AMPLIFICATION OF GROUND STRAIN IN IRREGULAR SURFACE LAYERS DURING STRONG GROUND MOTION

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SUMMARY

The characteristics of ground response in irregular surface layers must be made clear in the case of strong ground motion like that during the Hyogo-ken Nanbu Earthquake. To investigate these characteristics, 2D - FE analyses were conducted. In the results, the ground strain during strong ground motion is much less than that calculated by the present seismic design guidelines of high pressure gas pipeline in Japan. The cause seems to be the horizontal combination effect of the ground motion. The ground strain is saturated where the incline angle of the base rock is in excess of 30 degrees. As for pipe response, maximum strain of the pipe and the ground occur at almost the same position. And the maximum strain of the pipe does not exceed that of pipe. It is found that the ground strain in the irregular surface layers during strong motion can be set at 0.3% for design purposes.

INTRODUCTION

In ground in which the thickness of the surface layer varies remarkably, strains in ground occur due to differences of displacement at various points [JSCE, 1998]. In the seismic design guidelines of high-pressure gas pipeline in Japan [Japan Gas Association, 1982], the ground strain in the surface layer is taken into account at the level of the Miyagi-ken Oki Earthquake 1978 [Toki, Fukumori, Sako, Tsubakimoto, 1983], but not the Hyogo-ken Nanbu Earthquake.

For seismic design of pipeline to withstand strong ground motion such as “Hyogo-ken Nanbu earthquake”, the characteristics of amplification of the ground strain in the irregular surface layers should be considered for the non-linearity of ground stiffness and damping.

To investigate the above characteristics, 2D - FE analyses were conducted based on the results of former studies [Ando et al., 1996] [Sato et al., 1993]. There are two types of analysis. One type is focused on ground amplification. The conditions of analysis vary depending on the parameter: the incline angle of the base rock, seismic wave, the thickness of the surface layer. The other type is focused on the difference of the shape of base rock.

GROUND STRAIN ON THE IRREGULAR SURFACE LAYERS

In the present seismic design guidelines of high pressure gas pipelines in Japan, ground strain in the irregular surface layers is defined on the basis of the model shown in Figure 1. The total ground strain ε_{G2} is given by the following expression. The ground strain examined in this study is ε_{G_3} in given in (1) and (2).

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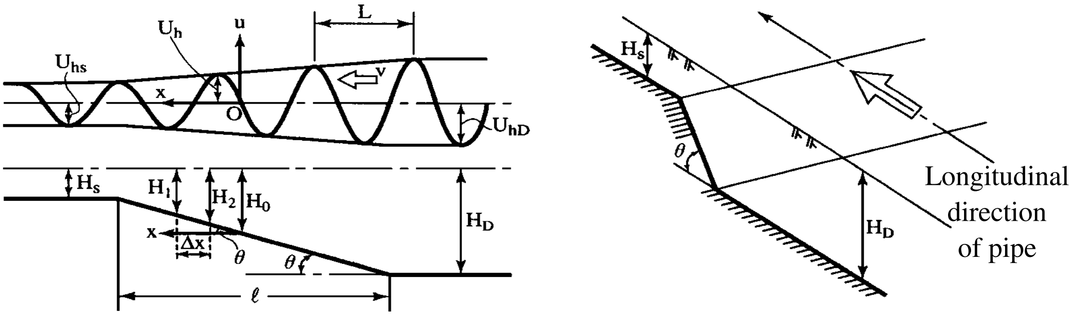

Figure 1: The model of irregular surface layers in the present seismic design guideline

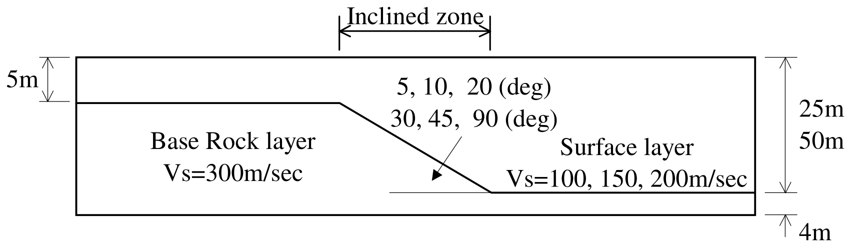

Figure 2: Analytical Model

$$
\begin{aligned}
\varepsilon_{G2} &= \frac{\Delta u}{\Delta x} \\
&= \frac{2\pi \cdot U_h}{L} \cdot \cos\frac{\omega}{V}x + \frac{\Delta U_h}{\Delta x} \cdot \sin\frac{\omega}{V}x \\
&= \sqrt{\varepsilon_{G1}^2 + \varepsilon_{G3}^2} \cdot \sin\left(\frac{\omega}{V} \cdot x - A\right)
\end{aligned}
\qquad (1)
$$

