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Studies of the effect of ground settlement on the buried pipe including a part passing through the building wall

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ABSTRACT

Wide or local deformation of the buried pipe line occurs by the change in ground condition caused by various reasons. For example, at the time of earthquakes, lateral spreading and also subsidence of the ground are produced by liquefactions caused by strong ground motion. A buried pipe line in which large strain and large stress are produced by the subsidence of the ground is the pipe line including a piping through the penetration part of a wall hole in buildings or abutments. In this study, in order to discuss the most suitable buried pipe line configuration including the building penetration piping, numerical case studies are performed for various types of buried pipe lines including the building penetration piping. And then, by discussing the results of numerical case studies, the tendency of whole pipe line system, appropriate allocation of bend and length of straight pipe are discussed from the standpoint for safety.

1. Background

Cogeneration System (hereinafter referred to as CGS), that is the overall highly efficient energy-saving facility, was introduced in the 1980s in Japan and spread speedy afterwards.

CGS is the excellent energy system which provides us more than two kinds of energy, namely electricity, heat and so on, continuously at the same time from fuels.

The status of CGS adoption in Japan at present is as follows. The total number of sites until the end of March 2014 is 15,127, and the amount is 10,046 MW in total[1).

Since the East Japan Big Earthquake Disaster, CGS is expected as the effective power source. And it is placed more important position in Japanese energy policy.

With the assistance of energy network and information and communication technologies, the electricity and the heat generated by the decentralized energy systems including CGS are utilized more effectively between each area and also between each building. This is expected the realization of bigger energy saving, minimize CO_2 discharge and improvement of the energy security[2)].

As the matter of course, in case that the CGS which operates on city gas is set as the emergency electric power supply unit, the city gas pipe line should satisfy the standard prescribed by the Fire Services Act. The standard for the privately owned electric power facility which is used as emergency power supplies such as facilities for firefighting is as follows. In the case that the privately owned electric power facility operates on gaseous fuels, the spare fuels are to be stored or the city gas is to be supplied steady even though it is attacked by a strong horizontal ground motion of 400gal which correspond to JMA seismic intensity of 6-lower caused by an earthquake[3)-5)].

2. Aims

The most important point to be evaluated on the earthquake resistance of the buried gas piping within customer's premises and that incorporated in customer's building is the part of the buried pipe which passing through the building wall. Because, there is a possibility to occur the ground differential subsidence caused by an earthquake. This means that the buried pipe including a part passing through the building wall has to be discussed any measure for absorbing the relative displacement caused by the ground differential subsidence. In order to absorb the relative displacement between the pipe and the ground surround it, it is very important to utilize not only welded steel pipe but also combination of bend for increasing the flexibility of the pipe line.

In this paper, the numerical case studies are performed for various kinds of buried piping system including a part passing through the building wall where the displacement of the pipe is restricted by the wall hole. By comparing the results of the numerical case studies, the most appropriate allocation of bend and also length of straight pipe in the buried piping system are discussed.

3. Methods

The method and condition of this numerical analysis are shown below.

The dimensions of the steel pipe are as follows: nominal diameter; 100 mm, outer diameter; 11.43 cm, wall thickness; 0.45 cm. The material of the pipe satisfy Japan Industrial Standard G, namely, JISG3452 (Carbon steel pipes for ordinary piping). The mechanical property of the pipe has bilinear relationship as shown in Figure 1. Regarding the bend, a commonly used long bend is used.

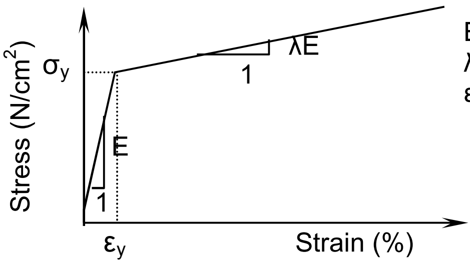


Fig. 1 Stress-strain relationship of the material of the pipe

In the pipeline deformation analysis caused by ground subsidence, ground displacements are statically transferred to pipelines through soil springs. Soil spring characteristics are modeled by a bilinear relationship of restraint forces exerted upon pipelines and the relative displacements of the ground and the pipeline. Figure 2 shows soil springs in three directions. Figure 3 shows the bilinear relationship of soil reaction characteristics.

