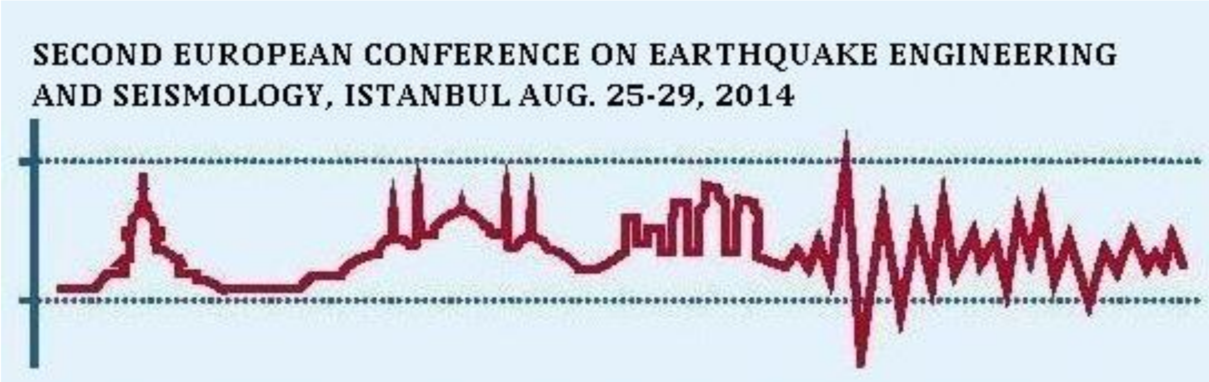


ANALYSIS ON LAYING FORM OF TELECOMMUNICATION CONDUITS SUSCEPTIBLE TO EARTHQUAKE

Masato WAKATAKE[1], Katsumi SAKAKI[2], Shin KATAGIRI[3] and Takanobu SUZUKI[4]

ABSTRACT

Telecommunication conduits are required to provide safe underground space for inner cable. Learning from the experience of many large earthquakes in Japan, , countermeasures that improve reliability of telecommunication facilities have been introduced. Many old standard conduits which were constructed high economic growth period from 1960's to 1980's are active service, and which are considered to earthquake-proof is lacking. To improve reliability of conduits, it is ideal to renew all old standard facilities to the latest ones. However it is not practical for a huge amount of facilities. In this study, the seismic evaluation method of underground pipeline systems wii be established to handle this problem. In this paper, the line type of conduits is especially focused. Conduit is modeled to reflect the line type which exists actually, the models are analyzed by seismic displacement method. In case of various line type forms, the forces acting conduits are evaluated quantitatively compared to standard line type.

INTRODUCTION

Nippon Telegraph and Telephone (NTT) owns conduits of about 620,000km all over Japan, and has provided communication services with laying the cable using underground pipeline systems. Many of them were constructed during 1960's to 1980's. These facilities were constructed efficiently with same design method in uniform following NTT's manual. Now the PVC pipe is standard, but at that time the steel pipe was standard for underground conduits. The number of conduits of constructed per year and pipe type is shown in Figure 1. Cause the communication quality is not greatly reduced even if some degradation occurs in the conduits, therefore the purpose of effective use of existing infrastructure stock, it is required to using these old steel pipes for a long term from now. However old conduits are considered to earthquake-proof is lacking because these do not have the elasticity or flexibility for the screw joint structure. In 1985, the latest standard of pipe was introduced, but from Figure 1 it can be seen over 80% of all conduits are old standard. The lining technology is solution for this issue (Okutsu et al.,2012). This is a pipe renovation technology that creates space by the new PVC inner pipe into the outer steel pipes; furthermore this technology can improve the seismic reliability. It is ideal to apply this technology to all old conduits, but it is not practical for a huge amount of facilities. For effective improvement of network reliability against earthquake, it is necessary to grasp the facilities to be weak point when earthquake happens. Moreover it is necessary to implement countermeasures to just weak point. So our goal is to establish evaluation method that can identify conduits which can be damaged during large earthquake considering deterioration due to

[1] Engineer, NTT Access Network Service Systems Laboratories, Tsukuba Japan, wakatake.masato@lab.ntt.co.jp
[2] Supervisor, NTT Access Network Service Systems Laboratories, Tsukuba Japan, sakaki.katsumi@lab.ntt.co.jp
[3] Professor, Setsunan University, Neyagawa Japan, shin-k@civ.setsunan.ac.jp
[4] Professor, Toyo University, Kawagoe Japan, tsuzuki@toyo.jp

corrosion, structural factors due to laying form and ground condition around buried conduits. In other words, the advancement of evaluation technology for earthquake-proof considering the real conditions is studied.

