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DAMAGE PREDICTION METHOD OF TELECOMMUNICATION PIPELINE ATTACHED TO ROAD BRIDGES DURING LARGE EARTHQUAKE

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Abstract

In this study, for the purpose of improving telecommunication network reliability at the river crossing section (in this study river crossing pipes attached to road bridge are focused), technology to identify the vulnerable river crossing pipes are developed. First damaged cases of pipes attached to road bridges in Tohoku Earthquake in 2011 are analyzed using pipe attributes and estimated seismic motion data. Seismic motion data was estimated (250m mesh size) by simple kriging method using seismic observation point data. From the damaged cases analysis, it is confirmed that the spectral-intensity is larger, damaged ratio of pipe attached to road bridge is higher. On the other hand, clear relationship between PGA (Peak Ground Acceleration) and damaged ratio did not show. In point of structure of the road bridge that pipes are attaching, the length of road bridges is longer, the damage ratio of pipes attached to road bridges is higher. In damage mode analysis, separation of pipe joints was most major damage mode. In this paper, the result of these basic analyses and result of site investigation are shown.

Keywords: telecommunication pipeline; conduits; pipeline attached to road bridges

1. Introduction

Nippon Telegraph and Telephone Corporation (hereafter, NTT) maintains underground conduits with a nationwide length of about 620,000 km and provides communications services by cables laid in those conduits. As for such underground communications conduit, it is required to maintain a safe space for the inner cable not just during normal times but also during disasters (like large-scale earthquakes). At points along the route of the conduit where a river must be crossed, the conduits and the inner cable are passed over the river by attaching them to general road bridges or private bridges. Since conduits at such river crossings are exposed above ground, they are more susceptible to the effects of earthquakes than underground conduit. In particular, according to an analysis of damage caused by Tohoku Earthquake in 2011 performed by Yamazaki et al. [1], the damage ratio in places where conduit is attached to bridges is higher than that in places where conduit is buried underground. In addition to this, river crossings are limited places, for this reason they are key factors in regard to reliability of the whole network because they have a high concentration of cables. Accordingly, to improve the reliability of a communications network, river-crossing points require superior seismic performance. NTT, however, maintains conduit facilities at 40,000 river-crossing points—both normal and private bridges—across Japan. Under those circumstances, implementing effective seismic measures necessitates a method for selecting those facilities with a high likelihood of suffering seismic damage. In light of the above-described state of affairs, in this paper shows the results of an investigation on such a selection method.

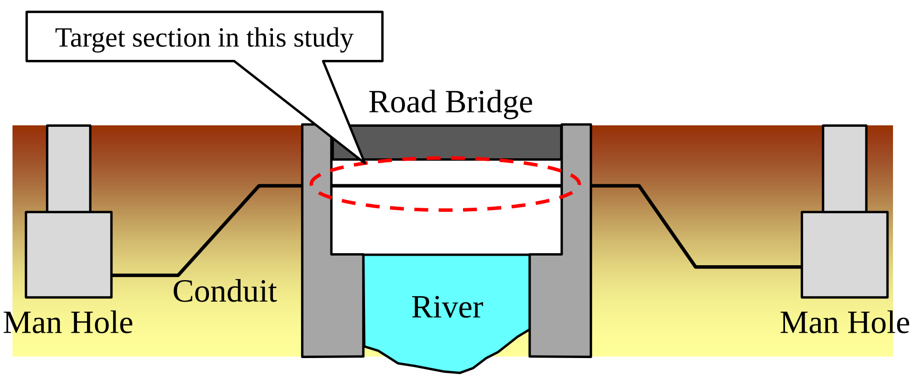

Fig. 1– Target facilities in this study

2. Target facilities for investigation

In this investigation, bridge facilities—in Japan's Iwate, Miyagi, Fukushima, and Ibaraki prefectures—that were subjected to seismic motion due to Tohoku Earthquake in 2011 were targeted for analysis. Focusing on preventing harm to third parties due to falling conduit after earthquake and understanding damage status, emergency inspections were performed at about 3000 points of all bridge sections (except certain sections) in the four targeted prefectural regions. In this study, in addition to damaged case analysis, a means of implementing effective measures was set as another target for this study. Accordingly, 978 places (at which photographs were taken during the emergency inspections) were targeted for analysis. Moreover, the emergency inspections were visual inspection, therefore only places exposed above ground (as shown in Figure 1) were targeted for this study. In other words, in this study, damage to sections of conduit buried underground was not targeted for investigation. In addition, facilities that were subjected to the ensuing tsunami were considered out of the scope of the study. The damage ratios for each of the targeted prefectures are listed in Table 1. Although the facilities targeted for inspection are limited, large discrepancy with damage ratios reported in reference works (about 14% across the four prefectures) could not be confirmed. Accordingly, it was considered that the damage trend concerning the facilities targeted in this study hardly deviates from all the trends so far reported. In this study, examples that can confirm damage to conduit facilities and support equipment for attaching conduit to beams were acknowledged as damage. As for damage to the bridges themselves (i.e., excluding damage to conduits) in

