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ANALYSIS OF TELECOMMUNICATION CONDUIT DAMAGES IN THE GREAT EAST JAPAN EARTHQUAKE, AND EFFECTIVE LINING REPAIR TECHNOLOGY

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Abstract

Focusing on uneven settlement of ground near a box culvert, seen at the time of the Great East Japan Earthquake, this study is based on an example in which optical cables actually break as a result of that settlement. It was confirmed that the shear force acting on optical cables after the joints of existing telecommunication conduit were broken by seismic motion was reduced by applying a new technology for restoring cable-containing conduit. A formula for calculating shear force acting on an optical cable is presented, and shear-load bearing capacity based on an earthquake-resistant design incorporating the new technology is demonstrated. It is anticipated that the reliability of communication networks will be improved by applying this technology at sections in which conduit traverses box culverts.

Keywords: Telecommunication conduit, Ground displacement, Uneven settlement, Shear, Optical fiber

1. Introduction

As for the damage situation concerning telecommunications conduit equipment after the Great East Japan Earthquake, Yamazaki et al. [1] reported a similar trend and disaster conditions (excluding damage due to tidal waves) as experienced after past earthquakes, that is, damage due to uneven settlement (in relatively soft ground associated with manmade creations like earth-filled sections at the back of bridge abutments and the periphery of box culverts) and lateral deformation (in earth-fill zones) was extensive. In this study, an example of actual breakage of cable, due to vertical sinkage of both the protection concrete and surrounding earth during the Great East Japan Earthquake, is described. In particular, a new pattern—namely, conduit joints break at points where they traverse box culverts, shearing force is applied to the optical cable inside and breaks it—is reported.

The disaster condition and breakage of optical cable are shown in Fig-1. In this study, a method that enables safety verification (including a technology for restoring optical-cable-housing conduit) was investigated. In particular, under the assumption that existing conduit is damaged by an earthquake, a level at which communication blackout is avoided when a shearing force acts vertically on an optical cable (hereafter, called "communication-blackout level") is defined, and shear-load bearing capacity at the communication-blackout level is expressed numerically.

Fig-1: Damage to optical-fiber cable after the Great East Japan Earthquake

2. Disaster situation concerning optical cable after the Great East Japan Earthquake

The devastation dealt with by the present study occurred at the intersection of a dedicated conduit facility (running under a footpath along a national highway) and a box-culvert-type waterway traversing the highway. The dedicated conduit must be located at a shallow depth, and, ordinarily, multiple conduits in multiple stages (i.e., nine conduits laid evenly side-by-side in each stage) are placed directly on top of the box culvert. Each conduit is a screw-joint steel pipe, and all the joints of the conduits are located in the same place (i.e., not in a staggered arrangement the pipe axial direction). As shown in Fig-2, the devastated conduit is the five pipes with joints not located above the box culvert, and the conduit, protection concrete, and asphalt paving all sank by about 15 cm in the perpendicular direction to the conduit axis. With the optical cable housed in the conduit gets sandwiched between conduit laid along the box culvert and conduit that sank after breaking away, a shearing force corresponding to loading from above is generated, and communication is blocked by breakage of the optical cable. At that time, as a result of the thickness of the concrete above the outer diameter of a joint decreasing (owing to multiple conduit joints being arranged uniformly along the same line), the thickness of the concrete above a section of joint and pipe decreasing, and so on, the protection concrete breaks into a discontinuous body at the damaged points of the conduit joints.

