ANALYSIS OF CAUSAL FACTORS GENERATING LARGE-SCALE DEFORMATION PATTERNS IN BURIED PIPELINE UNDER THE INFLUENCE OF LATERAL FLOWS BY LIQUEFACTION

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SUMMARY

The deformation of gas pipelines exposed to lateral ground displacement due to liquefaction was analyzed by use of the shell/beam hybrid modeling proposed by Yoshizaki et al. The influence of such parameters as ground constraint, displacement incident angle, angle of bent pipe, and pipe diameter were investigated. Standard buried pipe models were then proposed for use in designing earthquake-resistant buried pipes that may be exposed to lateral flow due to liquefaction.

1. INTRODUCTION

In the Hyogoken-Nanbu Earthquake (the Great Hanshin-Awaji Earthquake) in January 1995, gas pipelines were seriously deformed by ground liquefaction. Although many researches have been studied on liquefaction, no methodology has been established for seismic-proof design of buried pipes, which may be exposed to lateral flow caused by liquefaction. The authors computed the deformation of gas pipelines under the lateral ground displacement caused by liquefaction, and investigated the influence of causal factors on the deformation of pipes . Based on the result, this paper proposes standard buried pipeline models for use in practical design.

2. ANALYTICAL MODELS

2.1 Analytical method

In this study, the shell/beam hybrid modeling proposed by Yoshizaki et al.[1)] was applied to analyze the large-scale deformation patterns of buried pipes. Fig. 1 shows the shell/beam hybrid model. The gas pipeline was modeled using a shell element (four-node thick wall element) and a beam element. The ground was modeled by nonlinear ground spring elements.

2.2 Analytical conditions

The authors[2)] selected slope and revetment as topographies subject to lateral flow due to liquefaction, and analyzed buried pipe models including a bent pipe of ϕ600 mm × 90°, using the shell/beam hybrid model. The result indicated that the maximum strain in a gas pipeline saturated when liquefied area width was 200 m or more on slopes.

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This study investigated the influence of ground constraint, displacement incident angle, angle of bent pipe, and pipe diameter, assuming the liquefied area width to be 400 m. The analytical conditions are shown in Table 1. The ground displacement incident angle is that formed by the pipe and the lateral flow direction. Analyses were performed on the three types of buried pipes of ϕ600 mm, ϕ400 mm, and ϕ150 mm, using ABAQUS version 5.8 software. Fig. 2 shows schematic of slope and revetment. The displacement incident angle is defined as 0° at the position in which the bent pipe is symmetric with respect to the lateral flow direction (here in after this model is called "symmetric model").

The values for maximum ground constraint in the ground spring model in the pipe axial direction were based on "Recommended Practice for Earthquake-resistant Design of Gas Pipeline"[4]; the values in the direction transverse to the pipe axis were based on the result of experiments by Ando et al.[5] Fig. 3 shows soil reaction characteristic. When soil is liquefied and lateral flow occurs, ground constraint is presumably reduced. Therefore, in order to examine the influence of ground constraint, analysis was also conducted on buried pipes of ϕ600 mm and ϕ150 mm when the maximum ground constraint in the direction transverse to pipe axis was reduced. Table 2 shows the maximum ground constraint values in the direction transverse to the pipe axis.