In this paper, the laying form of conduits is especially focused. By numerical analysis reflecting the line type which exists actually, the stress acting conduits are evaluated quantitatively compared to linear structure.

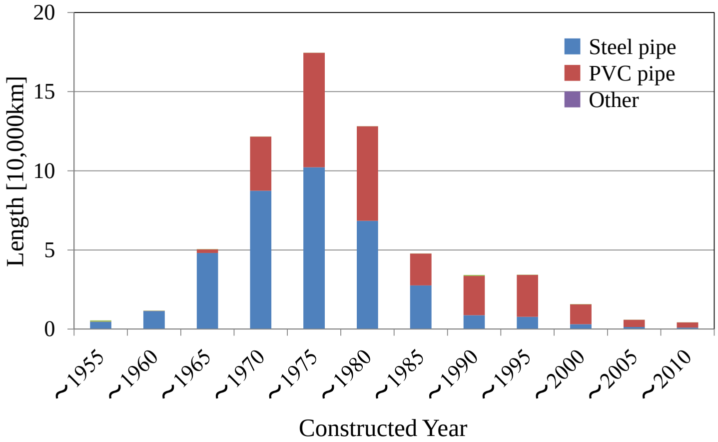


Figure 1. The number of conduits and pipe type concerned to constructed year

TOHOKU EARTHQUAKE (2011)

Before the main topics of our study, the damage cases of telecommunication facilities in Tohoku Earthquake are introduced.

The areas damaged in Tohoku Earthquake ranged widely in eastern Japan, and about 1.5million fixed lines (only NTT service) were damaged and over 6,500 base stations of mobile phone (only NTT service) were damaged. Tsunami and power failure were the main cause of damage, but there were damaged cases that caused by conduits damage. After the earthquake, NTT has carried out inspections of facilities in the entire area where was affected by the earthquake. Table.1 shows the damage number of conduits.

Table 1. Damage numbers of telecommunication conduits

Area classification	Number of facilities[km]	Inspection number[km]	Damage number[km]	Damage ratio[%]
Tsunami area	430	70	13.7	3.1
Liquefaction area	230	41	8.1	3.6
Other area	5,100	280	41	0.8

Fig.2 shows the examples of damaged case in Tsunami area. Fig.3 shows the examples of damaged case in liquefaction area. Fig.4 shows the examples of damaged case of conduits in other area that the conduits are affected only seismic wave or ground deformation.

Figure 2. Damaged cases of telecommunication infrastructure in the tsunami area

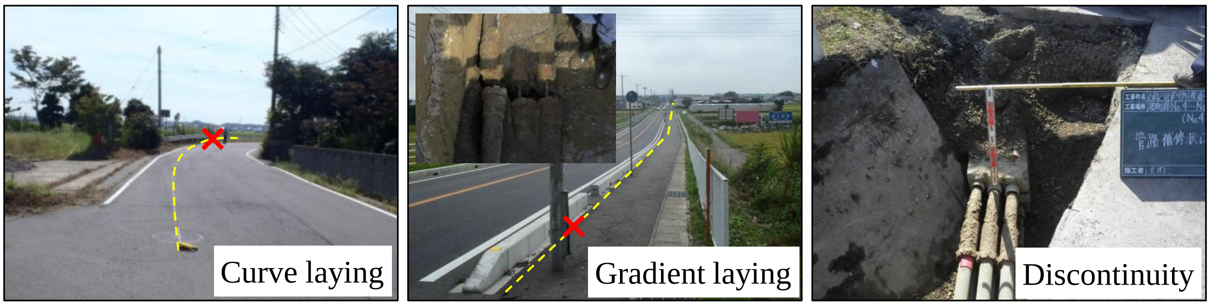
Figure 3. Damaged cases of telecommunication infrastructure in the liquefaction area

Figure 4. Damaged cases of telecommunication infrastructure in the other area

ANALYSIS OF DAMAGED STEEL PIPE IN OTHER AREA FOCUSING ON LINE TYPE OF CONDUITS

In this paper the damaged cases of steel pipe in other area are focused. The reasons of this are the targets for improvement of seismic reliability by lining technology is steel pipes, a study focusing on line type of conduit during large earthquake has never done in NTT, further the amount of facility in this category is most often. In this section, the damaged case focusing on line type and statistical analysis of these damaged pipes in the Tohoku Earthquake are shown.

