were pulled into manhole ducts at road collapses or land subsidences, as well as at conduit fracture and disengagement. This was reported to have increased the optical transmission loss and cut a cable by tensile force in some cases (Figure 2).

As reported in this paper, we experimentally verified how underground communication cables had been damaged at these earthquakes.

Future anti-seismic measures on communication facilities should be taken to cope with large displacements at connections by making buildings and bridges absorb earthquakes and changing axial contractility to flexibility. As basic data to study anti-seismic measures, we confirmed the basic characteristics about the seismic disaster characteristics of optical fiber cables at earthquakes.

2. Seismic Disaster Characteristics of Underground Communication Cable

We experimentally verified external force to work on a cable in a conduit after conduit damage by a ground change and the mechanism of damaging the cable damage.

2.1 Structure of Underground Cable

Optical fiber cables laid under the ground generally has a slot structure shown in Figure 3 where an optical fiber conductor is formed into a tape and accommodated in a cavity called a slot. Tension at cable laying works on the tension member (steel wire) but hardly on the optical fiber conductor.

In a manhole, a cable is usually secured by binding to the bracing as shown in Figure 2. If there is an optical fiber connection point (hereinafter, closure), the tension member is secured with a metal bracket to relieve the optical conductor from tension.

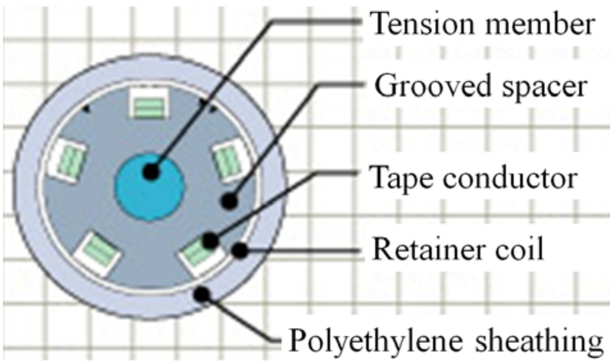

Figure 3 Cross-sectional structure of optical fiber cable

2.2 Seismic Experiment on Underground Cable

To check the damage status at conduit fracture and disengagement or in a manhole, we conducted a demonstration experiment by using an experimental model shown in Figure 4. The manhole on the left side of the figure has the standard size. Like an ordinary cable, the cable or closure was bound to the bracing for securing. The load section on the right side of the figure reproduces conduit fracture and disengagement under the ground. In this experiment, we gave forced displacement in the conduit axis direction (G) and perpendicular to it (D)and measured the optical transmission loss of the optical fiber cable by OTDR and the strain of the optical fiber conductor by BOTDR.

OTDR is to measure the optical transmission loss from the intensity of back scattering at the incidence of optical pulses into an optical fiber. BOTDR is to measure the strain of an optical fiber conductor itself by using the phenomenon where the peak frequency spectrum of Brillouin scattering shifts in proportion to the strain.