Table 1 – The number of target facilities in this study

	Damaged	No damage	Total	Damage ratio
Iwate	16	284	300	5.33%
Miyagi	48	357	405	11.9%
Fukushima	25	148	173	14.5%
Ibaraki	8	82	100	8.00%
Total	97	881	978	9.92%

the form of cracking of parapets and ground settlement at the around abutments, it was also considered out of the scope of this study.

3. Assumptions concerning seismic-motion data

As for the damage analysis, in addition to data stored in NTT's existing database concerning various kinds of conduit, data concerning distribution of seismic motion during the Great East Japan Earthquake and ground information was utilized. Since the data concerning seismic-motion distribution was inferred as surface data from point data available to the public, a method for estimating spatial distribution of seismic-motion data is proposed in this report.

As for this estimation of spatial distribution, data from a total of 1114 observation points were utilized. On the basis of this data and epicenter data, spatial interpolation by the simple Kriging method was applied, and PGA (peak ground acceleration), PGV (peak ground velocity), Spectral intensity values were estimated in terms of 250-m-mesh units. In this paper, Spectral intensity is used for damage case analysis, hence the method for calculating Spectral intensity is explained in simple terms as follows.

3.1. Spectral intensity

By integrating velocity response spectrum (S_V) in a section in which the periodic band concerning the damage to a structural object is 0.1 to 2.5 seconds, the following equation is obtained.

$$SI = \frac{1}{2.4}\int_{0.1}^{2.5} S_V(h,T)dT \tag{1}$$

Attenuation constant h was taken as 0.2. Here, Equation (1) and the next degree of ground amplification were applied, and SI_{b500} was obtained in the same manner as follows equations [1].

$$X_S=\alpha\cdot X_b \ (X_b<X_1) \tag{2}$$

$$X_S=X_L-\beta\cdot(X_b-X_2)^2 \ (X_1<X_b<X_2) \tag{3}$$

$$X_2 = \frac{2}{\alpha}X_L - X_1 \tag{4}$$

$$\beta = \frac{X_L - \alpha \cdot X_1}{(X_2 - X_1)^2} \tag{5}$$

$$X_S = X_L \ (X_b > X_2) \tag{6}$$

$$\log\,(\mathrm{ARS}) = 1.889 - 0.7 \cdot \log(AVS20) \tag{7}$$

$$\log(SI_1) = 1.6 \cdot \log(AVS20) \tag{8}$$

$$\log(SI_L) = 0.48 + 0.8 \cdot \log(AVS20) \tag{9}$$

Here, in Eq. (2)-(9), $\alpha=ARS$, $X_1=SI_1$, $X_L=SI_L$, $X_S=SI$, and $X_b=SI_{b500}$. From SI_{b500} obtained as explained above, SI_{b500} for each mesh was estimated by the Simple Kriging method.

AVS20 was obtained from AVS30 by using the following empirical formula [2].

$$AVS30 = 1.13 \cdot AVS20 + 19.5 \tag{10}$$

As for the data concerning AVS30, data for each 250-m mesh obtained by Wakamatsu et al. [3] was used.

The following distance-attenuation formula was used for the trend components used by the Simple Kriging method [4].

$$\log_{10} SI_{b500} = c_1 \text{-} \log 10(R + c_2) + c_3 \tag{11}$$

Here, R is shortest distance of a fault, and c_1, c_2, and c_3 are regression coefficients. Moreover, as a covariance model, an exponential model—expressed by the following equation—was used.

$$\gamma = Var\left[X^2\right] \exp^{(-h/a)} \tag{12}$$

Here, $Var[X^2]$ is the variation of $X=SI_{b500}$ for each observation point, h is the distance between the calculation target point and the strong-motion observation point, a is a correlation range, γ expresses the covariance of X and h. In this study, a was set to 40 km. By applying Eq. (2)-(10) to SI_{b500} for each mesh, SI(Spectral Intensity) for each mesh was obtained.