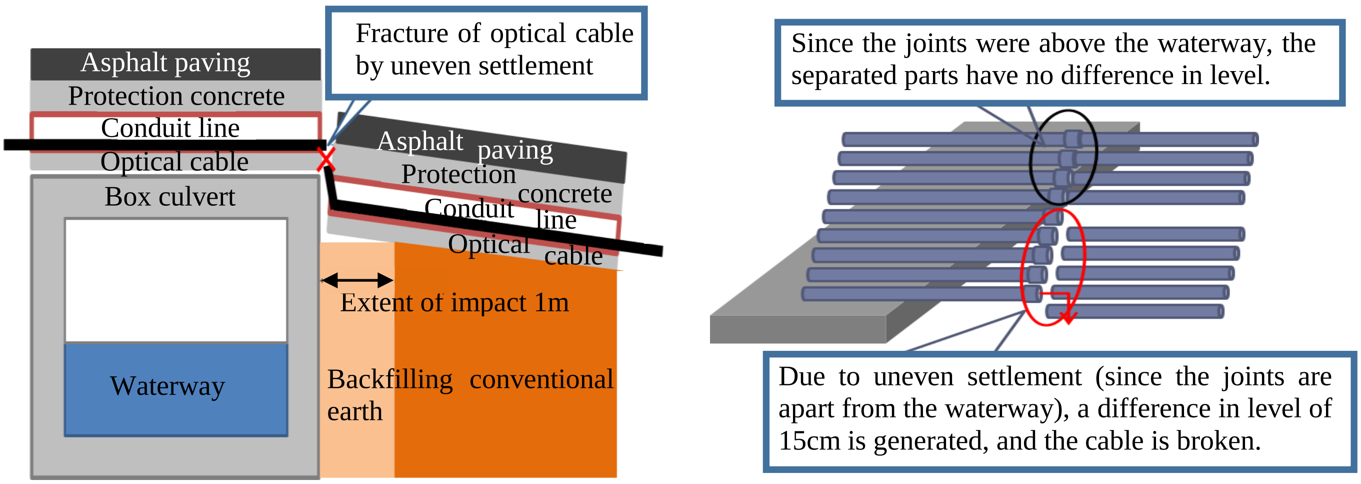


Fig-2: Fracture state of optical cable (left: longitudinal direction; right: transverse direction)

3. Shear force acting on optical cable

It is known that uneven settlement accompanies the rapid formation of the difference in levels occurring near backfilling earth of the box culvert, the axial direction of the protection concrete and the conduit under the settling inclines downwards in the direction that burial depth increases, and the ground at a distance from the box culvert is stable and the protection concrete is supported. In consideration of these facts, the phenomenon focused on in this study is considered in terms of a safe-side model in which half the total load is supposed as a shear force acting on the optical cable (according to the one-end-lifting load model shown in Fig-3). The upper-load model considered here is shown in Fig-4. As for the vertical load (F), it is considered to be generated by the weight of the asphalt paving, the weight of the protection concrete, and the weight of existing conduit.

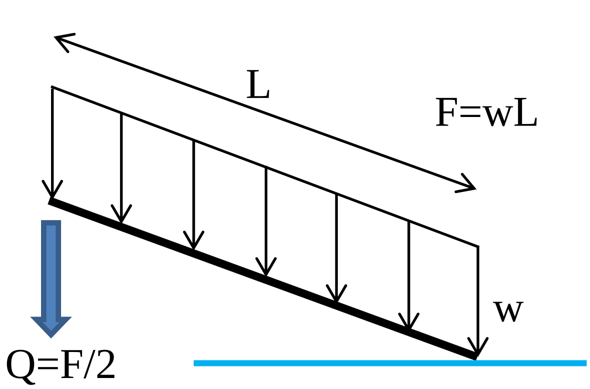


Fig-3: One-end-lifting load model

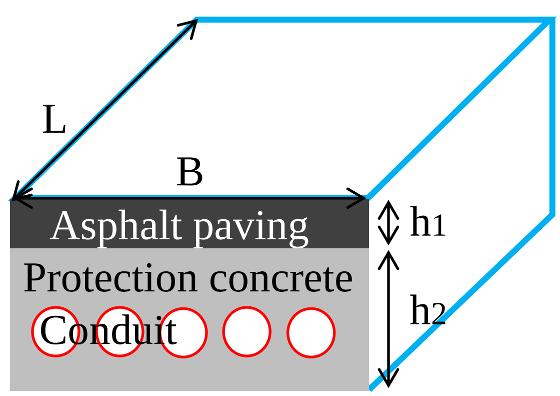


Fig-4: Vertical -load model

Given the length of the zone of sinkage in the axial direction of the conduit as *L*, width of protection concrete that sinks in the vertical direction of the conduit as *B*, thickness of asphalt as h_1, unit-volume weight of asphalt as γ_1 (22.5 kN/m^3), thickness of protection concrete as h_2, unit-volume weight of protection concrete as γ_2 (23.0 kN/m^3), external diameter of conduit as *D*, internal diameter of conduit as *d*, unit-volume weight of conduit as γ_3 (78.5 kN/m^3), and number of conduits as *C*, the shear force acting on an optical cable (*Q*) (as half the total weight given by the weight model in Fig-4) is given by Equation (1) below.

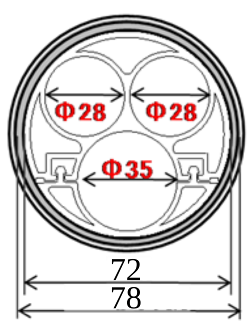
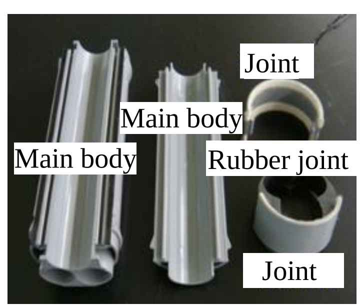
$$Q = \frac{F}{2} = \frac{L}{2}\left[Bh_1\gamma_1 + \left(Bh_2 - \frac{\pi D^2}{4}C\right)\gamma_2 + \frac{\pi(D^2 - d^2)}{4}C\gamma_3\right] \tag{1}$$

The shear force acting on an optical cable in the case of the disaster phenomenon focused on in this study was calculated from Equation (1). In accordance with the actual conditions at the disaster site, *L* is 1 m, *B* is 1 m, *C* is five conduits, h_1 is 0.15 m, and h_2 is 0.2 m, so Equation (1) gives a shear force of 3.9 kN.