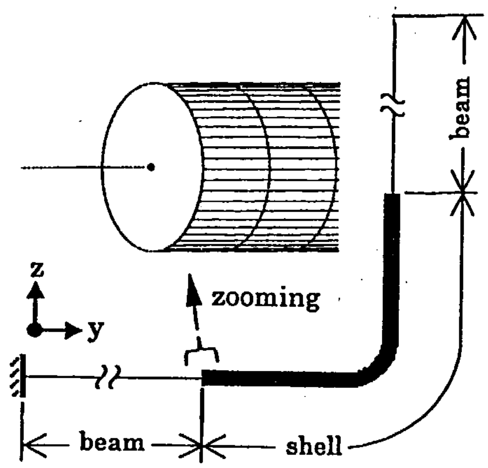
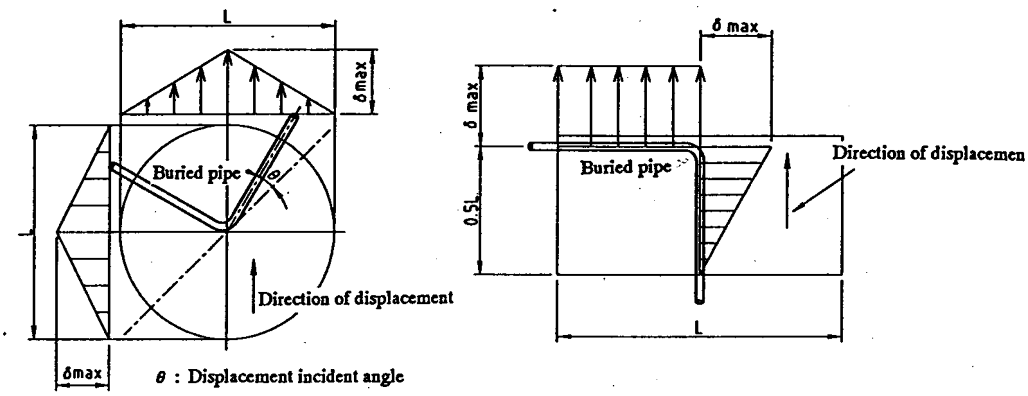


Fig. 1 Shell/beam hybrid models

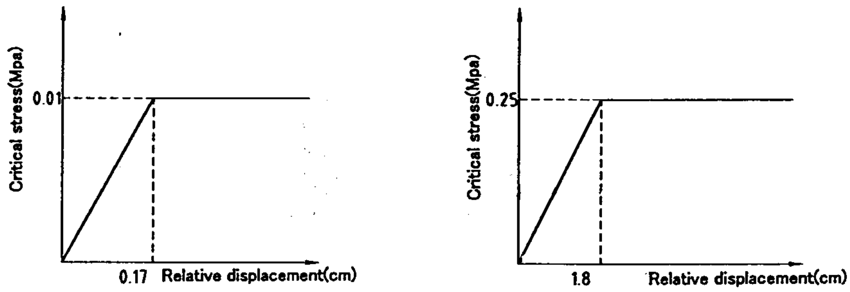
Table 1 Analytical conditions

	ϕ600 mm	ϕ400 mm	ϕ150 mm
Pipe diameter × Wall thickness (mm)	610 × 15.1	406.4 × 7.9	165.2 × 7.1
Material	API 5L X65	API 5L X52	STPG370
Angle of bent pipe (degree)	90, 45, 22.5		
Radius of curvature	3 DR	1.5 DR	1.5 DR
Internal pressure (MPa)	8.9	7.5	5.6
Topography	Slope, Revetment		
Displacement distribution	Slope: triangle; Revetment: rectangle		
Ground spring models	Nonlinear (bylinear-type)		
Liquefied area width L (m)	400		
Maximum displacement, δ max (m)	5		



(a) Slope (b) Revetment

Fig. 2 Analytical models for displacement due to liquefaction[2)]



(a) Pipe axial direction (b) Transverse to pipe axial direction

Fig. 3 Ground spring characteristics (ϕ600 mm, without reduction in ground stifleness)[3),4)]

Table 2 Maximum ground stifleness of transverse to pipe axial direction

Unit: MPa

	ϕ600 mm	ϕ400 mm	ϕ150 mm
Without reduction in ground stifleness k	0.25		0.25
With reduction in ground stifleness k	0.08	0.09	0.12

3. ANALYTICAL RESULTS FOR CAUSAL FACTORS

The analytical results were evaluated in terms of maximum tensile strain and bent pipe deformation angle.

3.1 Slope model

(1) Influence of ground constraint

Fig. 4 shows relationship between ground displacement incident angle and rate of maximum strain reduction due to ground constraint reduction, for pipes of ϕ600 mm and ϕ150 mm. The rate of maximum strain reduction is defined that the rate of maximum strain with ground constraint reduction to maximum strain without it.

This indicates that with ground constraint reduction, the generated strain is reduced by up to approximately 80% at a ground displacement of 5 m.