4. Investigation of cause of damage

In this section, the cause of damage is shown. In this investigation, first, the cause of damage was inferred from the damage mode of the conduit. As shown in Fig. 2, when the damage mode is classified as two cases, one in which displacement in the axial direction is ascertained, and the other one in which displacement in direction perpendicular to the axial direction is ascertained, it becomes clear that the great majority of damage cases were ascertained as displacement in the axial direction. It is also clear that in the majority of the damage cases in which damage is caused, telecommunication-conduits attached to bridges are subjected to a large seismic action in the axial direction of the conduit.

Fig. 2– Examples of damage mode

Next, the damage ratio due to the performance of joints was investigated. The NTT conduit attached to bridges can be generally categorized as two types. The first type is equipment installed before renewal according to current design guidelines (hereafter referred to as “old-standard conduit”); the second type is equipment installed in accordance with current design guidelines (hereafter referred to as “current-standard conduit”). The biggest difference between the old- and current-standard conduits is the expansion and contraction performance of the joints. The joints of old-standard conduit are designed in consideration of expansion and contraction due to temperature variation; on the other hand, the joints of current-standard conduit are considered in terms of displacement due to seismic motion in addition to expansion and contraction due to temperature variation. As examples, joints of the current-standard conduit and those of old-standard conduit (using steel pipe) are shown in Fig. 3. Compared to the joints of the old-standard conduit, those of the current-standard conduit can expand and contract more than twice the distance.

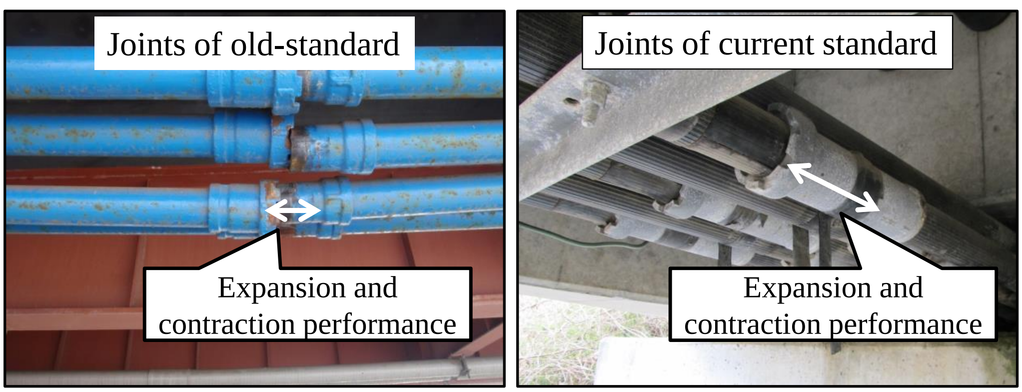

Fig. 3– Jonits of old-standard and joints of current-standard

The damage ratios for the old- and current-standard conduits are listed in Table 2. It is clear that since performance takes seismic motion into account, the damage ratio for current-standard conduit is smaller. And it is considered that since bridge-attached conduit is attached to beams of bridges, the behavior of conduit in the axial direction is dominated by that in the axial direction of the bridge beams. Although it is considered that displacement in the axial direction of the bridge beams is large at places that depend on the structure of the bridge itself (such as length of supports and spans, shoe), in this section, damage analysis is performed with focus on bridge length and intensity of seismic motion.

Table 2 – The damage ratios for the old- and current standard conduits

	Damaged	No damage	Total	Damage ratio
Old-standard	78	613	691	11.3%
Current-standard	19	247	266	7.14%
Total	97	881	978	9.92%

As for the intensity of seismic motion, according to the results of a damage analysis of road bridges performed by the Japan Society of Civil Engineers, damage ratio has a good correlation with PGV and Spectral intensity value. Moreover, from the viewpoint of the present study, which focuses on amount of displacement of the beam of a bridge, spectral intensity was applied as a parameter. The results of damage analysis taking bridge length as a parameter and the results of damage analysis taking Spectral intensity as a parameter are shown in Fig. 4. It should be noted that in regard to some equipment, data on bridge length could not be acquired, for this reason the analysis results concerning that equipment were excluded from the figures. Although error due a lack of certain data is present, a clear trend is confirmed: as bridge length increases, Spectral intensity value increases and damage ratio for conduits also increase.

