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Earthquake damage analysis to telecommunication conduit in liquefied area

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ABSTRACT: Structural safety and maintenance of communicational function of lifeline communication systems at the time of an earthquake are important subjects for disaster prevention, hence investigations have been made from various viewpoints. Investigation of the earthquake resisting strength of conduits for buried communication cables is one of those subjects. This report describes the results of analysis of damage to conduits for communication cable in Noshiro City. The damage was caused by Nihonkai-chubu earthquake in 1983. The analysis concern the relationship between the strength of the conduit joint and the permanent displacement of the ground.

1 DAMAGE TO CONDUITS FOR COMMUNICATION CABLES

An example of damage to a conduit joint is shown in Fig. 1. This conduit is a steel pipe with 89.1 mm outer diameter and 4.2 mm wall thickness. It is connected by a threaded joint of 120 mm total length. As shown in the photograph, jointing parts of the conduits show crank like bending by rotation around the socket. However, because the rigidity of the socket was higher than the conduit, deformation of the socket was hardly found, and one of the conduits was bent until the section of pipe was completely closed, while the section of another conduits remained open because of the plastic deformation of the threadridge in spite of the bending.

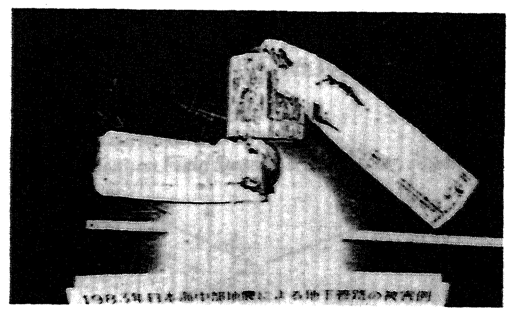


Fig.1 Example of telecommunication conduits damage caused by Nihonkai-chubu earthquake

2 DISTRIBUTION OF GROUND PERMANENT DISPLACEMENT

Fig. 2 shows the plan of one section (length: about 250 m) of Telecommunication conduits which includes damaged positions(▲). Also, permanent displacement vectors, which were obtained by an aerial photographic survey, are shown. Each measuring point was set on both sides of the conduits at intervals of about 20 m and permanent displacements of the conduits were obtained by interpolating measured data from pairs of measuring points which hold conduits between them. Fig. 2 shows the results.

As seen in Fig. 2, the distance between the manholes at each end shows a relative reduction of about 85 cm, distribution of permanent displacement in the direction of the pipe axis shows nearly linear change over the total length of about 250 m, and compressive strain of about 0.35% was generated. In addition, the horizontal distribution of displacement in the direction which is rectangular to the pipe axis is small within an interval of about 50 m around the damaged position, and shows 34 cm maximum displacement at the front and rear ends of the above interval. Displacements in the vertical direction (amount of subsidence) varies in the range of 26 to 47 cm but, as a whole, subsidence is nearly uniform.

Permanent displacement in the direction of the pipe axis and permanent displacement in the direction rectangular to the axis, which were described above, are called lateral shifts and can be shown by the models in Fig. 3. Permanent displacements which were observed in Noshiro City were expressed by a model as seen in Fig. 3. The upper limit of the relationship between the length of transition