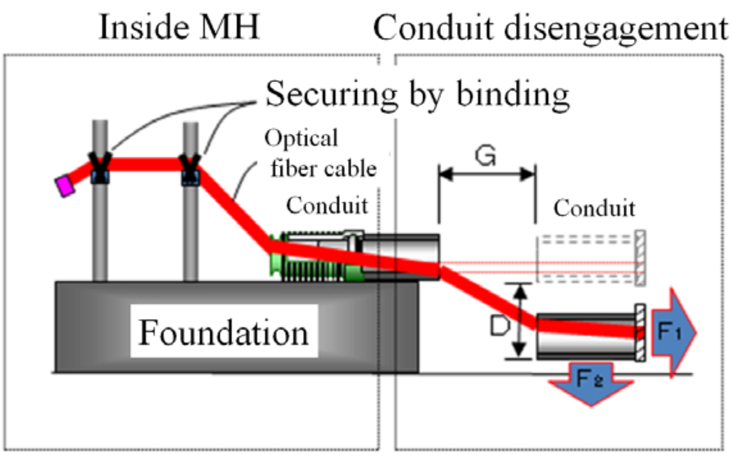

Figure 4 Optical fiber cable model for disaster experiment

2.3 Experimental Results

In a span with closure, optical fiber cables were damaged in manholes. In a span with no closure, fine optical fiber cables (20 mm or less in diameter) were damaged in manholes when the conduits were pulled in the axial direction and at conduit disengagement when shearing force was produced, as well as tensile force. In a span with no closure, bold optical fiber cables (over 20 mm in diameter) were not damaged by axial tension only but by bending and shearing as well as axial tension.

Table l Cable damage patterns

	In manhole	Disengagement
With closure	①	———
With no closure	②	③

① Damaging process in a span with closure

1) The cable is pulled into the manhole due to conduit disengagement and tension is generated throughout the cable.
2) A conductor strain is generated throughout the optical fiber. (Similar strain in all slots)
3) The tension member bracket in the standard closure is damaged and the tension member is extracted.
4) Tensile force rapidly works on the sheathing and conductor and cuts the cable. The disaster at the Niigata Chuets Earthquake in Figure 2 could be reproduced. (Figure 5)

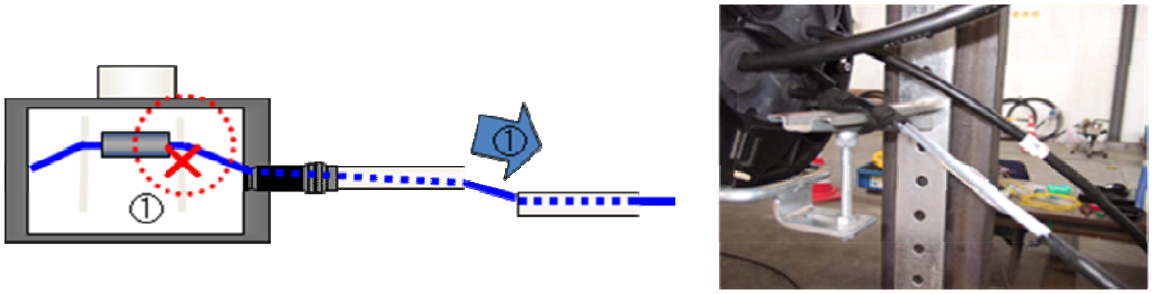

Figure 5 Disaster in a span with closure

Figure 6 shows the relationship between the conduit disengagement gap (G) and the tension working on the cable. × in the graph indicates a point where the optical transmission loss and strain on the optical fiber exceed the criteria. Since the cable is secured by binding, the tension is not uniform. However, the tension causes damage about when the conduit disengagement gap exceeds 10 cm.

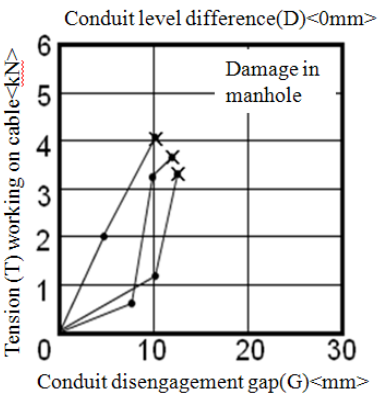

Figure 6 ①Conduit disengagement gap and tension

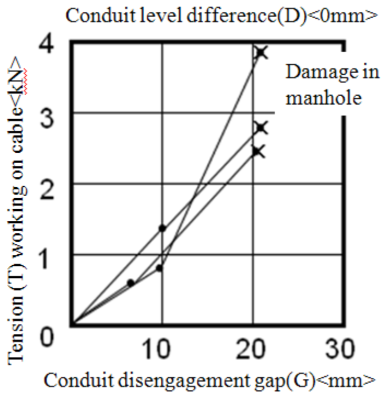

Figure 7 ②Conduit disengagement gap and tension

②Damaging process in a manhole in a span with no closure

1) The cable is pulled into the manhole due to conduit disengagement and tension is generated throughout the cable.
2) The cable comes off from the bracing near the duct and tension works on the far bracing.
3) A conductor strain is generated throughout the optical fiber. (Similar strain in all slots)
4) The strain increases the optical transmission loss or the biting string cuts the conductor. (Figure 8)