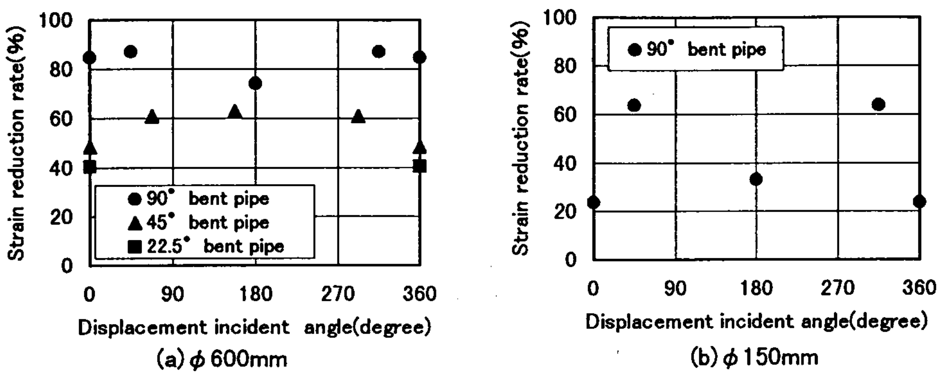


Fig. 4 Relationship between displacement incident angle and maximum strain reduction (input displacement of 5 m)

(2) Influence of ground displacement incident angle

Fig. 5 shows relationship between ground displacement incident angle and maximum strain, for pipes of ϕ600 mm and ϕ150 mm.

It was revealed that generated strain reaches maximum at the displacement incident angle where bent pipe is nearly symmetric with respect to the lateral flow direction (at displacement incident angle of 0°and 180°), regardless of pipe diameter, angle of bent pipe, and ground constraint.

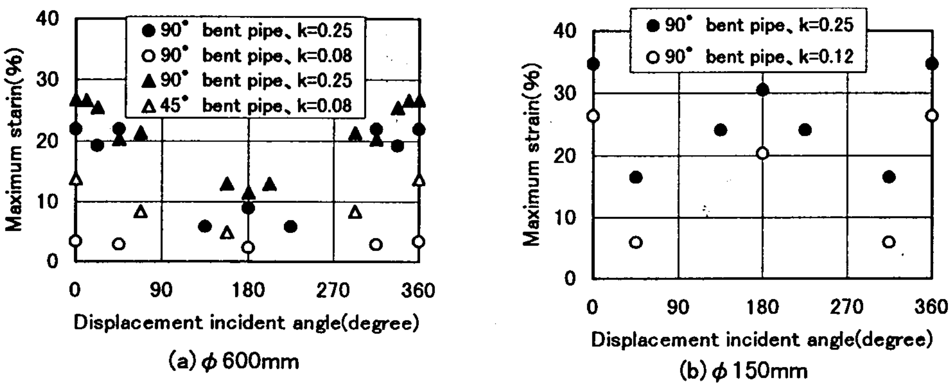
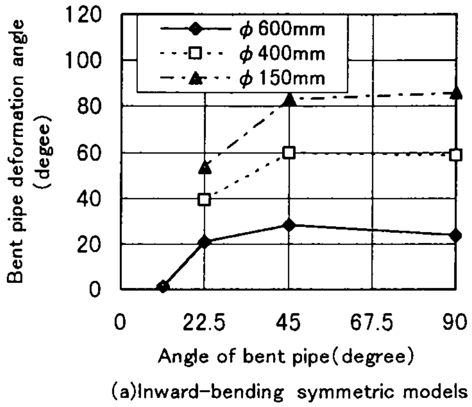


Fig. 5 Relationship between displacement incident angle and maximum strain (input displacement of 5 m)

(3) Influence of angle of bent pipe

Fig. 6 shows relationship between the angle of bent pipe and bent pipe deformation angle, in the inward and outward bending symmetric models when the ground constraint is reduced. The bent pipe deformation angle is defined as 1D from the dead end of the bent pipe for ϕ600 mm pipe, and the deflection angle with respect to the dead end of the bent pipe for ϕ150 mm and ϕ400 mm pipes.

Whether in ϕ600 mm, ϕ400 mm, or ϕ150 mm pipe, the bent pipe deformation angle tends to reach maximum in 90° or 45° bent pipe. Fig. 7 diagrams the deformation of the ϕ600 mm × 90° bent pipe model when displacement is 5 m.