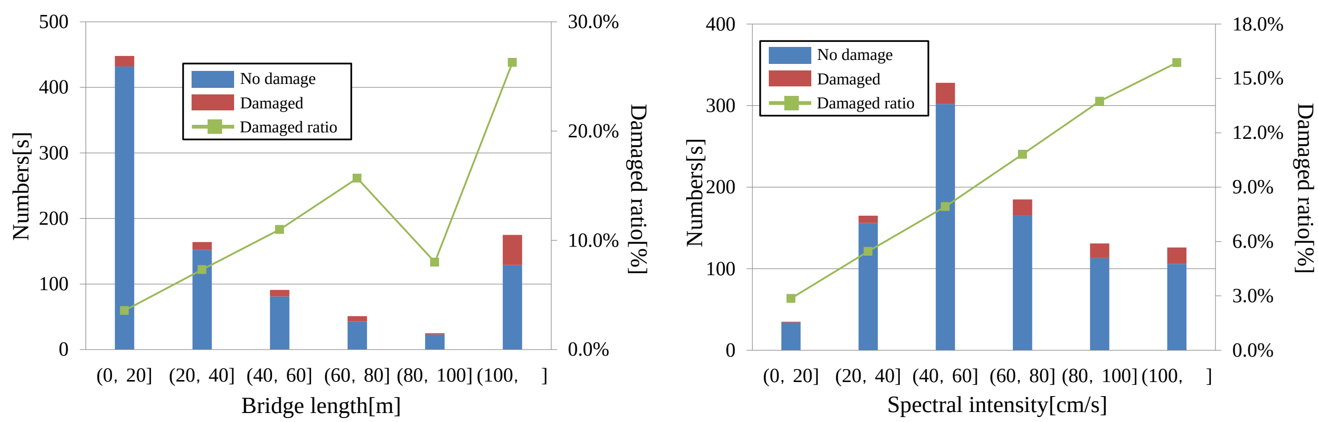

Fig. 4– The damage analysis by bridge length and spectral intensity

From the results presented above, it is conceivable that the mechanism by which bridge-attached conduit is damaged can be explained as follows. The beams of the bridge are subjected to seismic motion and are thereby displaced in the axial direction; simultaneously, the conduit attached to the beams follows that displacement. The displacement of the conduit is absorbed by the expansion and contraction performance of the joints. However, in the case that the joints are subjected to a large displacement exceeding their admissible displacement, the conduit attached to the bridge suffers damage. To validate that tentative theory, damage analysis focusing on certain parameters, the standard of the pipe, bridge length, and Spectral intensity, used in previous analyses was performed. The results of that analysis for old-standard and those for current-standard are given in Fig. 5.

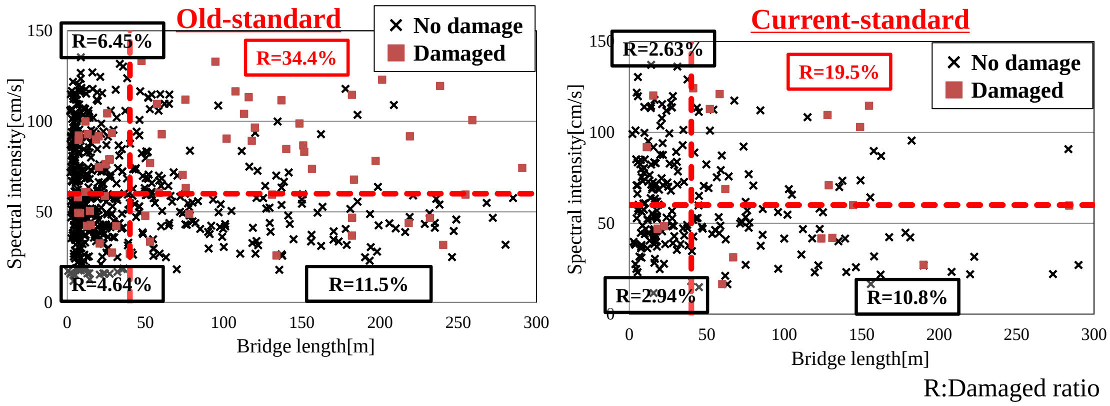

Fig. 5– The damage analysis by bridge length, spectral intensity and kind of joints

In this paper, bridge length of 40 [m] and spectral intensity of 60 [cm/s] are taken as tentative thresholds, and damage ratios for each quadrant were shown in Fig. 5. It was revealed that as bridge length and seismic-motion intensity increase according to the tentative theory derived from each analysis result, damage ratio also increases. When individual groups are focused on, bridge length in the case of the old-standard conduit is 40 [m] or more, and it became clear that the group whose SI value was revealed at seismic motion of over 60 cm/s has a damage ratio that is more than ten-times higher than that of the group that might conceivably receive the greatest damage. As for enforcing seismic strengthening, although individual investigations considering, for example, the structure of bridges are required, it is conceivable that the results of the present investigation will be useful for primary screening of targeted facilities.