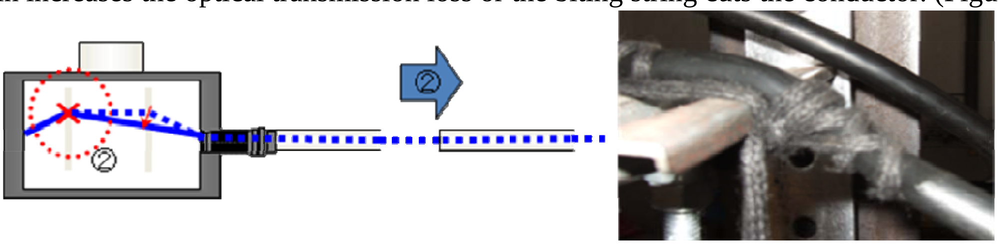

Figure 8 Disaster in a manhole in a span with no closure

Figure 7 shows the relationship between disengagement gap (G) and tension (T). As in the previous section, the tension is not uniform but causes damage about when the disengagement gap exceeds 20 cm.

③Damaging process at conduit disengagement in a span with no closure

1) Same as 1) to 3) in ②
2) As the level difference (D) at conduit disengagement increases, side pressure works on and makes the cable cross section flat.
3) The side pressure by tension and the abrasion with the conduit edge damage the cable sheathing.
4) The cable slot is crushed and presses the conductor, increasing the optical transmission loss. (Almost simultaneous occurrence of excessive optical transmission loss, conductor elongation, excessive strain, and boring in sheathing)(Figure 9)

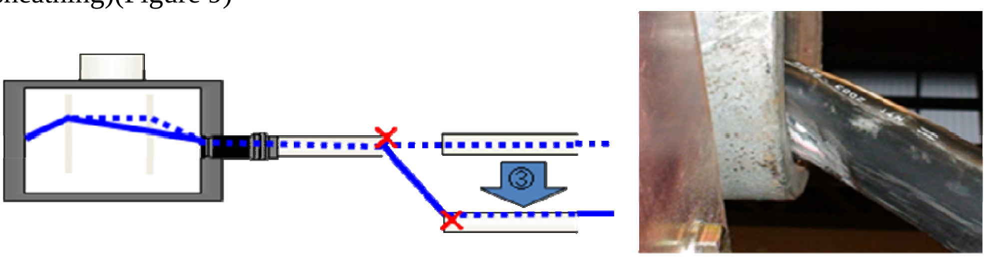

Figure 9 Damage at conduit disengagement in a span with no closure

Figure 10 shows the relationship between the level difference (D) and tension (T) when the disengagement gap was 10 and 20 cm. Although the tension decreased when strings became loose, the cables were damaged almost uniformly about when the level difference exceeded 20 cm.