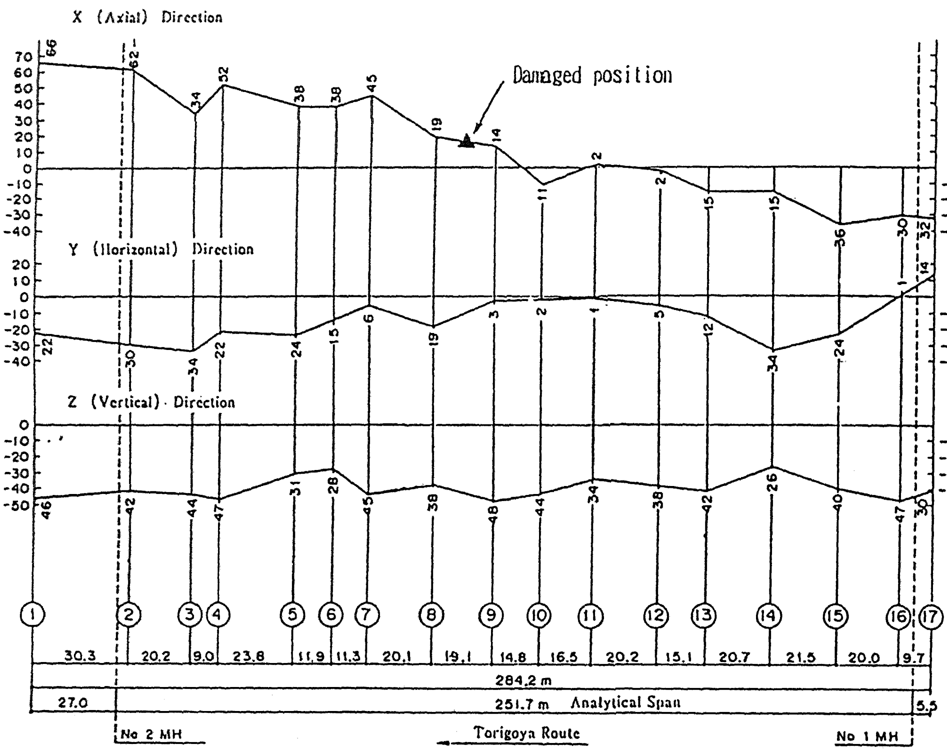
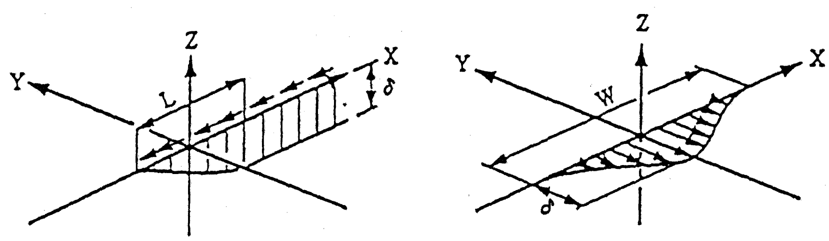


Fig.2 Distribution of permanent displacement in the damaged interval



① Displacement in the direction of pipe axis

② Displacement in the direction rectangular to pipe axis

Fig.3 Model of lateral shift of ground

interval and relative displacement δ, and the relationship between the width of the permanent displacement W and permanent displacement δ is shown by Table 1. Accordingly, in the case of displacement in axial the direction of the pipe, axial strain of the ground ($\varepsilon_g = \delta / L$) is $\varepsilon_g = 3\%$ (constant) when $L \leq 50$ m, but axial strain of the ground in the case of 50 m $< L$ is $\varepsilon_g = 0.6\%$ which is inversely proportinal to L. For instance, when L = 250 m, which is the damaged interval, is substituted in the above equation, $\varepsilon_g = 0.6\%$, which is about 1.7 times the value of the actual measurement (about 0.35%), is obtained. For the direction rectangular to the pipe axis, W = 100 m, δ = 0.2 m is obtained in the neighborhood of damaged position. Accordingly, δ = 1 m is

Tab.1 Upper limit of distribution of permanent displacement (laterral shift)

	L	δ
Displacement in the direction of conduit	$L \leq 50$	3/100*L
	$50 < L < 400$	1.5
Displacement in the direction of rectangular to conduit	$W \leq 150$	1/100*W
	$150 < W < 500$	1/300*W+1

(unit:m)

obtained when W = 100 m is substituted in the above equation. The upper limit of displacement by actual measurement is about 5 times the damaged position.

3 EXPERIMENT COMPRESSIVE STRENGTH OF THE CONDUIT JOINT

Fig. 4 shows the Load-Displacement Curve which was obtained from compression tests on a conduit joint of conduits of 220 m in total length. Yielding load was about 20 tonf and maximum load was 26.7 tonf. Yielding displacement and displacement of maximum loading point were about 1 mm and about 3 mm, respectively. Axial stress on the conduits which corresponded to yielding load and maximum load were 1785 kgf/cm² (0.085%) and 2330 kgf/cm² (0.111%), respectively. As shown in Fig. 5, for the inside of a joint, the screwed part of one conduit was pushed in causing it to penetrate and ride over the inside surface of the other conduit.