In this numerical analysis, a FEM code which is called an ABAQUS Ver. 6. 12 is used. The Element used in this FEM analysis is a 4 nodes shell element. The shell element dividing of this FEM analysis model is shown in Table 1 and Figure 4.

The Allowable value of the pipe is limited by the critical equivalent plastic strain. The Allowable value is 2 percent for straight pipe, and 5 percent for bend.

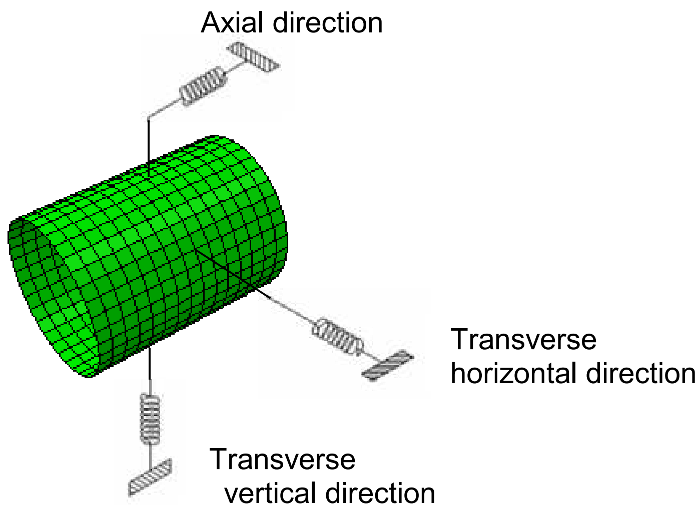
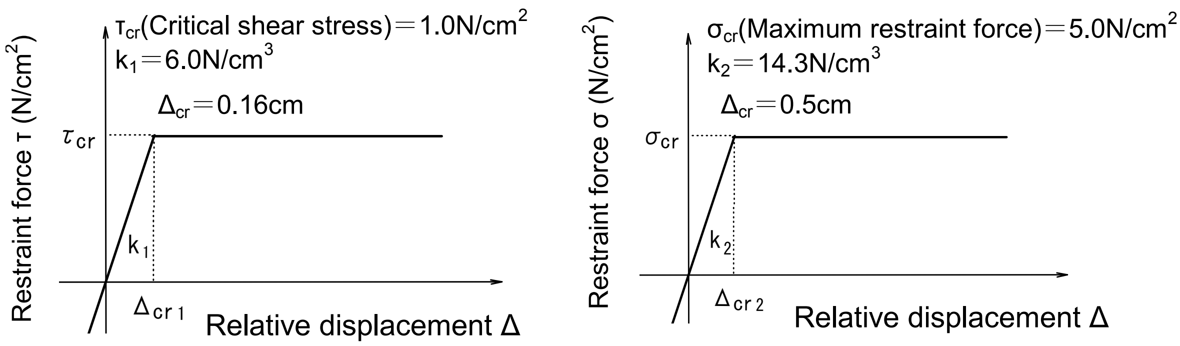


Fig. 2 Images of the soil springs in three directions



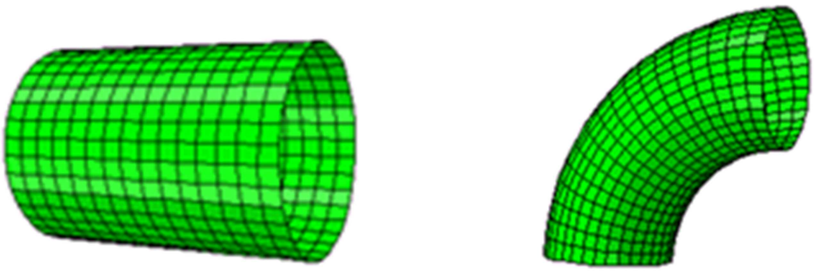
(a) Axial direction

(b) Transverse direction

Fig. 3 Soil reaction characteristics

Table 1 Shell element dividing of FEM analysis model

	Circumferential direction	Axial direction
Straight pipe	36 divide／（10°pitch）	Divide at about 1 cm
bend pipe		Curvature : 5°pitch（18 divide／90°bend）