5. On-site survey

In this section, parameters that might contribute to damage were determined by on-site surveys, and which of those parameters contribute especially to damage was identified analytically. The numbers of surveys performed are listed in Table 3. Among 978 places targeted for analysis, 140 places (namely, 97 places confirmed to suffer damage due to Tohoku Earthquake in 2011 plus 43 places that did not suffer any damage at that time) were surveyed.

Table 3 – The number of on site surveys

	Damaged	No damage	Total
Old-standard	78	19	97
Current-standard	25	18	43
Total	103	37	140

The items surveyed, estimated to be related to displacement in the axial direction, were number of spans, gap length between beam and abutment, type of bearing, and expansion joints. Hereafter, number of spans and gap length between beam and abutment, which were ascertained to be well correlated with damage, are focused on. The relationship between number of spans and damage ratio and that between gap length and damage ratio is shown in Fig. 6. Although scatter in the number of data points exists, it is clear that as number of spans, gap length between beam and abutment increase, damage ratio also increases.

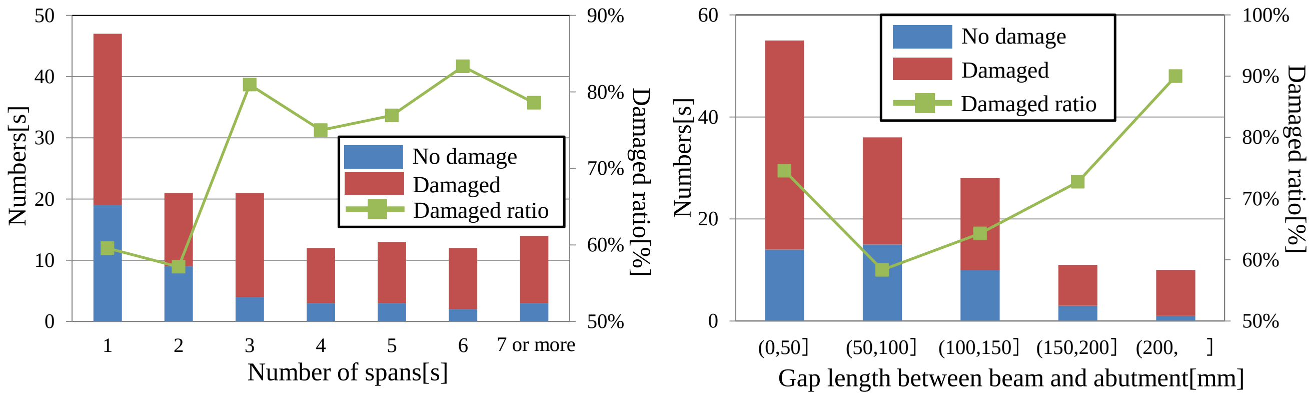

Fig. 6– Damage case analysis by the result of on-site investigation

According to specifications for highway bridge [5] gap length between joints is designed so as to prevent impact between for example, upper structures, upper structures and bridge abutments. As a result, in case of bridges with large gap length between joints, the displacement in the axial direction of bridge beams during an earthquake is bigger. It is thus conceivable that conduit facilities attached to the bridge beams will be subjected to large displacement in the axial direction and thereby be susceptible to damage. As for span number, it is presumable that when the span number increases, the behavior of the bridge itself becomes complex, and the damage ratio increases as a result. These results suggest the order of priority for seismic strengthening to assign to each conduit facilities identified by the primary screening to have a high susceptibility to damage during an earthquake.

6. Conclusions and future research

In this paper, the results of seismic-damage analysis focused on bridge-attached conduits which are vital parts of a communications network were presented. To perform damage analysis of bridge-attached conduits subjected to seismic action during the Great East Japan Earthquake and identify facilities with a high susceptibility to damage, a tentative theory that draws attention to displacement of the beams of the bridge itself as well as the expansion and contraction performance of the conduit was put forward, and the susceptibility to damage of conduit facilities was quantitatively estimated by applying multiple parameters. In particular, the damage ratio for groups most susceptible to damage was quantitatively estimated to be over-ten-times higher than that for groups presumed to be less susceptible to damage.

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