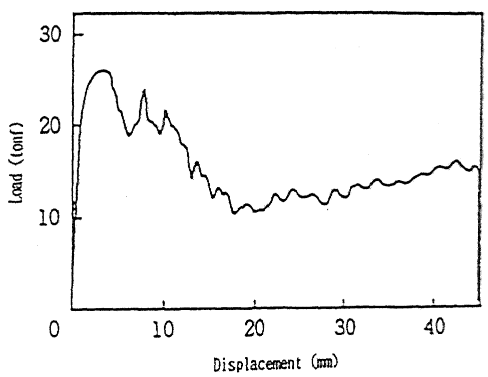


Fig.4 Load to displacement curve of threaded joint

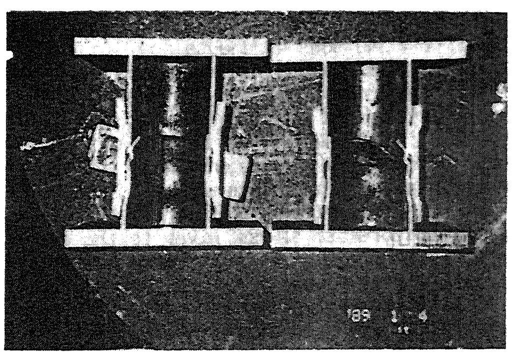


Fig.5 Section of joint after compression test

4 SIMULATION EXPERIMENT OF DAMAGE IN A SOIL TEST TANK

To simulate the damage to a conduit joint, one conduit was buried in a soil test tank made of steel (LBD = 5 × 2× 2 m) and was deformed by applying an axial force using a hydraulic jack, as shown in Fig. 6. To investigate the effect of spring properties of the ground, hard condition (Case H /N = 17 to 21) and soft condition (Case S /N = 4 to 5) were used for test ground. Spring properties of the ground in the direction rectangular to the pipes were directly measured by pulling up a single pipe as shown in Fig. 7.

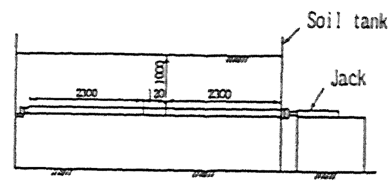


Fig.6 Simulation experiment of damage

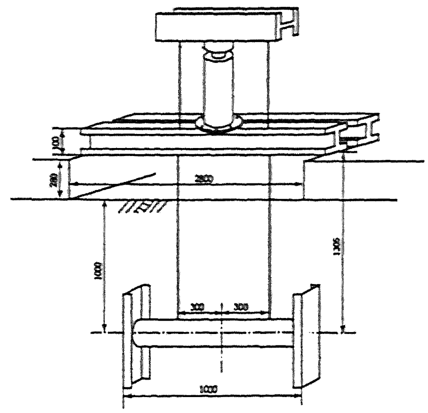


Fig.7 Measuring method of ground spring property

Fig. 8 shows the Load-Displacement Curve which were obtained from experiments on the spring properties of the ground. As shown in the figure, there is a large difference between the spring properties of the ground in Case H and Case S. Namely, in Case H, in the early phase of deformation where displacement is

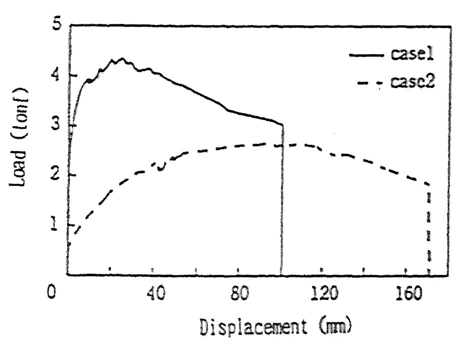


Fig.8 Vertical and upward ground spring property

less then 5 mm, the spring factor is so large that $k = 29.3$ kgf/cm³, and the load shows decrease after the maximum load is reached with a displacement of 20 to 25 mm. It then decreases to about 70% of the maximum load in the phase of displacement of 100 mm. On the other hand, the Load-Displacement Curve in Case S shows a rounded appearance as a whole. Particularly, the spring factor in the early phase of deformation is $k = 7.0$ kgf/cm³, and it shows an increase of load without clear yielding. Maximum load is reached in the phase of displacement of 100 mm, and after that load shows a gradual decrease.

The relation between load and displacement, obtained by simulation experiment, is shown in Fig. 9. Maximum loads are 23 tonf for Case H and 21 tonf for Case S which are nearly the same, and proportional factors in the early phase of deformation are 49.8 tonf/cm for Case H and 40.5 tonf/cm. In this case, such a large difference in spring properties as in Fig. 8, is not observed. The joints of specimens which were dug out show deformation as shown in Figs. 10 and 11. These deformation simulate actual damage very well. In addition, protective conduits which were connected to sockets, were bent by rotating deformation, and plastic deformation remained.