The laying forms have classified into three types by investigating damaged cases (including authors do not show in this paper), curve laying, gradient laying and discontinuity. The damaged cases of steel pipe of each line type are shown in Fig.5. The curve laying is applied when pipes are buried under curved road. The gradient laying is applied when pipes have to avoid obstacle, such as other company's conduits. Discontinuity is applied when pipes are buried shallowly underground, and in that case pipes are protected from such as road excavation, thus pipes are reinforced by concrete.



(a) (b) (c)

Figure 5. Damaged cases of each line type

Fig.5 (a) is the damaged case of curve laying. The dashed line is conduit route and the cross mark is damaged point. In this case from the result of inspection by pipe inspection camera, soil inflow was confirmed. Break of the joint part of conduits is expected. Fig.5 (b) is the damaged case of gradient laying. From the situation of the repair work, it can be seen the joints were pulled out.

Fig.5 (c) is the damaged case of discontinuity. This picture was taken at repair work. The pipes are reinforced by concrete to protect pipes and inner cables from other works. In this case, joints at the edge of concrete were broken by seismic motion. The reason of damage is the behavior of concrete part and that of the conduits part are different during earthquake. In other words, the concrete parts are easier-to-follow the ground motion than conduits part. Behavior of the pipeline systems becomes discontinuity, strain of the pipe is amplified. Therefore this damaged case was happened.

Next, the analysis of damaged steel pipe in the Tohoku Earthquake that was confirmed laying form is shown. Table.2 shows the damage ratio of each defined laying form. The definition of each laying form is as follows: the curve laying is containing the section of radius of curvature is under than 100m, the gradient laying is containing the section of slope angle is more than 1degree, discontinuity is containing the concrete reinforcement section.

Table 2. Damaged number of metal pipe concerned to each laying form

Laying form	Inspection number[span]	Damaged number[span]	Damage ratio[%]
ALL	1,064	82	7.7
Curve laying	61(estimation)	6	9.8
Gradient laying	Unknown	56	Undefined
Discontinuity	100(estimation)	22	22

Of course there are conduits that have no features defined, or conduits have more than two features. Therefore the total number of damaged case is not match the sum of the number of each laying form. Inspection number of curve laying and discontinuities is estimated by NTT's investigation result of conduits laying form. In Table.2, the damage ratio of curve laying and discontinuity are higher than that of the entire steel pipe. In the following section, this fact is quantified by numerical analysis using seismic displacement method.

SEISMIC DISPLACEMENT METHOD CONCERNING LAYING FORM OF CONDUITS (CURVE LAYING)

In this section, the numerical analysis of curve laying conduits is executed . In deed the NTT's steel pipes are connected by joints which have nonlinear property every 5.5m. However in this study for the purpose of grasping the trend of response value by laying form, the nonlinear properties of joints are ignored. The pipe property is shown in Table.3, the ground property between steel pipe and soil is shown in Table.4. The ground property is set by past NTT's experimental. The digest is shown in Table.5, and from the result, the ground property is set as Table.4. The ground property is bilinear form as shown in Fig.6. The letter k and k' are spring constants per unit area.

Table 3. Pipe property

Elastic modulus[N/mm^2]	Outer diameter[mm]	Thickness[mm]
$2.06*10^5$	89.1	4.20

Table 4. Ground property

	Axial direction	Cross axial direction
k[N/mm^3]	$5.80*10^{-3}$	$2.70*10^{-3}$
k'[N/mm^3]	$5.00*10^{-4}$	$2.70*10^{-5}$
δ	5.00	40.0

Table5. Result of soil-steel pipe interaction test(Axial direction)

	Parameter of steel pipe		Input parameter	
Cross-sectional structure	Circumference [mm]	Length [mm]	Frequency [Hz]	Amplitude [mm]
2×2	880	8000	0.5	30
3×3	1480	8000	0.5	30
	Results of soil tank experiments			
Cross-sectional structure	Displacement of pre-slip[mm]	Restraining force pre-slip[N]	Maximum displacement[mm]	Maximum restraining force[N]
2×2	2.1	$7.6*10^4$	27.1	$1.6*10^5$
3×3	1.2	$7.7*10^4$	27.3	$2.1*10^5$

From the Table.5, the average of k, the soil-steel pipe spring constant is $5.3*10^{-3}$[N/mm^3], the average of k' is $4.65*10^{-4}$[N/mm^3]. The letter k' is a soil-steel pipe interaction after slippage (For example Fuchida et al 1991). The spring constant used in numerical analysis are set to the average that increased about 10%. In the soil tank test, displacement of pre-slip were around 2[mm], though in the numerical analysis, the value is set as 5[mm] to act the large restraint force to the steel pipe and to emphasize the difference of the result of the numerical analysis considering line type. The image of bilinear property of soil-steel pipe interaction is shown in Fig.6.