(a) Straight pipe (b) Bend

Fig. 4 Shell element dividing of FEM analysis for straight pipe and bend

4. Results

4.1 Outline of the case study

In this case study, the effect of ground subsidence on the buried piping is analyzed for the piping having two or three bends by changing the length of the straight pipes or allocation of bends as a parameter. The deformation of the pipe and the strain induced in the pipe are computed for each case. The maximum amount of the ground subsidence is set as 50 cm in the vertical direction. The evaluation of the piping against ground subsidence is made by the minimum amount of subsidence at which the equivalent plastic strain induced in the deformed piping attains the allowable value for the straight pipe or the bend. This amount of subsidence is called as ability for ground displacement absorption (hereinafter referred to as AGDA). The unit of AGDA is cm. This means that the maximum amount of the ground subsidence for the respective piping with no damage, namely, the maximum amount of subsidence for which the piping can be absorbed the effect of the ground subsidence.

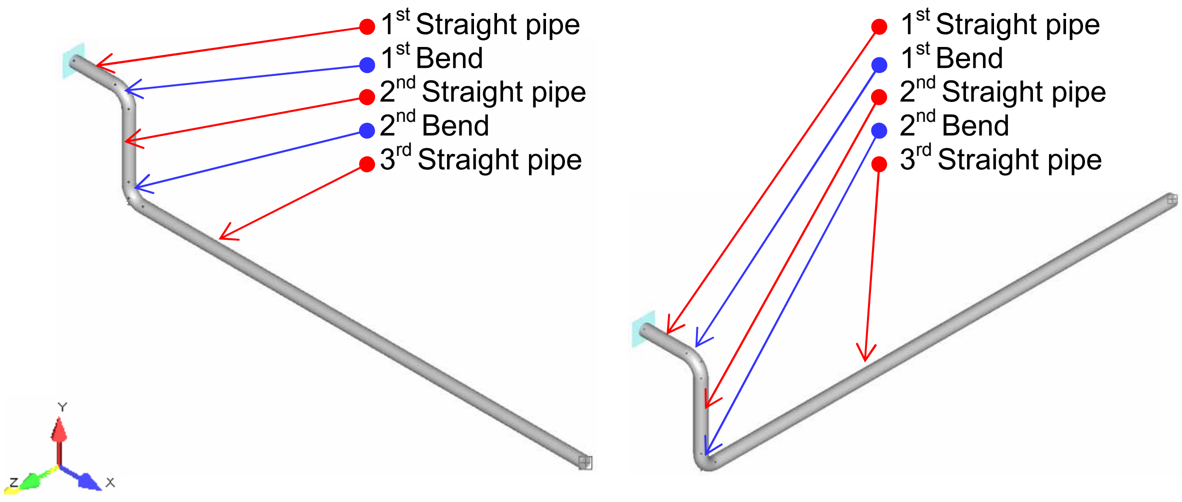
4.2 Piping having two bends

In the case of the piping having two bends, the two kinds of piping are used for the analysis as shown in Figure 5. In the case of Piping A, the 3rd Straight pipe is set parallel to the X axis. And in the case of Piping B, the 3rd Straight pipe is set parallel to the Z axis. The length of each straight pipe that is used as a parameter is shown in Table 2.