Hence, the maximum value of the ground strain is obtained from following expression (2).

$$\varepsilon_{G2} = \sqrt{\varepsilon_{G1}^2 + \varepsilon_{G3}^2} \qquad (2)$$

Where,

ε_{G1} : Strains in ground with uniform surface layer $\left(= \frac{2\pi \cdot U_h}{L}\right)$

ε_{G3} : Strains in ground occur by differences of thickness of the surface layer along longitudinal points $\left(= \frac{\Delta U_h}{\Delta x}\right)$

U_h: Displacement amplitude of the surface ground layer

L: Apparent wave length of seismic motions

ANALYTICAL APPROACH

Figure 2 shows the analytical model. Ground properties are shown in Table 1. Shear velocity Vs is defined in terms of the present seismic design guidelines of high-pressure gas pipeline in Japan. The shear velocity of 100m/s which is used in this study is almost equal to the N-value "1" of clay and N-value "10" of sand. From the practical point of view, these N-values are the lower limits for the soft layer thickness of 25m to 50m. Figure 3 indicates the concept of this analysis. Ground response is modeled by solid element and analyzed by TDAP II. Pipe response is modeled by beam element and analyzed by ABAQUS and TDAP II ground response.

Table 1: Ground Properties

Thickness of surface layer H (m)	25,50 5	(thick side) (thin side)
Degree of base rock inclination	5,10,20,30,90	
Shear Velocity Vs (m/s)	100,150,200 300	(surface) (base rock)
Poisson ratio	0.49 0.45	(surface) (base rock)
Unit weight of soil (kN/m^3)	14.7 19.6	(surface) (base rock)
Damping factor h	0.1 0.05	(surface) (base rock)

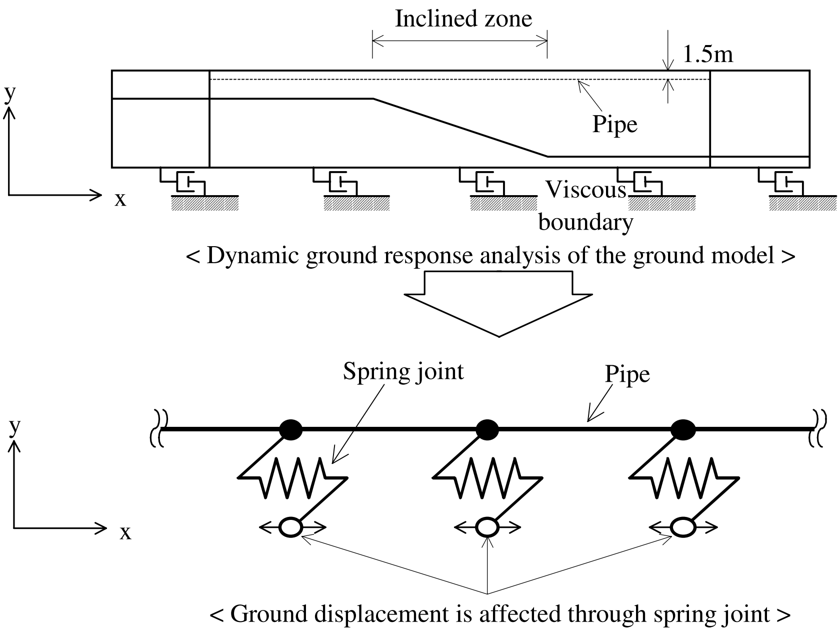

Figure 3: Analytical Concept

Table 2: Pipe Properties

	Diameter (mm)	Thickness (mm)	Code	Yield Stress (MPa)
300A	318.5	6.9	JIS SGP	252
600A	609.6	15.1	API 5L X65	448

Properties of pipes are shown in Table 2. Stress-strain model for pipe is an isotropic hardening model based on the bi-linear model.

Longitudinal ground restraint force is given as spring-joint. Spring model is an isotropic hardening model. Considering the loading tests results [Kobayashi, Ando, Oguchi, 1998], critical ground restraint force τ_{cr} is set at 0.15kgf/cm^2 (1.5N/cm^2), and spring coefficient k is set at 0.6kgf/cm^3 (6N/cm^3).

Three waves, which are observed at the equal to base rock during the Hyogo-ken Nanbu Earthquake, are selected. These are “Port Island NS wave (Max=679gal)”, “Higashi-Kobe Bridge NS wave (Max=442gal)” and “Kobe Univ. NS wave (Max=270gal)”.