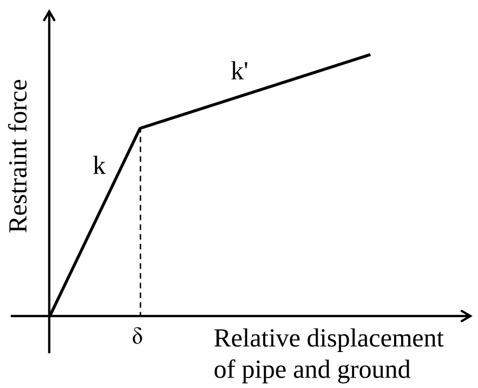


Figure 6. Bilinear model of ground and metal pipe

Using these defined parameters, conduits models are analysed. The parameters of curve laying are crossing angle θ and radius of curvature R. The range of parameters are as follows: R={2.5m,10m},θ={4°,8°,10°, 20°, 30°, 60°, 90°}. According to NTT's construction manual, minimum radius of curvature allowed is 10m, only in the unavoidable case it is instructed to 2.5m or more. Maximum crossing angle allowed is 60°, thus these parameters are selected. In this study, curve section is exist in the center of the conduits shown in Fig.7.

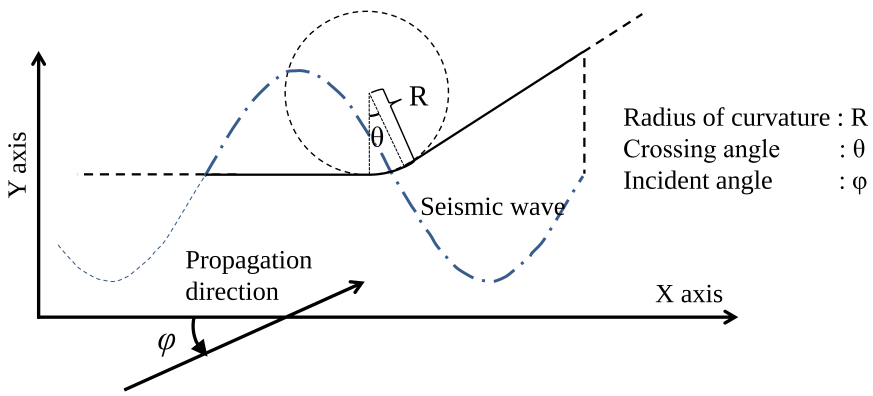


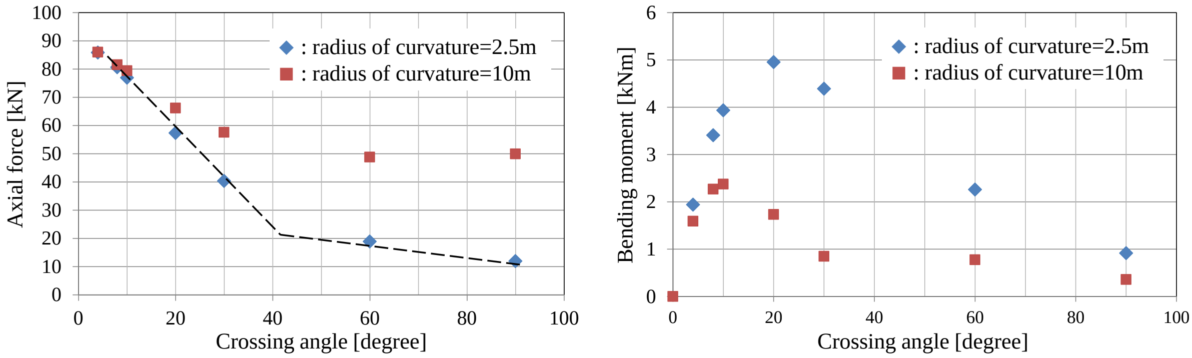
Figure 7. The outline of curve laying model

Incident angle is tangent direction of the midpoint of curve section(φ=θ/2 in Figure 7), phase is that the maximum ground strain occurs at the midpoint of the curve section. The reason of these seismic situation is that when small diameter pipe like telecommunication conduit is received seismic wave, it is known the external force actiong in the axial direction of pipe especially ground strain by surface wave strongly influences to the behavior of the buried pipe (Shi P et al 2008). For this reason, the incident angle is set the deirection that the axial force of midpoint of the curve section is prevailing. The input seismic wave has a displacement amplitude in the direction of travel. The scale of the seismic motion, the apparent wavelength is L, amplitude of surface ground is U, the ground strain ε is defined as Eq.(1).

$$\varepsilon = \frac{2\pi U}{L} \tag{1}$$

In this study, the sine wave input and its ground strain ε is 0.3% are considered The length of conduits is about 100m, the boundary is fixed end, the amplitudes of both ends are 0.