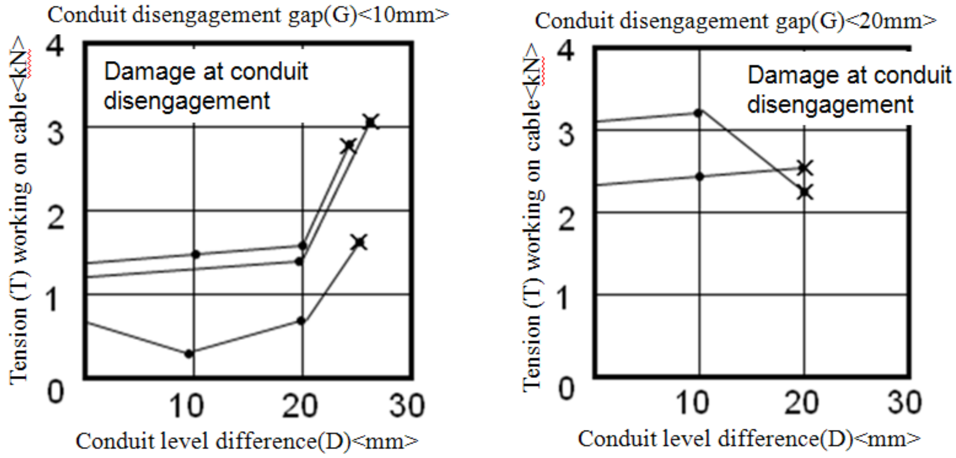

Figure 10 ③ Conduit level difference and tension

2.4 Summary of Underground Cable Disaster Experiment

The cable disaster experiment had complicated factors, such as the loosening and falling of strings, but its results can be summarized as follows:

In a span with closure, a conduit disengagement gap of about 10 cm caused damage by the pattern of ①. In a span with no closure, fine cables suffered from damage of a combined pattern of ② and ③. Bold optical fiber cables suffered from damage of the pattern of ③. Figures 11 and 12 show the damage areas of fine and bold cables in a span with no closure.

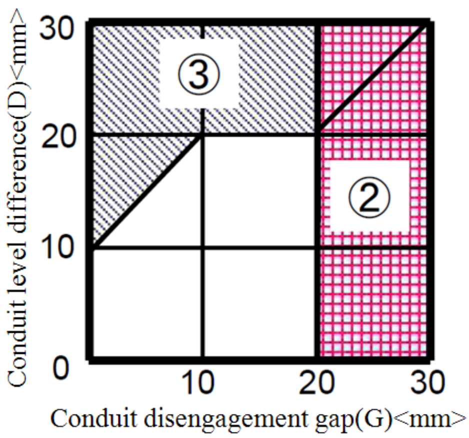

Figure 11 Fine cable damage area

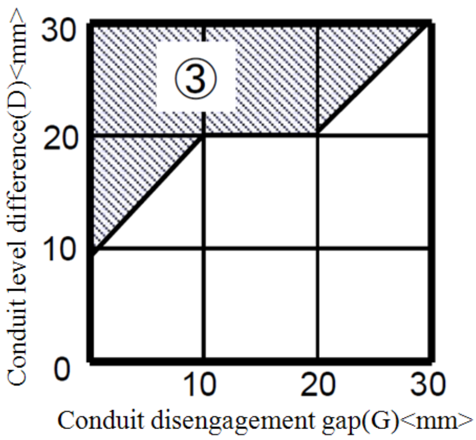

Figure 12 Bold cable damage area

3. Basic Characteristics of Optical Fiber Cable

An optical fiber cable is not designed resistant to external force. However, the steel wire and polyethylene sheathing may be making the structure resistant to external tension, compressive force, and bending force. Therefore, the optical transmission loss and conductor strain when a communication cable is pulled or bent are checked to clarify the limit of using a communication cable. By clarifying the relationship between cable forced displacement and tension and communication fault, the allowable conduit deformation is evaluated.

3.1 Tensile Test of Optical Fiber Cable

As shown in Figure 13, a tensile test was performed by using a hydraulic jack. This test was performed on the six types of optical fiber cables listed in Table 2. The cables were measured about the limits of load, displacement, strain, and optical transmission loss were measured. The criteria of a seismic disaster were conductor strain over 2.0% and optical transmission loss over 1.6 dB that would affect the long-term reliability.