4. Experiment for verifying the cable-protection effect of a technology for restoring cable-housing conduit

The technology for restoring cable-housing conduit was developed under the aim of restoring existing conduit under the condition that it contains optical cables and has suffered degradation such as erosion and corrosion of the metal piping. The cable-containing-pipe restoration technology [2] is overviewed in Table-1. It consists of one space (with bore diameter of 35 mm) for housing an existing 1000-core optical cable and two empty spaces (with bore diameter of 28 mm) for housing two thinner 1000-core optical cables (which are to be laid in the future). The main material is rigid polyvinyl chloride (PVC). Even in the case that the strength of the existing outer metal piping is reduced by corrosion, the technology provides cross-sectional strength for bearing the earth pressure. Accordingly, the extent to which the optical cable can be protected against communication blackout like that caused by the earthquake in question was investigated.

Table-1: Overview of new technology for restoring cable-containing conduit

Outline	Extemal appearance
For restoring conduit with optical cable already laid inside, this technique involves assembling factory-model components (while the optical cable in bundled inside a monhole) by sequentially inserting them into the conduit. No contact with existing conduit. Possibly "adherence" or "sticking".	 Cross section of components after assembly.  Components  Continuously connected state

As for the region satisfying the communication-blackout level, in the case that a shear force acts on optical cable housed by applying the new technology (under the assumed condition that the conduit breaks at the joints and is displaced in the vertical direction), communication-blackout level is satisfied if the external pressure does not act on the optical cable under the condition that the internal diameter of the optical-cable-housing bore is bigger than the external diameter of the optical cable, and that critical load is defined as the space limit load. The experiment is outlined in Fig-5. Shear force was gradually applied to the separated part of the conduit, and the breaking force that fractures the material and the spatial-limit load were measured. However, as for the components used with the new technology, their weak points are the joints that connect them together. Accordingly, shear load was applied to the joints.

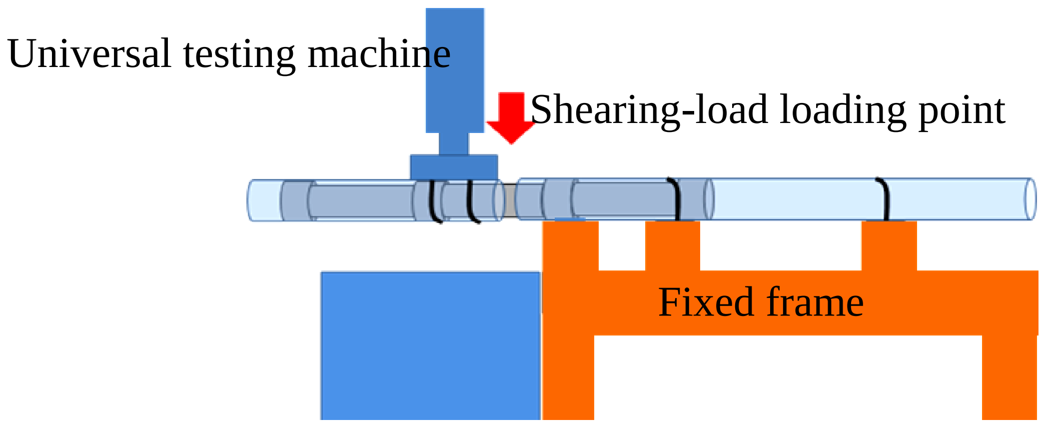


Fig-5: Outline of experiment

If it can be confirmed that the change state after the load was applied is given by the relationship stating that fracture load changes to spatial-limit load and that the spatial-limit load in the elastic region is transformed, it would be possible to set the level to avoid communication blackout under a stable condition according to structural dynamics. The experimental results concerning spatial-limit load and fracture load are plotted in Fig-6.