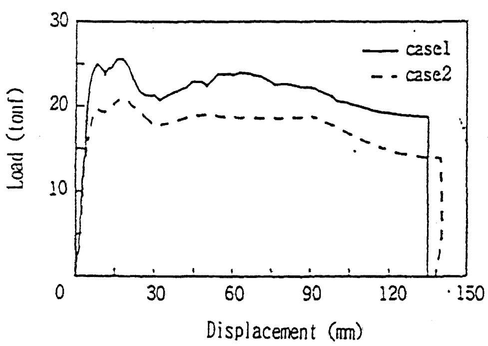


Fig.9 Load to displacement curve obtained by simulation experiment

5 ANALYSIS OF DAMAGE

For long column buckling of a straight elastic beam which is placed on an elastic support, and has infinite length, the fundamental differential equation is expressed by (1). The buckling load N and the buckling wave length L are given by (2) and (3) respectively.

$$EI\frac{d^4y}{dx^4} + N\frac{d^2y}{dx^2} + k_L Dy = 0 \quad (1)$$

$$N = 4EI\,\beta^2 \quad (2)$$

$$L = \frac{\pi}{1.414\beta} \quad (3)$$

Where $\beta = (k_L D/4EI)^{1/4}$. Figs. 12 and 13 show the results of calculations for the buckling load (Eq.(2)) and buckling wave length (Eq.(3)), taking k_L which is the spring factor of the ground in the direction rectangular to the pipe axis, as parameter. L = 0.98 m, N = 470 tonf for Case H, and L = 1.40 m, N = 240 tonf were obtained. In these cases, apparent strains generated in the protective conduits are 1.90% and 0.97%, respectively and both values exceed the elastic limit (0.085%) of strain which is generated in the conduits. Thus, elastic buckling in the long column mode is found not to occur in the ground condition of the soil tank. Consideration is now given to the case in which the threaded joint shows plastic deformation under axial force as shown in Fig. 5, and shifts to deformation by rotative movement of the socket as shown in Figs. 10 and 11. In this case, conduits becomes elongated because of the loss of axial rigidity of the socket, and rotative movement of socket results. Hence, the total length of conduits is assumed to become shorter by the rotative displacement of the socket. The behavior of conduits at the time of an earthquake can be estimated by approximating the half of value of reduction as displacement of free and of semi-infinite straight conduits in uniform field of strain of ground

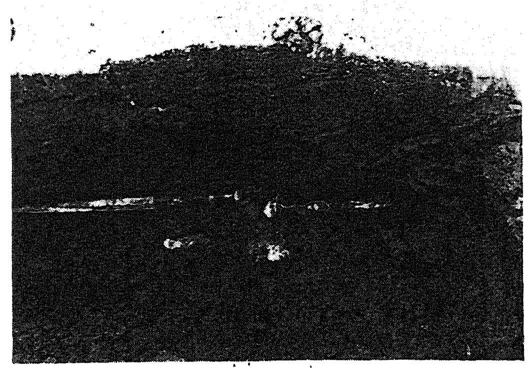


Fig.10 Specimen after test (Case H)

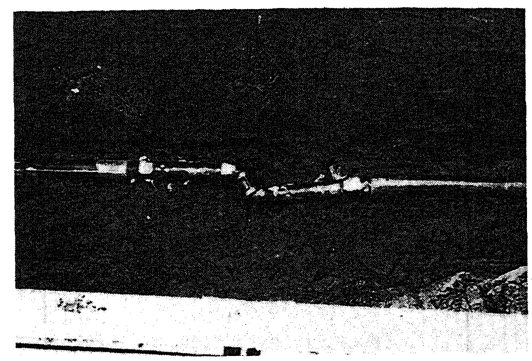


Fig.11 Specimen after test (Case S)