Table 2 Length of the straight pipe used as the model parameter

	Piping A	Piping B
1st Straight Pipe(1stSP)	30 ㎝, 60 ㎝	same as on the left
2nd Straight Pipe(2ndSP)	60 ㎝, 100 ㎝	same as on the left
3rd Straight Pipe(3rdSP)	500 ㎝	same as on the left

As the results of the analysis, the values of AGDR for piping A and piping B are shown in Figure 6. It is recognized from the results shown in Figure 6 that the values of AGDR show almost no large difference among respective case except the Case60-60R.



Piping A (in-plane piping) Piping B (out-of-plane piping)

Figure 5 Piping models having two bends

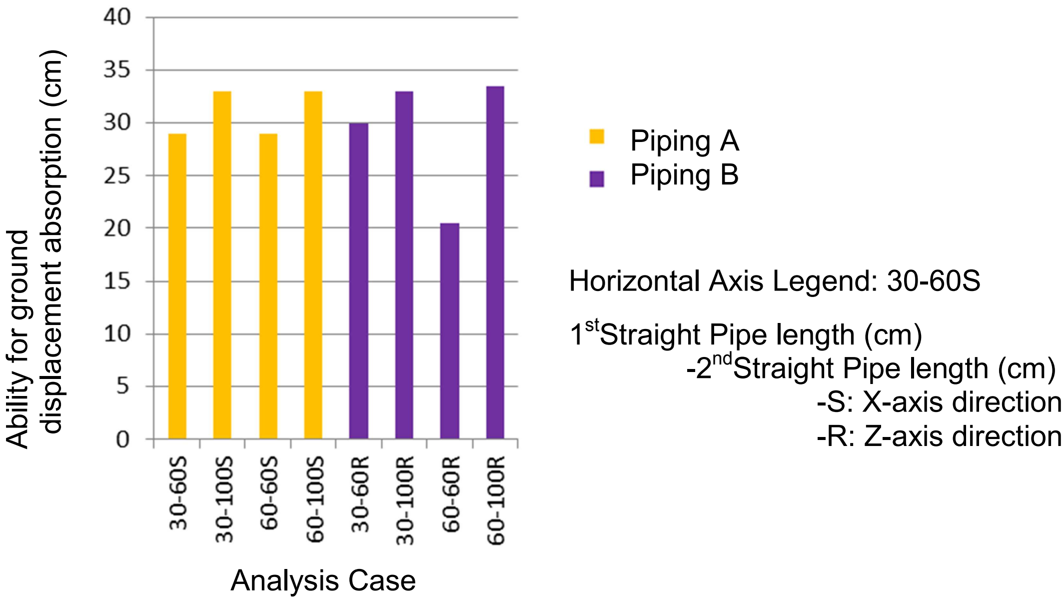


Figure 6 Ability for ground displacement absorption

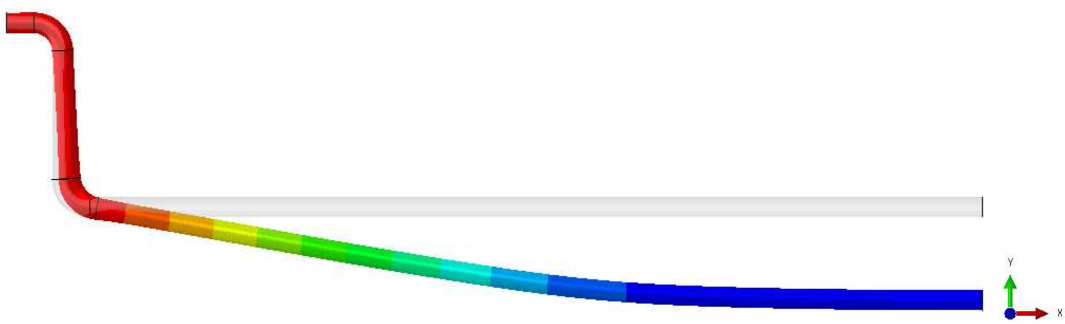


Figure 7 Deformation of the pipe for Case30-100S

The mechanism to absorb ground movement in piping system is considered as follows. The 2nd Bend which is placed most away from the fixed point deforms so called outward bending deformation. This deformation leads the change in inclination and bending of the straight pipes those are connected to the both side of the bend. These deformations absorb the ground movement by the subsidence. As an example, figure 7 shows the deformation of the pipe, and Figure 8 show the equivalent plastic strain induced in the pipe and the deformations.