Under the conditions defined, the trend of axial force and bending moment gained by seismic displacement method is considered by the parameter of curved section. The maximum response values of each model are shown in Fig.8(a) (axial force) and Fig.8(b) (bending moment), maximum response were observed at the point of maximum ground strain.



(a) (b)

Figure 8. The result of numerical analysis (curve laying)

From the result, it found that the large axial force is generated as a laying form is closer to linear structure. On the other hand the bending moment, the larger bending moment is generated as a radius of curvature is smaller, and it is a local maximum value near the corssing angle is 20 degree.

Next, the results of curve laying gained the numerical analysis are compared to the that of the linear structure model. The linear structure model is the model that θ=0 in Fig.7. In the linear structure model, the bending moment is not occur, so axial force is P, bending moment is M, cross-sectional area is A, modulus of section is Z, the axial stress σ gained in Eq.(2) is compared. Fig.9 is the result of comparison of the axial stress σ, vertical axis is ratio of the stress of the linear model, the value is larger, the larger force occurs at the curve section. The dashed line is described in order to explicitly the same value as linear structure.

$$\sigma = \frac{P}{A} \pm \frac{M}{Z} \tag{2}$$

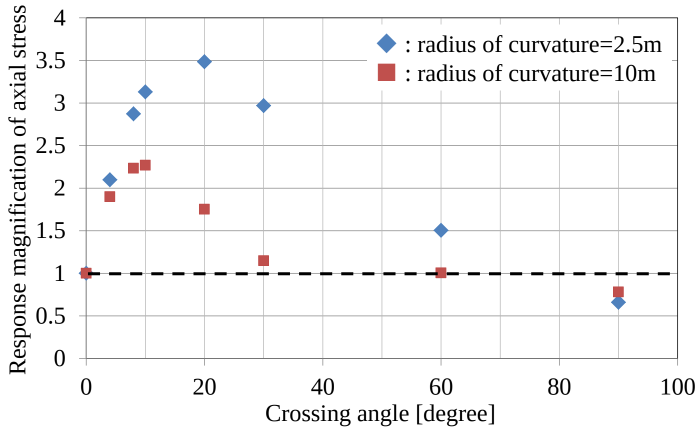


Figure 9. Compare the axial stress (curve laying)

In the larger case of the response magnification, more than 3 times of the axial stress occurs at the curved section compared to the linear structure. The trend of the response magnification is similar to the that of the bending moment, that is, the crossing angle is main parameter to the response magnification.

SEISMIC DISPLACEMENT METHOD CONCERNING LAYING FORM OF CONDUITS (GRADEIENT LAYING)

In this section, the model and result of numerical analysis of gradient laying are shown. The model is shown in Fig.10.