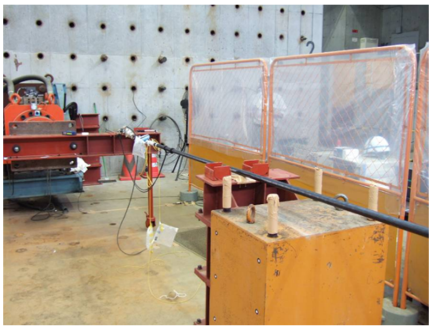

Figure 13 Optical fiber tensile test status

Table 2 Optical fiber tensile test conditions

Cable type	Measurement Item
・SM40cores ・SM100cores ・SM200cores ・SM300cores ・SM400cores ・SM1000cores	・Load ・Displacement ・Strain （Tension member） （Grooved spacer） （polyethylene sheathing） （Optical fiber conductor） ・Optical transmission loss

Figure 14 summarizes the relationship between cable tension and optical transmission loss. Irrespective of the tensile load on the communication cable, the optical transmission loss is constant with almost no change from the initial value, despite dispersion depending on the number of cores. Under tensile force only, the optical transmission loss was found not to change until cable fracture by the tension.

Figure 15 the relationship between cable tension, cable strain, and conductor strain about the two cases of SM200 and SM1000. For long-term reliability, the conductor strain limit is considered to be about 0.2%. Until the tension member fractures, there is no problem about the conductor strain.

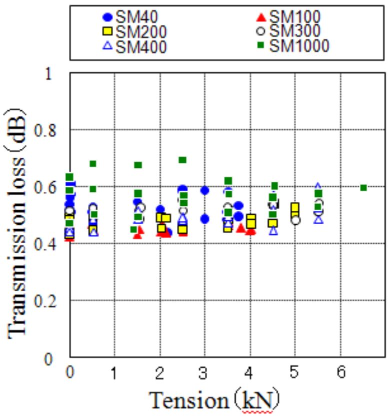

Figure 14 Cable tension and optical transmission loss

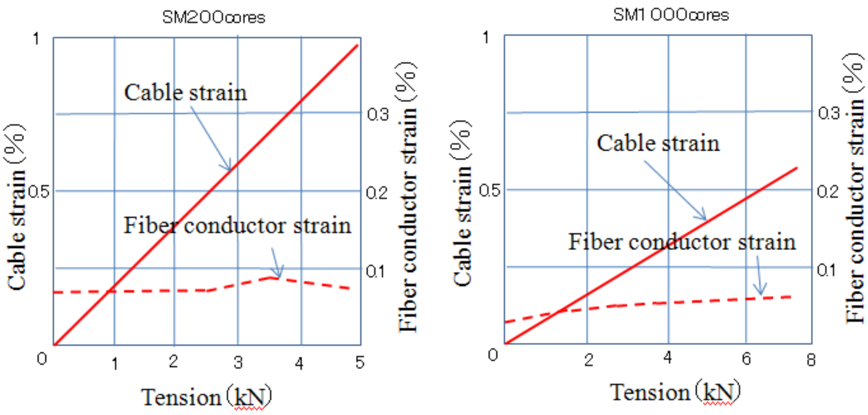

Figure 15 Relationship between cable tension, cable strain, and conductor strain

3.2 Bending Test of Optical Fiber Cable

As shown in Figure 16, conduits accommodating optical fiber cables are turned to clarify the relationship between bending angle, optical transmission loss, and conductor strain. This test was performed under the measuring conditions listed in Table 3.

Under three patterns of frictional tension, each optical fiber cable was checked about the angle where a transmission fault occurred. For the tension patterns, the cable lengths were designed for a crossing angle of 60 degrees in a 75-meter span, a 150-meter span, and 250-meter span

Figure 17 shows the relationship between cable bending angle and optical transmission loss about the two cases of SM200 and SM1000. A transmission loss tends to occur at a bending angle about over 60° , despite dispersion depending on the number of cores.

As the cores of the optical fiber cable are fewer, an optical transmission loss tends to occur at a greater bending angle. This is advantageous for a fine cable (small number of cores). As the design cable length is shorter, an optical transmission loss tends to occur at a greater bending angle. When the design cable length is 75 meters, an optical transmission loss occurs at a bending angle of about over 100°. At the design of a conduit for a great bending angle, the conduit span should be reduced to suppress frictional tension on the cable.