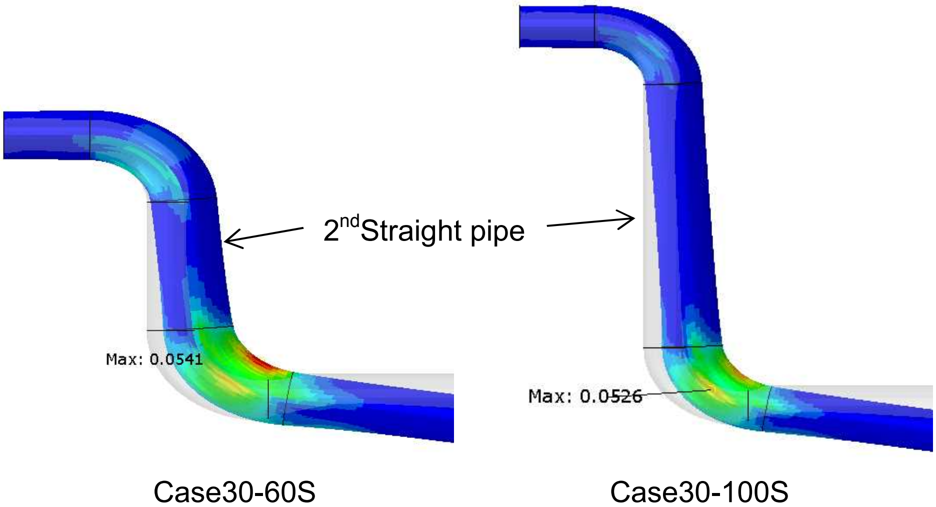


Figure 8 Equivalent plastic strain and deformation (The initial shape is shown with gray)

4.3 Piping having three bends

In case of the piping having three bends, the two kinds of piping are used for the analysis as shown in Figure 9. In the case of Piping C, the 2nd Straight pipe is set vertically. And in the case of Piping D, the 2nd Straight pipe is set horizontally. The length of each straight pipe that is used as a parameter is shown in Table 2. The values of AGDR for piping C are shown in Figure 10.