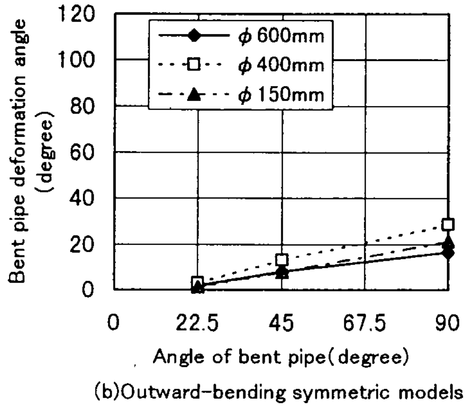


Fig. 6 Relationship between angle of bent pipe and bent pipe deformation angle (input displacement of 5 m)

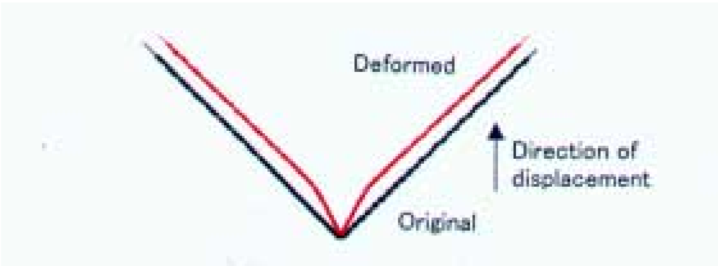


Fig. 7 Diagram of deformation (input displacement of 3 m)

3.2 Revetment model

(1) Influence of ground constraint

Fig. 8 shows relationship between ϕ600 mm bent pipe angle and rate of maximum strain reduction due to ground constraint reduction. This indicates that with ground constraint reduction, the generated strain is reduced by up to approximately 70% at a displacement of 5 m.

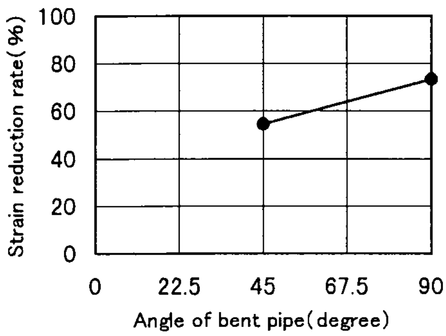


Fig. 8 Relationship between angle of bent pipe and rate of maximum strain reduction (φ 600mm bent pipe, input displacement of 5 m)

(2) Influence of angle of bent pipe

Fig. 9 shows relationship between the angle of bent pipe and bent pipe deformation angle when ground constraint is reduced.

Whether in ϕ600 mm, ϕ400 mm, or ϕ150 mm pipe, the bent pipe deformation angle tends to maximize in 90° bent pipe. Fig. 10 shows the diagram of deformation of the ϕ600 mm × 90° bent pipe model at displacement of 5 m.

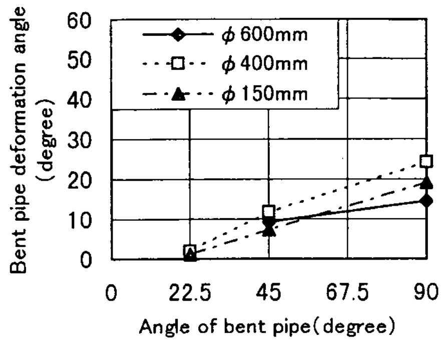


Fig. 9 Relationship between angle of bent pipe and bent pipe deformation angle (input displacement of 5 m)

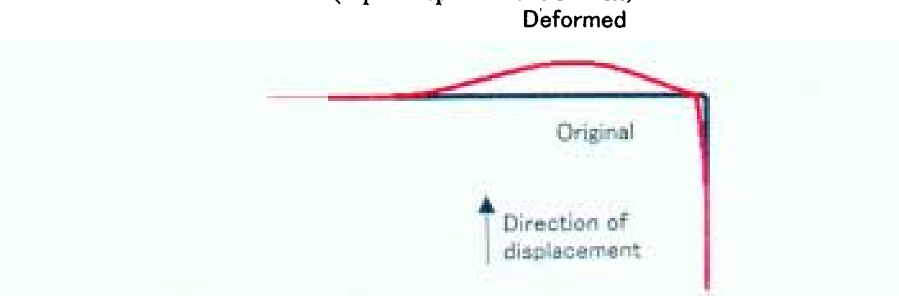


Fig. 10 Diagram of deformation(input displacement of 3 m)

4. SELECTION OF STANDARD BURIED PIPES

In practical design, it is necessary to develop a simple calculation method that allows easy design work without detailed analysis, and achieves safety regarding any mode of analysis of influence on buried pipes. To this end, this paper compares the results of analysis of influence on buried pipes and selects typical models for practical use in designing gas pipelines. These models are referred to herein as “standard buried models.”