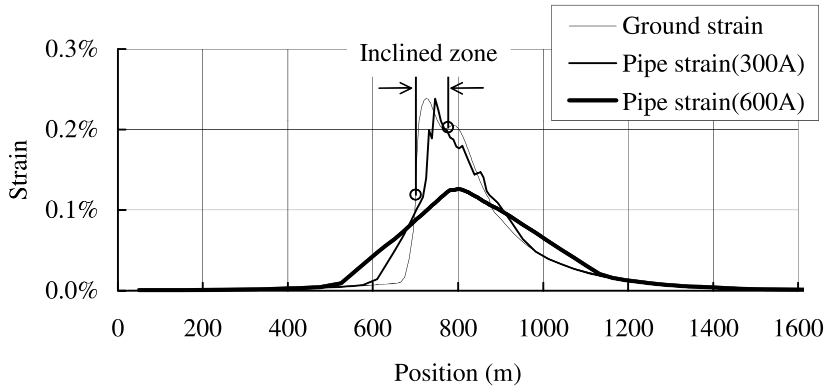

Figure 4: Distribution of the ground and pipe strain
- Surface 50m / 30 deg / Vs 100m/sec -

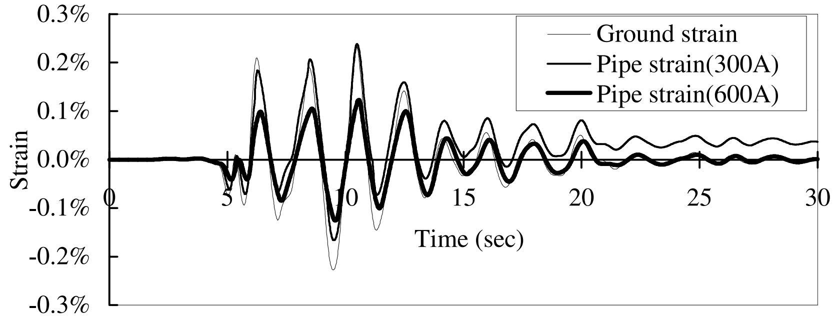

Figure 5: Time history of strains at the highest response position
- Surface 50m / 30 deg / Vs 100m/sec -

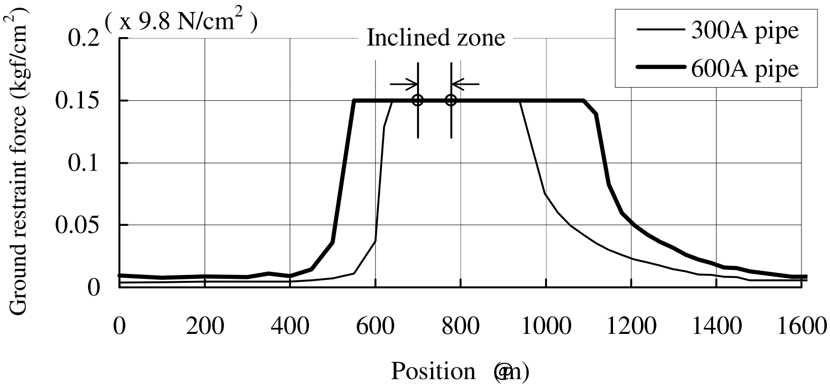

Figure 6: Distribution of ground restraint force
- Surface 50m / 30 deg / Vs 100m/sec -

ANALYTICAL RESULTS

Pipe Strain

Figure 4 shows the distribution of the ground and pipe strain, and Figure 5, the time history of those strains at the highest response position by applying the Higashi Kobe Bridge NS wave, which causes the maximum response among the three input waves. Maximum strain of the ground and the pipe occurred at the base rock inclined zone, and these are at nearly the same position. By comparing 300A and 600A, it is found that the smaller stiffness and strength (300A) causes larger pipe strain. In every result, the maximum strain of the pipe does not