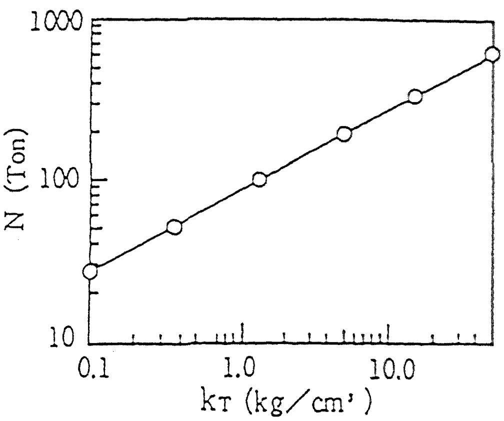


Fig.12 Buckling load

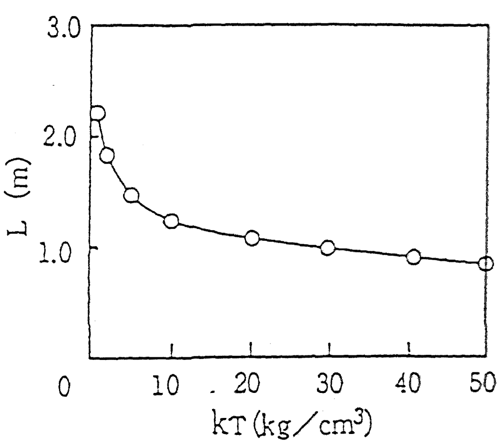


Fig.13 Buckling wave length

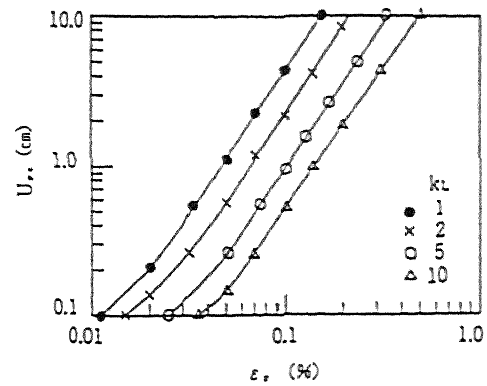


Fig.14 Displacement of semi-infinite straight conduit

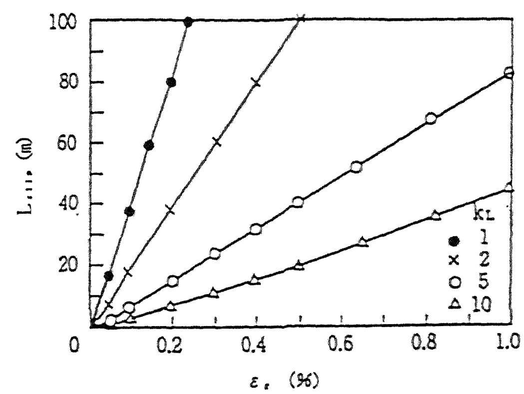


Fig.15 Slip length of semi-infinite straight conduit

When displacement of the ground is distributed in an axial direction of a semi-infinite straight conduits, the equation of balance is expressed by (4). Assuming the spring property of the ground by elasticity to complete plastic body, displacement of pipe end Upe is expressed by equation (5), and the length of slipping ℓ_{slip} is expressed by equation (6). Results of calculations using equations (5) and (6) with U_{cr} = 0.1 cm are shown in Figs. 14 and 15.

$$EA\frac{d^2U_p}{dx^2} + \pi Dk_L\,[U(X) - U_p(X)] = 0 \qquad (4)$$

$$U_{pe} = \frac{1}{2\alpha^2U_{cr}}(\varepsilon_g^2 + \alpha^2U_{cr}^2) \qquad (5)$$

$$\ell_{slip} = \frac{1}{2\alpha^2U_{cr}}(\varepsilon_g - \alpha U_{cr}) \qquad (6)$$

where, $\alpha = (\pi Dk_L/EA)^{1/2}$, k_L: Spring factor and U_{cr}: Relative displacement of yielding.

As described formerly, assuming that ε_g = 0.35% and displacement of the pipe end is 10 cm, $k_L \fallingdotseq$ 5.5 kgf/cm³ is obtained from Fig. 14. Frictional force of the ground is estimated to be about τ = 0.55 kgf/cm² because U_{cr} = 0.1 cm. This frictional force is significantly larger than the frictional force in a completely liquefied state, so the strength of the ground in the neighborhood of the conduit is assumed to be little reduced. the length of slip is estimated to be about 30 cm from Fig. 15.

6 CONCLUSION

Earthquake damage to conduits for buried communication cables, which was caused by Nihonkai-chubu earthquake, was analyzed in relation to permanent displacement of the ground, and simulation experiments were carried out using a soil tank. The results of the experiments showed that a compression strain of 0.35% was caused in the ground in an axial direction by permanent displacement. Hence, the collapse of the joint is assumed to be caused by this compressive strain. Spring properties of the ground at the time of generation of permanent displacement was estimated from fundamental analysis of deformation. Frictional force in the neighborhood of the conduit was τ = 0.55 kgf/cm^2 at least, and this value is assumed to be sufficiently larger than the value in the state of complete liquefaction.

7 FUTURE DIRECTION

We have studied the cause of the conduits damage due to each of ground motion and ground deformation. Particularly, as concerns ground deformation, the actual damaged conduits by Nihonkai-chubu earthquake was an object of study, and we have investigated the cause of the conduits damage due to ground deformation with analytical method. The experiment of this paper has two purposes. One is simulation of conduit damage by Nihonkai-chubu earthquake, and the other is verification of propriety of above analysis results. In the future, we will appriciate these results, and investigate how to construct the high reliability conduit facilities and reinforce of earthquake resistant for existing conduit facilities.

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