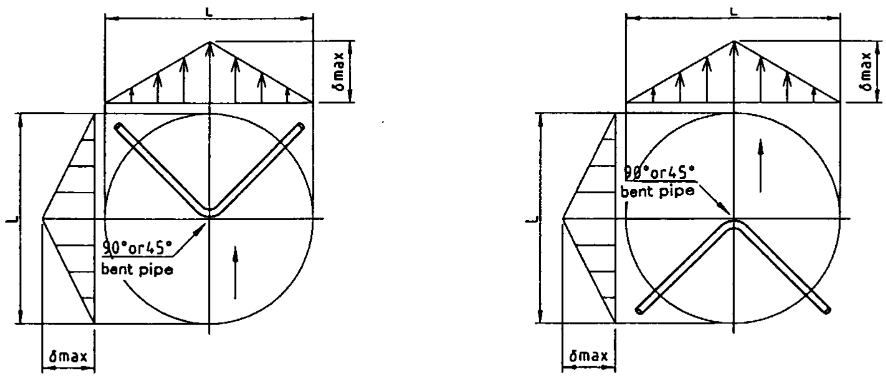
As selection standards, the following three conditions are considered with regard to pipes of 600 mm, 400 mm, and 150 mm diameter.

1) The bent pipe is inwardly deformed and the deformation angle reaches maximum on a slope.

2) The bent pipe is outwardly deformed and the deformation angle reaches maximum on a slope.

3) The bent pipe deformation angle reaches maximum on a revetment.

If the standard buried pipe models are chosen in accordance with the above, the symmetric model of the 90°or 45°bent pipe is selected for slope, and the model including the 90°bent pipe is selected for revetment. By using these models, it is possible to develop a simple calculation method. Figs. 11 and 12 show the standard buried pipe models.



(a)Inward-bending symmetric model (b)Outward-bending symmetric model

Fig. 11 Standard buried pipe models (Slope)

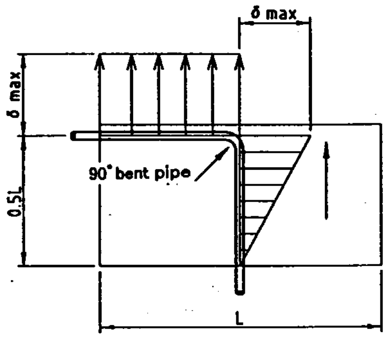


Fig. 12 Standard buried pipe model (Revetment)

5. CONCLUSIONS

(1) It has been confirmed that in revetment and slope soil subject to lateral flow, reduction of ground constraint in the direction transverse to the pipe axis results in considerable decrease in generated strain and bent pipe deformation angle.

(2) It has been clarified that in a slope topography, generated strain reaches maximum where the bent pipe is symmetric with respect to the lateral flow direction, regardless of pipe diameter or ground constraint.

(3) It has also been clarified that in either revetment or slope topography, and in pipe of 600, 400, or 150 mm diameter, generated strain reaches maximum in 90° or 45° bent pipe.

(4) By comparing the analytical results of influence on buried pipes (maximum strain and bent pipe deformation angle), the typical models have been selected for practical use in designing gas pipelines.

ACKNOWLEDGMENTS

This study was conducted during fiscal 1998 by the Japan Gas Association, as part of the "Investigation for Gas Pipeline Protection against Liquefaction" program (fiscal 1996 through 2000), commissioned by the Ministry of International Trade and Industry's (MITI) Agency of Natural Resources and Energy. We would like to express our gratitude to all related parties, including MITI staff, and each member of the Special Committee on Investigation for Gas Pipeline Protection against Liquefaction (headed by Tsuneo Katayama, general manager of the Science and Technology Agency's National Research Institute for Disaster Prevention), for their kind assistance in our study.

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