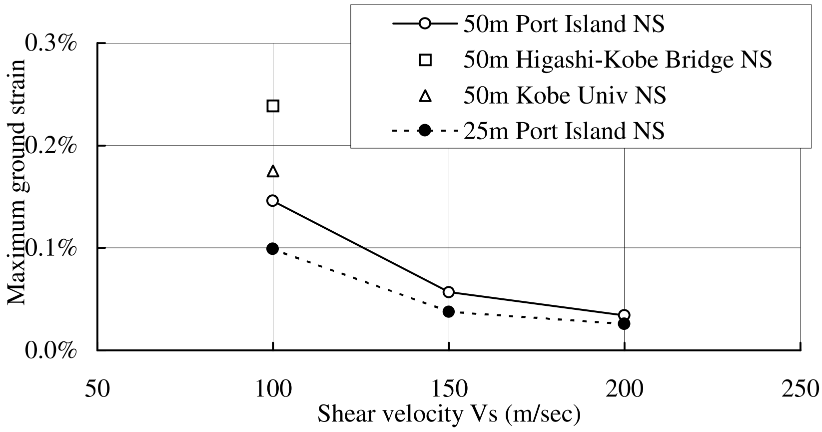

Figure 7: Effect of the shear velocity and the thickness of surface layer - Base rock inclination 30 deg -

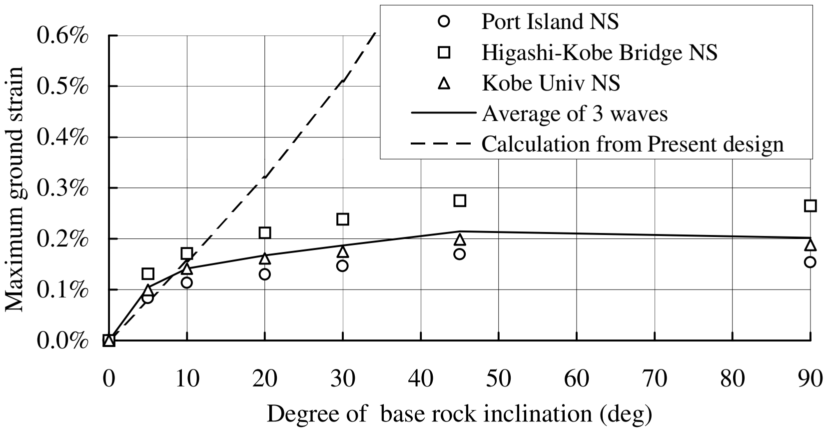

Figure 8: Effect of the degree of base rock inclination - Surface 50m, Vs 100m/sec -

excess that of the ground. Distribution of maximum longitudinal ground restraint force is shown in Figure 6. It is found that longitudinal ground restraint force reaches its critical value at the base rock inclined zone and even at its vicinity. In other words, slippage between pipe and the ground may occur at the base inclined zone and its vicinity.

Effect Of Surface Layer Inclination And Ground Stiffness

Figure 7 shows the effect of the shear velocity and thickness of the surface layer at the 30-degree base rock inclination. As the surface layer becomes thicker and the ground stiffness becomes softer, the ground strain becomes larger. Therefore, the surface layer and the ground stiffness are conservatively set at 50m and 100m/s, respectively.

Figure 8 shows the effect of base rock inclination. From this figure, the ground strains are saturated where the incline angle of the base rock is in excess of 30 degrees as indicated in the present seismic design guidelines of high pressure gas pipelines in Japan. The cause seems to be the horizontal combination effect of the ground motion. Figure 8 also shows the calculation of ε_{G3}, which is indicated in the present design guideline, by applying strong ground motion to the eq. (2) at the level of waves at clause **3.3**, which was observed during the Hyogo-ken Nanbu Earthquake. The ground strains during strong ground motion as calculated by 2D-FE analysis were much lower than those calculated by the present design guideline for seismic design of high-pressure gas pipelines in Japan. As the angle of the base rock becomes steeper, the ground strain calculated by the present design guidelines becomes larger linearly. Although there is some dispersion among the three sets of wave results by 2D-FE analysis, the strain at 10 degrees was found from Figure 8 to be roughly 0.1%, and that at 30 degrees, to be roughly 0.2%. Therefore, it is found that the ground strain in the irregular surface layers during strong motion can be set at 0.3% for design purposes.