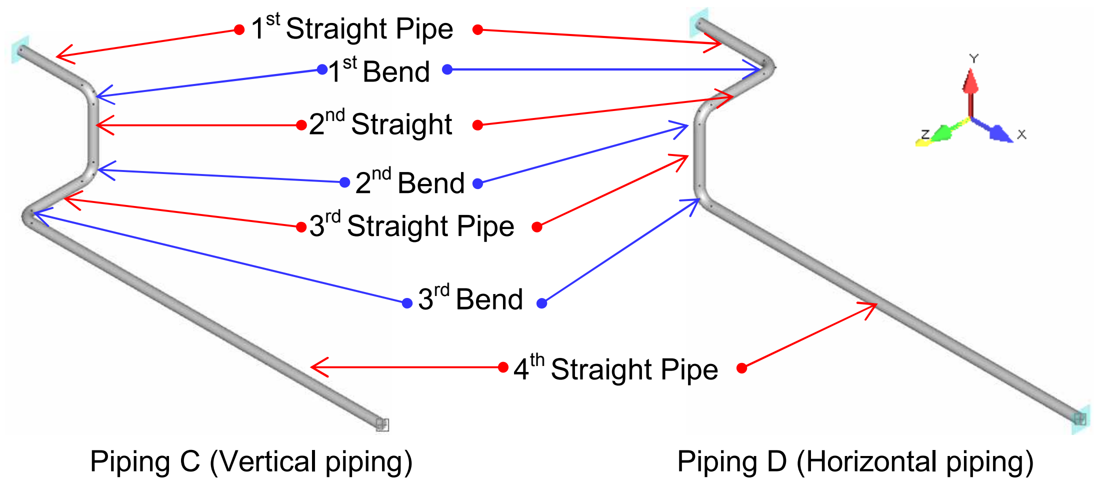


Figure 9 Piping Models having three bends

Table 2 Length of the straight pipe used as the model parameter

	Piping C	Piping D
1^{st}Straight Pipe(1^{st}SP)	30 cm, 60 cm, 100 cm	30 cm, 60 cm
2^{nd}Straight Pipe(2^{nd}SP)	60 cm, 100 cm, 150 cm	same as on the left
3^{rd}Straight Pipe(3^{rd}SP)	60 cm, 100 cm, 150 cm	same as on the left
4^{th}Straight Pipe(4^{th}SP)	10m	same as on the left

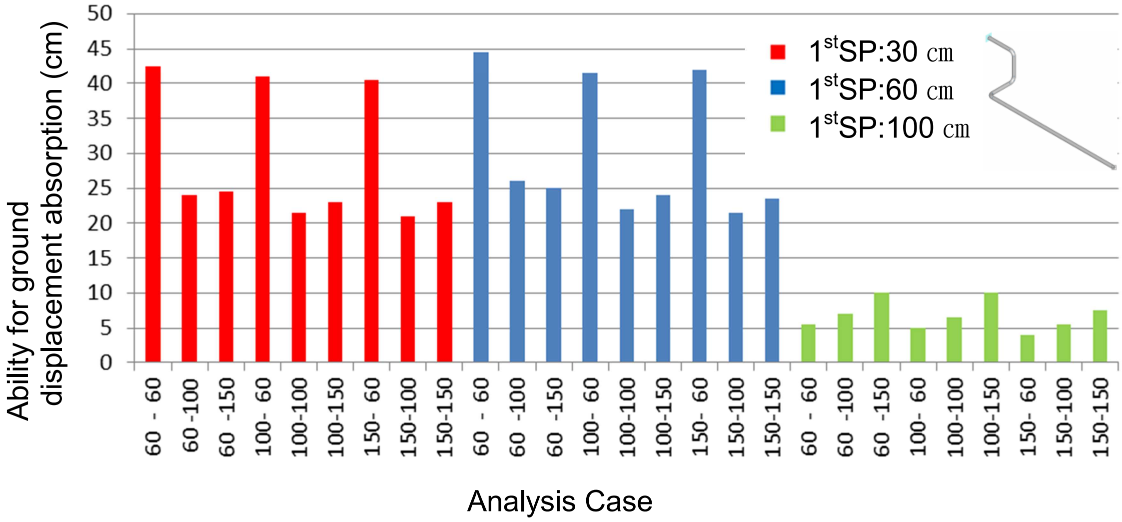
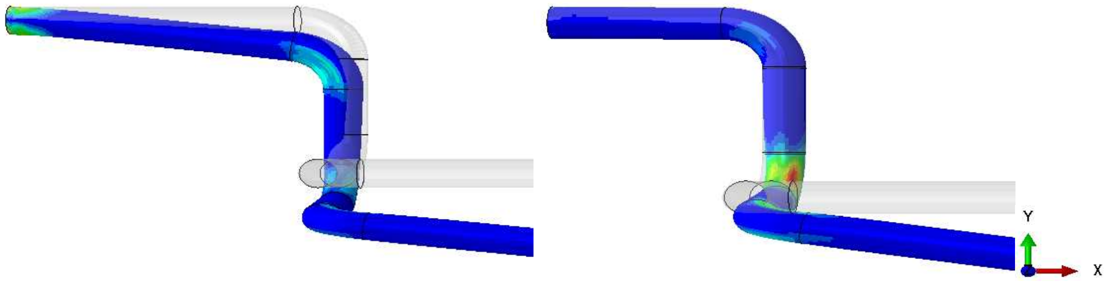