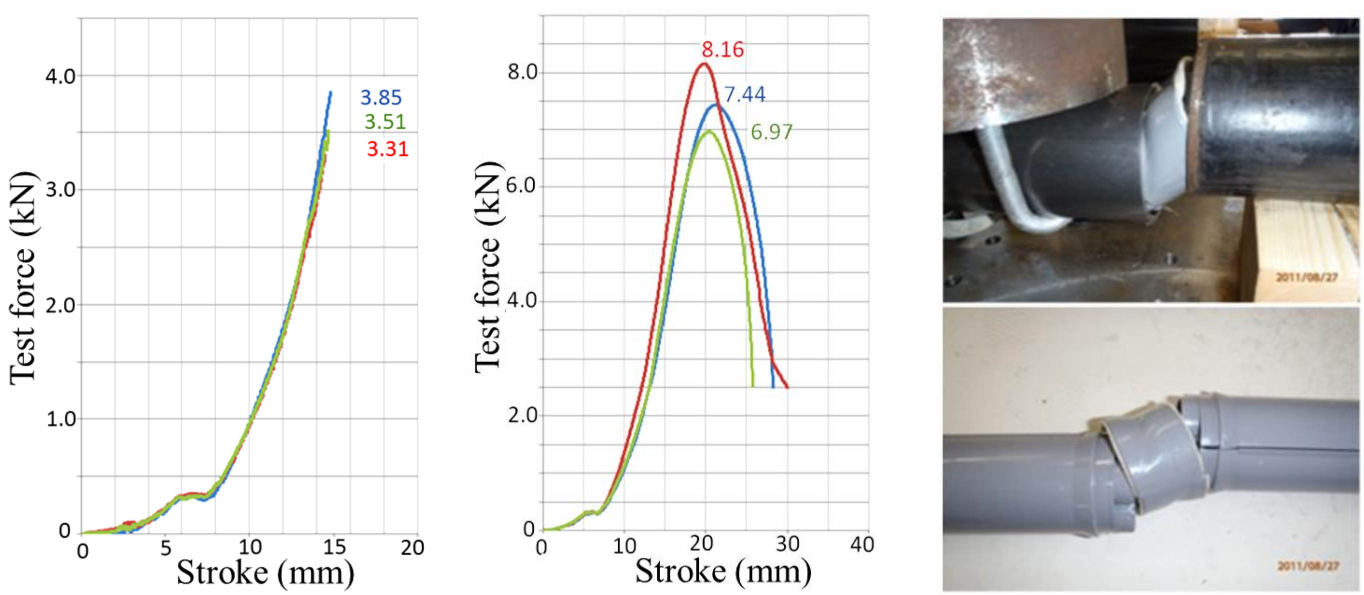


Fig-6: left: spatial-limit load; middle: breaking load; right: fracture state

The joints are disengaged and fractured in a manner in which they get torn up or down while they resist the shear strain. The average value of the spatial-limit load is 3.6 kN, and according to the diagram of breaking load versus displacement, the elastic-deformation region is 5.5 kN. Accordingly, the spatial-limit load can be considered to be within the elastic region. From these experimental results, it is confirmed that even in the case that the position at which the shear load is applied changes at some future time, the following relationship holds: “breaking load transforms to spatial-limit load in the elastic region.”This result means that it is possible to use the spatial-limit load to design the communication-blackout-avoidance level under stable condition given by structural dynamics. According to these experimental results, the shear-load-bearing capability of the cable-housing conduit restoration technology is a numerical value for each conduit to which the technology is applied. Moreover, it can be concluded that under a shear force applied to optical cable during a disaster of 3.9 kN (as determined in Section 3), communication blackout can be avoided if more than two conduits are installed. In conduit zones that are assumed to pass over box culverts in the future, it will be practicable to adopt a design that allows for safety inspection by determining the number of conduits (based on the cable-housing-conduit restoration technology) needed when the shear load given by Equation (1) is surpassed.

5. Concluding remarks

In this study, which concerned the Great East Japan Earthquake, a “communication-blackout avoidance level”—in regard to protection performance in the case that the developed cable-housing-conduit restoration technology is utilized when a shear force is applied in a hitherto-unexperienced disaster pattern—was defined and investigated. First, the condition of broken optical cable was ascertained, and an equation [Equation (1) above] for calculating the shear force applied to the optical cable was suggested. Then, a communication-breakdown avoidance level (for assuring communications after conduit is damaged by an earthquake) was defined, and a verification experiment—concerning the behavior of conduit under shear force in the case that the developed cable-housing-conduit restoration technology was applied—was performed. By clarifying the shear-load bearing capacity per conduit (based on the new technology) at the communication-breakdown avoidance level determined through experimental verification, it becomes possible to investigate earthquake-resistant designs that will enable safety inspections. Although investigations focused on conduit damage have been performed before now, in the case that a level-2-equivalent earthquake is considered, if a design that protects optical cables even if the conduit is broken were made possible, new measures for avoiding communication blackout could be investigated. The conditions under which damage to optical cable occurs have become approximately understood from past seismic damage. One of those conditions occurs in zones that traverse box culverts, and strengthening that zone can greatly improve the reliability of a communication network. From the viewpoint of practicality, that improvement can be considered a major step forward.

6. References

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[2] Akira Koizumi, et al., “Development of the Repair Technology of Telecommunications Conduit Equipment, and Stable use of Underground Space,” 20th underground space Symposium, Japan Society of Civil Engineers, 2014.