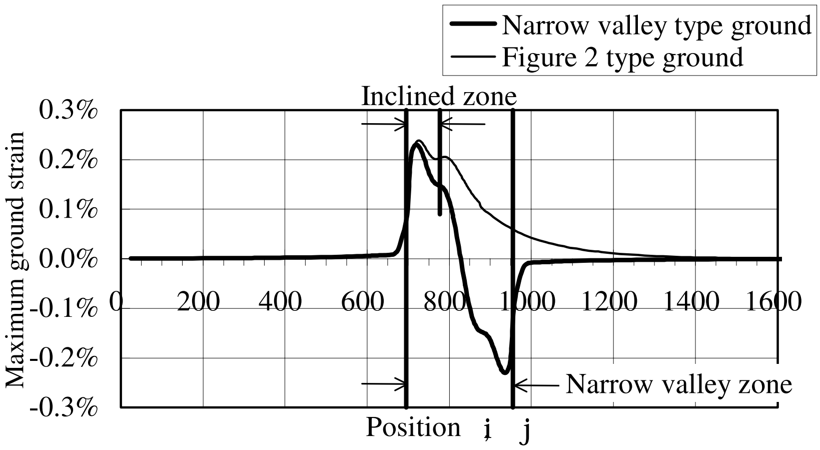

Figure 9: Effect of the shape of the base rock layer

Effect Of Landform Surface And The Shape Of Base Rock Layer

The above study is premised on flat ground in which one side is a thin surface layer and the other side is a thick surface layer as shown in Figure1 and Figure 2. However, there are non-flat ground surfaces and many kinds of base rock layer shape in the actual irregular surface layers. Therefore, additional studies must be conducted for investigating the effect of ground surface and the shape of base rock layer.

As for the effect of ground surface, Noda et al. [Noda et al., 1991] found that ground strain tends to excel at the lowland side of the boundary between plateau and lowland by analyzing the non-flat surface ground in the irregular surface layer. They concluded that there is not so much difference of ground response between flat ground surface and inclined ground surface in irregular surface layers. Consequently, for the ground motion, this conclusion is applied in this study. But in the case of liquefaction and slope failure, the ground behavior is different. Another approach should be taken in the future.

As for the effect of the shape of the base rock layer, a narrow valley-shaped base rock is selected for the analytical evaluation model because of the high possibility of high amplification of strain. Figure 9 shows a comparison of the narrow valley and the ground strain from Figure 4 (Figure 2 type ground). The narrow valley-shaped base rock does not exceed the above-mentioned analytical results.

CONCLUSION

The ground motion and ground strain in irregular surface layers can be amplified by the landform structure and the ground stiffness. At present, from the pipeline seismic design point of view, one of the most important topics is the handling of strong motion. Hence, it is necessary to quantify the ground strain in irregular surface layers in the case of strong ground motion like that during the Hyogo-ken Nanbu Earthquake. To investigate these characteristics, a 2D – FE Analysis has been conducted. The specific conclusions from this study are:

1) The maximum strain of the pipe does not exceed that of the ground. Maximum strain of the ground and the pipe occur at almost the same position.
2) As the angle of the base rock becomes steeper and the surface layer becomes thicker, the ground strain during strong ground motion becomes larger.
3) The ground strains during strong ground motion are much lower than as calculated by the present seismic design guidelines of high pressure gas pipeline in Japan. As the angle of the base rock becomes steeper, the ground strain as calculated by the present design guidelines becomes larger.
4) The ground strains are saturated where the incline angle of the base rock is in excess of 30 degrees. This result is the same as indicated in the present seismic design guidelines of high pressure gas pipeline in Japan. The ground strain in the irregular surface layers during strong motion can be set at 0.3%.
5) It was confirmed that the ground strains in the surface layer in which the surface is inclined and the shape of base rock is like a narrow valley do not exceed the analytical results when the incline angle of the base rock is 30 degrees.

REFERENCES

Ando H, et al. (1996), "A Procedure of Seismic Evaluation of Buried Gas Pipeline with Three-Dimensional Fully Soil - Pipe Interaction Dynamic Analysis", (In Japanese), *Annual Technical Report of Tokyo Gas Fundamental Technology Research Laboratory,* Vol.41, pp1-10.

Japan Gas Association. (1982), "The Seismic Design Guideline of High Pressure Gas Pipelines".

JSCE (1998), *Proc. of the Local Site Effects Symposium 1998*, pp153-170.

Kobayashi M, Ando H, Oguchi N (1998), "Effects of Velocity and Cyclic Displacement of Subsoil on its Axial Restraint Force Acting on Polyethylene Coated Steel Pipes During Earthquakes", (In Japanese), *Journal of the Japan Society of Civil Engineers,* No.591 / I-43, pp299-312.

Noda S, et al. (1991), "An Analytical Approach for Vibration Characteristics of the Irregular Surface ", (In Japanese), *The 46th annual convention of Japan Society of Civil Engineers,* I, pp1324-1325.

Sato S, et al. (1993), "Evaluation of Seismic Strain on a Pipe on the Irregular Surface", (In Japanese), *The 48th annual convention of Japan Society of Civil Engineers,* I, pp410-411.

Toki K, Fukumori Y, Sako M, Tsubakimoto T (1983), "Recommended Practice for Earthquake-Resistant Design of High-Pressure Gas Pipelines", *Proc. Of 4th National Congress on Pressure Vessel and Piping Technology, ASME,* PVP-Vol.77, pp349-356.