Figure 10 Ability for ground displacement absorption of piping C

It is very clearly recognized from the results shown in Figure 10 that the AGDR for the case of 1^{st}SP=100 cm becomes very poor compared with that for the case of 1^{st}SP=30 cm and 1stSp=60 cm. This comes from the reason that the 1^{st} straight pipe can be regarded as a kind of a cantilever from the stand point of the structural mechanics. Figure 11 shows deformation of the piping C and the distribution of equivalent plastic strain induced in the pipe. In this figure, the initial shape of piping is shown with gray. As shown in Figure 11, increase in the length of the 1^{st} straight pipe increases the bending moment at the fixed point logically having no relation with the length of the 2^{nd} and 3^{rd} straight pipes. In cases of 1^{st}SP=30 cm and 1^{st}SP=60 cm, the rigidity of the 1^{st} SP suppress the increase of the plastic deformation at the fixed point. It is recognized from the results shown in figure 10 that the values of the AGDR for the case of 3^{rd} SP=60 cm is much larger than the others. Figure 12 shows the deformations of the piping and induced equivalent plastic strain for the case of interest. The initial shape of piping is shown with gray. As shown in this figure, the effect of subsidence on the piping is absorbs gently in the long range of the piping in the case that the length the 3^{rd} Straight pipe is short



Case100-60-60 Case60-60-60

Figure 11 Deformation and equivalent plastic strain at the ground subsidence of 50 cm

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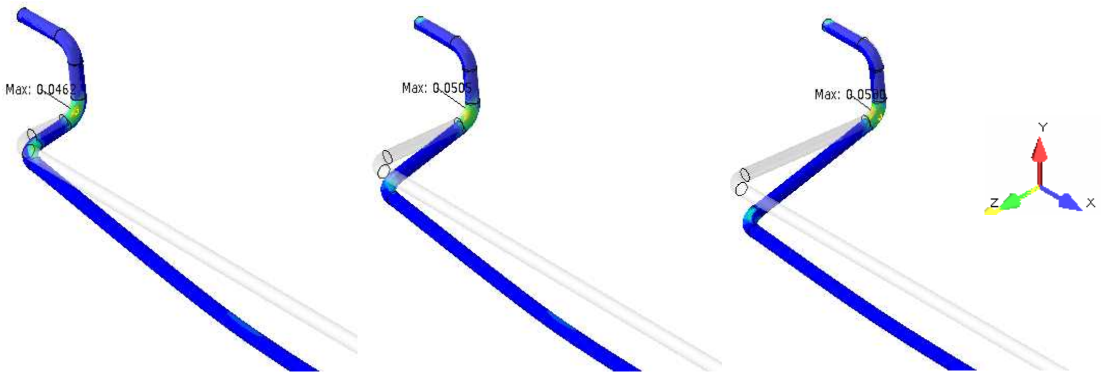


Case60-60-60 Case60-60-100 Case60-60-150

Figure 12 Deformation of piping and distribution of equivalent plastic strain at the ground subsidence of 50 cm (Maximum Rage: 0.06)