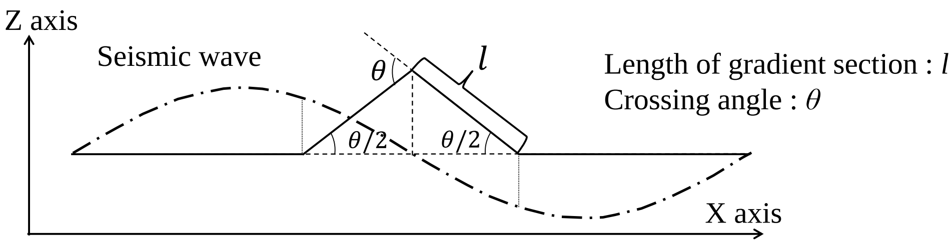


Figure 10. The outline of gradient laying model

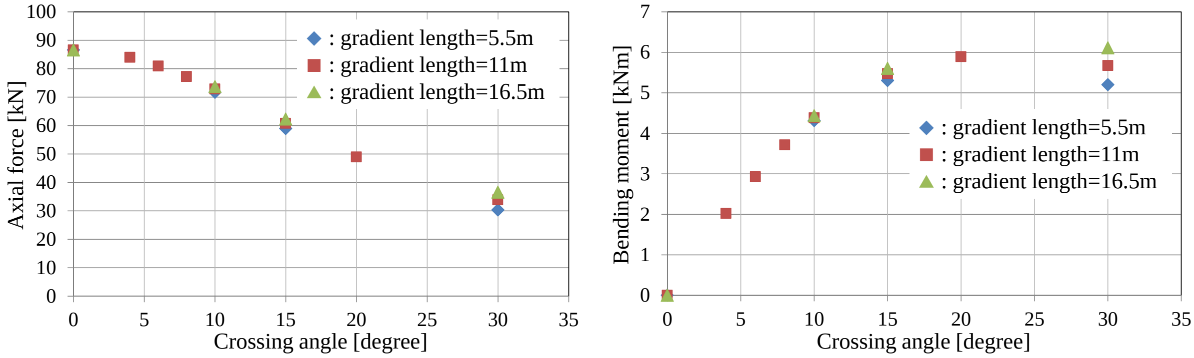
This is assumed that the obstacle exists in the conduits route then the pipe is laid changing laying form shaply over the top of the obstacle to avoid another buried object. The reason authers consider this laying form, damaged cases like this laying form has been confirmed. The basic condition of numerical analysis like pipe properties is equivalent to the that of curve laying. The parameters of gradient laying model are gradient length l and corssing angle θ shown in Table.5.

Table 5. Parameters of gradient length

Crossing angle [degree]	Gradient length [m]
10, 15, 30	5.5, 16.5
4, 6, 8, 10, 15, 30	11

The crossing angle is the value of until the specified limit by the construction manual. The gradient length is 3 patterns with respect to unit length of steel pipe, 5.5m. Conduit lengths are about 100 m, incident angle is along X axis that axial force at the flection point is prevailing.

Under the conditions defined, the trend of axial force and bending moment gained by seismic displacement method is considered by the parameter of gradient laying. The maximum response values of each model are shown in Fig.11(a) (axial force) and Fig.11(b) (bending moment), maximum response were observed at the point of maximum ground strain, at the center of conduit.



(a) (b)

Figure 11. The result of numerical analysis (gradient laying)

The trends of axial force and bending moment show similiar trend of curve laying. The larger axial force occurs, the laying form is closer to the straight. The bending moment reaches local maximum value near the corssing angle is 20 degree.

As with curve laying, comparison of straight conduits and gradient laying of axial stress is shown in Fig.12.

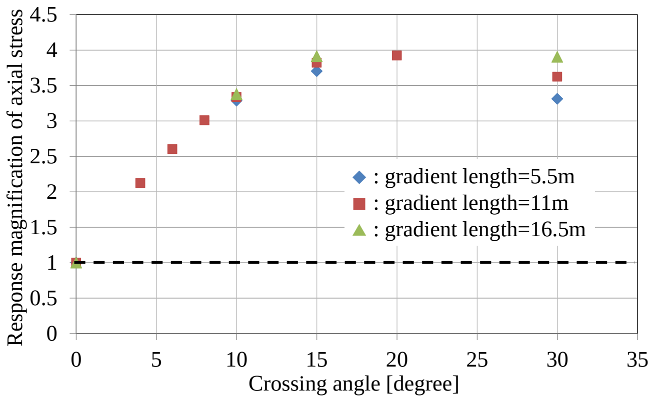


Figure 12. Compare the axial stress (gradient laying)

From the Fig.12, in the case of the magnification is large, the axial stress of four times occurs as compared with liner structure.

SEISMIC DISPLACEMENT METHOD CONCERNING LAYING FORM OF CONDUITS (DISCONTINUITY)

In this section, the concrete is placed around pipe to protect innner pipe from the other work, like road excavation work is considered. In Tohoku Earthquake, the damage case of conduits contain concrete structure is shown, the damages cases like authors show are reported in other lifelines. For example, Higashide et al discuss the damage case of structure encased concrete in water pipeline (Higashide et al 2012). In our study, the concrete protects single pipe shown in Fig.13. The size of concrete is set following construction manual.