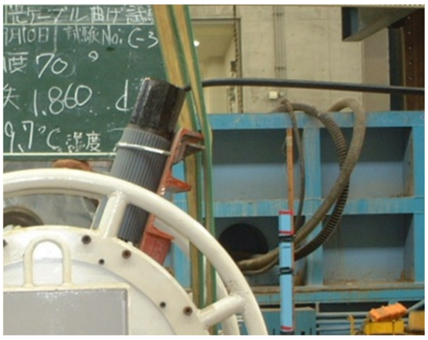

Figure 16 Optical fiber bending test status

Table 3 Optical fiber bending test conditions

Cable type	Tension	Measurement Item
· SM40cores · SM100cores · SM200cores · SM300cores · SM400cores · SM1000cores	Design cable length ·75 m ·150 m ·250 m	· Angle · Conductor strain · Optical transmission loss

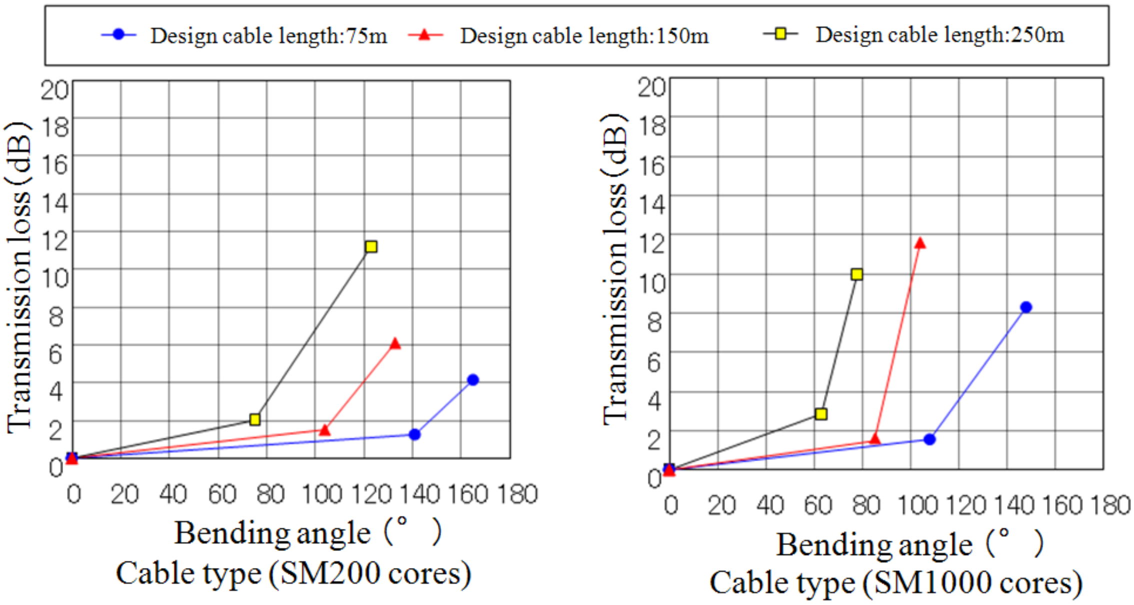

Figure 17 Relationship between cable bending angle and optical transmission loss

4. Conclusion

By modeling the seismic damage of underground conduits for the experiment, we could confirm that optical fiber cables are damaged not only at conduit fractures but also in manholes where they are pulled in. The cable securing method needs to be studied at the future adoption of flexible anti-seismic conduits.

When the seismic disaster characteristics of optical fiber cables were verified by testing, tension alone was found not to cause a transmission fault but at certain bending angles. When designing spans of large displacement for anti-seismic bridges in future, we will apply the data to the planning of design policies based on the relationship between design cable length and maximum bending angle to maintain the communication services even at earthquakes.

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