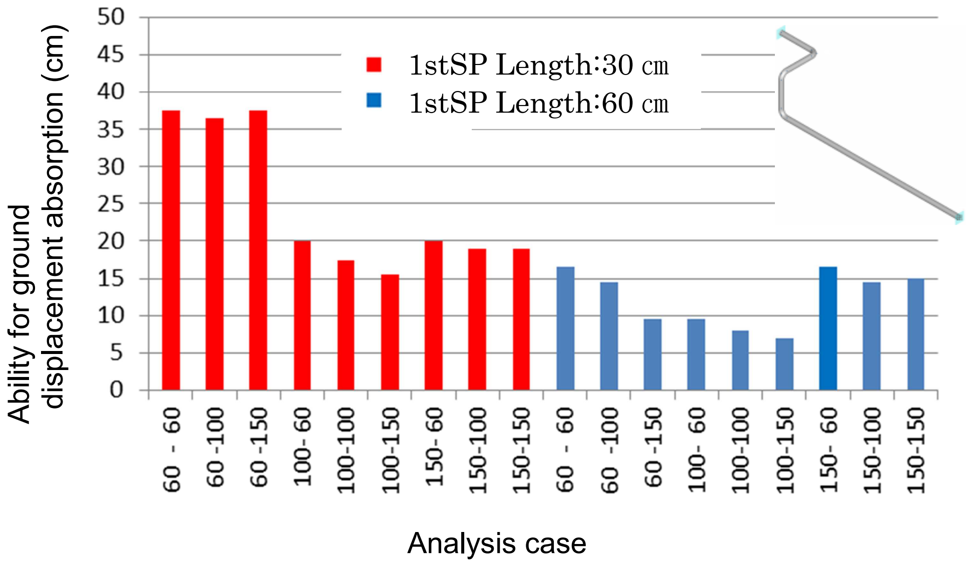
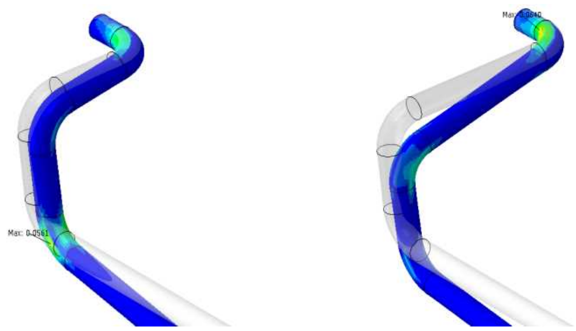


Figure 13 Ability for ground displacement absorption of Piping D

Next, let's discuss the results of the analysis for Piping D. The values of AGDR for piping D are shown in Figure 13. As shown in this figure, the case of 1stSP Length=30 cm shows the larger value of AGDR. And the values of AGDR for Case30-60-60, Case30-60-100 and Case30-60-150 are much larger than the others. But the value itself is smaller than the case of Piping C. Figure 14 shows the deformation of the piping and induced plastic equivalent strain for Case30-60-60 and Case30-100-60 for comparison.



Case30-60-60 Case30-100-60

Figure 14 Deformation of the piping and distribution of induced plastic equivalent strain
(At Ground displacement of 50 cm, Maximum Rage: 0.07)

In the case of Case30-60-60, ground displacement caused by subsidence is absorbed by both outward bending deformation of 3rd bend and bending of 4th Straight pipe. On the other hand, in the case of Case30-100-60 where the length of the 2nd straight pipe is longer, the ground displacements are absorbed by the torsional deformation of the 1st bend and the outward bending deformation of the 2nd bend. In this case, 2nd straight pipe can be regarded as a cantilever.

5. Conclusions

The conclusions are itemized below.

(1) An ABAQUS Ver. 6. 12 is one of the useful tools to discuss the effects of ground subsidence on a buried piping.

(2) The straight pipe just in front of the building wall penetration point (1st straight pipe) is regarded as the cantilever which receives a distributed load by the ground subsidence because the building penetration point is fixed. Therefore longer the length of the 1st straight pipe makes larger the bending moment and tends to make it plasticity at the building wall penetration point.

(3) Among the entrance pipe to the buildings, the horizontal straight pipe receives the effect of subsidence on the pipe, then, the pipe tends to follow the movement of the ground subsidence. Therefore, the large effects are induced at the fixed point.

(4) The piping which absorbs the effects of the ground subsidence by the outward bending

deformation of the 2^{nd} Bend and the after and also absorbs the bending or inclination of the straight pipe is desirable for the piping close to the building penetration point.

(5) The piping having three bends absorbs the effect of ground subsidence more smoothly than the piping having two bends. This means that the increase in the number of the bend in the piping decrease the possibility of the damage of the piping by ground subsidence caused by liquefaction induced by big earthquakes.

(6) As the subject in the future based on this case study is as follows: discuss the modeling of the bend by use of plasticity hinges, and proceed making of the design methods for the entrance pipe to the buildings.

Acknowledgements

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