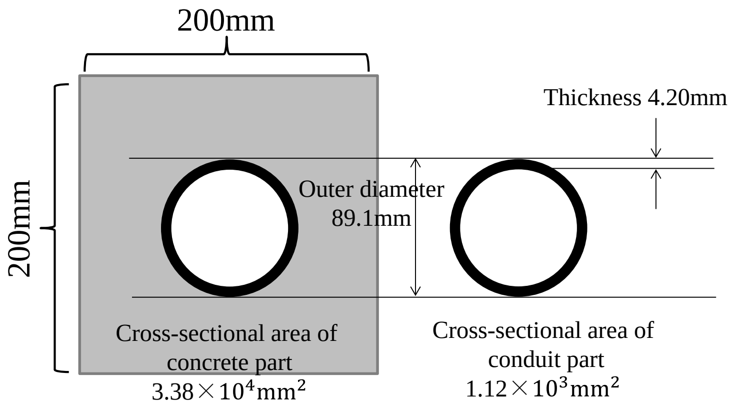


Figure 13. Cross sectional structure of concrete protection part

This part shows a different behavior from the usual conduit (no concrete part). When ground is displaced during earthquake, concrete part moves through the concrete-soil spring. In this study, it assume that the steel pipe and concrete firmly adhere and in this protected part, pipe and concrete show the samse behavior during earthquake. Usually soil-pipe spring constant is defined by frictional force between soil and pipe, however the cross-sectional area of concrete part is larger than that of the non-concrete part. Therefore the restraint force of concrete part is defined by frictional force and the pressure that overhanging concrete part is pressed by ground. From the NTT's experiment of the reflecting the behavior of the concrete part constructed in the shallow buried section, the both forces are defined as follows: the frictional force = $3.92*10^{-2}$*[circumference of concrete]*[length of concrete] (kN), pressure = $7.84*10^{-1}$*[the cross-sectional area of concrete part] (kN). In this study, the length of the concrete part is set $2.20*10^{4}$[mm] as a length of about averege through NTT's investigation, the external force acting whole concrete part is 716[kN], the force acting unit area is $4.07*10^{-2}$[N/mm^2]. The maximum slip value between concrete and soil is 5[mm] as the same value of that of steel pipe and soil, the concrete-soil spring constant per unit area is $8.14*10^{-3}$[N/mm^3]. In this study, this value is used. However this value is assumed value, future authors will study the effect of soil condition and cross-sectional structure that affects concrete-soil spring constant by experiment of soil tank test.

In the concrete part, because the concrete and steel pipe show the same behavior during earthquake is assumed, the properties of this part differs from usual part. In other words, the elastic modulus will difeer. Axial force *P* acts the concrete part, the strain is ε. The elastc modules, cross-sectional area, axial force of concrete part is respectively E_C, A_C, P_C, The elastc modules, cross-sectional area, axial force of steel pipe part is respectively E_S, A_S, P_S, the strain ε is Eq.(3)

$$\varepsilon = \frac{P_C}{E_C A_C} = \frac{P_S}{E_S A_S} \tag{3}$$

The axial force *P* acts to the usual steel pipe and strain of steel pipe is ε_1 then,

$$\varepsilon_1 = \frac{P}{E_S A_S} \tag{4}$$

Using condion of the $P=P_C+P_S$,

$$\frac{\varepsilon}{\varepsilon_1} = \frac{E_S A_S}{E_C A_C + E_S A_S} \tag{5}$$

In the numerical analysis, the difference of the elastic modulus is considered. In this study, because the trend that joints near the boundary of concrete part and usual pipe part are vulnerable is confirmed from the past large earthquakes like Fig.5(c), the axial force acting boundary of concrete and pipe shown in Fig.14 is focused. The concrete part exists in the straight conduits, maximam ground strain occurs at the boundary of concrete part and pipe part. The concrete part is modeled by using the parametes defined. The basic condition of numerical analysis is equivalent the former cases. The bending moment does not occur because the model is straight structure and the incident angle is along the X axis. The length of span is 99m that is divisible by unit length of steel pipe, 5.5m.

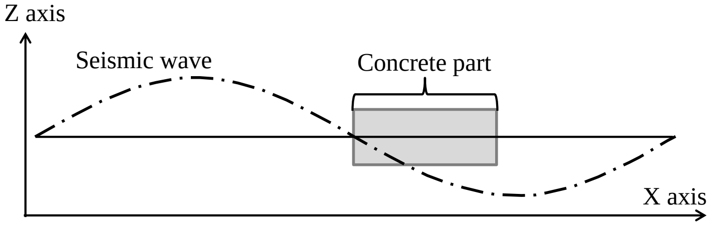


Figure 14. The outline of discontinuity model

The comparison of axial force with and without concrete part is shown in Fig.15.

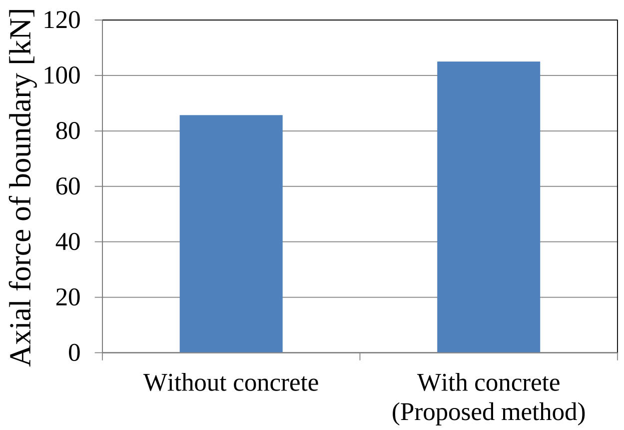


Figure 15. Comparison of axial force

From the result of the numerical analysis, the axial force acting the boundary of concrete and pipe is 1.2 times larger than the model without concrete part. In case that the structure easy-to –follow ground motion like concrete exists in the conduits, the behavior of conduits systems shows a discontinuity. The strain at this point accumulates for this reason. Therefore larger axial force occurs at the boundary of concrete and steel pipe than the conduits systems without concrete. This method is that can reproduce the behavior of the concrete in the span which is considered a weak point during earthquake.

The larger axial force is observed however the maximuma value is about 100 [kN]. In this study the nonlinear joint properties are excluded, even assuming that joints exists, the joints do not break against seismic wave of ground strain 0.3% equivalent (Becouse scrwew joint of steel pipe has a strength of more than 200kN agaisnt axial force). To reveal the high accuracy behavior of underground pipeline systems, it is necessary to reflect other elements than concrete.

Usually the concrete reinforcing steel pipe is placed at the shallow buried section of conduits. Typical case is around abutment. Considering only the effects of seismic wave to the buried pipes in the around abutment, it is be considered reasonable that the damage ratio of discontinuity (concrete part exists in conduits) is particular high shown in Table 2 as following three 3 reasons : soft ground as embankment, axial force actiong conduits systems is amplified due to concrete, gradient section that causing bending moment near the concrete section may exist due to shallow buried section. Especially the fact of the bending moment has large influence to the seismic performance of curve laying or gradient laying is obtaiend, the study and numerical analysis reflecting bending moment due to gradient laying at the concrete section are the future research.

CONCLUSION AND FUTURE RESEARCH

In this study, authors have studied the influence that laying form affects the earthquake reliability of underground conduits. The laying form is categorized into curve laying, gradient laying and discontinuity. Moreover authors have analyzed the damage cases of conduits in Tohoku Earthquake with respect to each defined laying forms. From the result of this analysis, it found that the damage ratio of the form of the discontinuity is particular high.

Then, the defined laying forms are modeled as a beam on the elastic foundation, numerical analysis by seismic displacement method is executed. Although the models are which exclude nonlinear joint properties, authors have grasped the trend of influence that the laying form exists actually affects the earthquake-proof quantitatively. From the numerical analysis reflecting the change of conduits' laying form, in large cases, the axial stress of 4 times larger occurs compared to the straight structure conduits. Together with result of the damage ratio of curve laying is a little higher, authors indicate that the curve laying may be weak point during earthquake. In case of discontinuity, the axial force acting the boundary of concrete and steel pipe is about 1.2 times larger than conduit systems without concrete is shown. From the analysis of damage case in Tohoku Earthquake and numerical analysis, authors indicate the concrete in conduits systems may be the weak point during earthquake.

The future research is as follows : the numerical analysis reflecting nonlinear joint properties, quantitative evaluation of ground condition by numerical analysis, for example sudden change of ground condition or soft ground, to clear the properties of concrete-soil spring constant by soil tank experiments, and the like.

REFERENCES

Fuchida K, Akiyoshi T, Toki K, (1991) "Seismic Response Analysis of A Common Duct and Internal Pipes", *Structural Engineering/Earthquake Engineering*, 8(1):49-56

Higashide T, Yabuguchi T, Imai T, Koike T (2012) "Seismic Performance Assessment of Expansion Joints for Water Lifelines", *15th World Conference on Earthquake Engineering*, Lisbon, Portugal, 24-28 September 2012

Okutsu M, Ishida N, Segawa N, Yamazaki Y, Katagiri S, Suzuki T (2012) "Aseismic Capacity of Telecommunication Conduit Repaired with Linings", *15th World Conference on Earthquake Engineering*, Lisbon, Portugal, 24-28 September 2012

Shi P, O'Rourke T, Wang Y, Fan K, (2008) "Seismic Response of Buried Pipelines to Surface Wave Propagation Effects", *14th World Conference on Earthquake Engineering*, Beijing, China, 12-17 October 2008