BEHAVIOR OF BURIED PIPELINE SUBJECTED TO REVERSE FAULTING: DEM-FEM APPROACH

Saitama University JSCE Society Member ○ Chowdhry Md Ilias
Saitama University Regular Member Hisashi Taniyama

1. INTRODUCTION

Permanent ground deformation (PGD) caused by fault movement has been a major cause for damaging communal facilities. Faulting depending on the direction of the movement can severely affect pipeline performance. Previous earthquakes (1923 Kanto, 1999 chi-chi, 2008 Wenchuan, 2009 Italy and 2010 Chile) uncovered the extreme vulnerability of the underground pipeline due to earthquake-induced PGD. Long length and large section pipelines are relatively weak in compression. Hence, we conducted Distinct element method (DEM) and Finite element method (FEM) analysis to study the behavior of buried pipeline subjected to reverse fault movement.

2. NUMERICAL MODELING

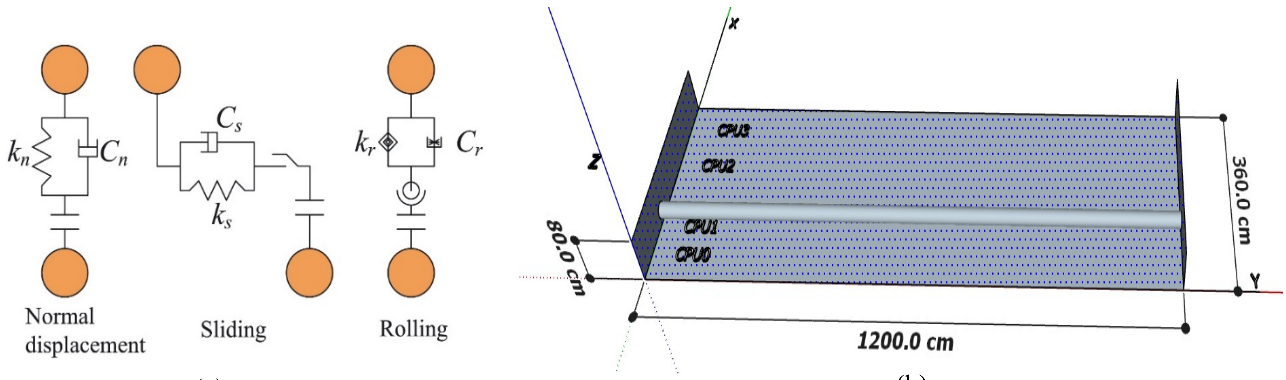
A three-dimensional (3D) model consist of ground surface and buried pipe has been created in the analysis. DEM for soil modeling and FEM for pipe modeling has been taken as a tool for analyzing the pipeline behavior caused by higher fault displacement. Material-Geometrical nonlinearity and soil-pipeline interaction were considered.

2.1 Modeling of soil

DEM is an effective tool developed by Cundall and Stack (1979) for modeling the behavior of granular assemblies. Soil is composed of granular materials which can freely make and break contact with their neighbors under applied force and deformation. These granular assemblies become inhomogeneous due to relative motions which influence the kinematics of soil particles. Each discrete particle is assumed as a rigid body, through small overlap is allowed at the contact point of each particle. Each contact point is then replaced by a set of springs, dashpots, no tension-joints, and a shear-slider. The contact forces correspond to the normal and tangential components balanced against resistance supplied by the spring and dashpots as shown in Fig. 1(a).

2.2 Modeling of pipe

In the analysis, the pipeline was considered as a continuous three-dimensional beam (shell) element. Newmark beta method has been adopted here to determine the dynamic behavior of buried pipeline during fault displacement and responses on the pipe due to displacement, velocity, and acceleration were computed using FEM. For the analysis process stiffness matrix, mass matrix, and damping matrix were derived for a 3D beam element.



(a) (b)

Fig. 1: (a) Schematic model of DEM (b) Layout of proposed model

3. PROPOSED MODEL

For creating initial assemblies of the model total 3,144,000 numbers of spherical particles were taken into consideration for each sample. Each particle was modeled separately, and the motion was computed step by step based on its interaction with neighboring materials. To know the performance of the pipe under dense soil conditions soil particles with different sizes had been deposited by sedimentation method so that the height of the final sample becomes 2m.

For pipe modeling, the whole pipeline has been segmented into 100 elements consisting of 12cm each. During the application of fault, the resultant force from soil particles will be distributed to each nodal point of the pipe as equivalent

Keywords: Buried pipe, DEM, Dense soil, Material and Geometric Nonlinearity, Soil-pipe interaction
Contact address: Vibration engineering lab, Dept. of Civil and Env. Eng., Saitama University, 338-8570, Saitama, Japan

load so that deformation of the pipe can be simulated. The properties of soil and steel pipe had been displayed in Table 1 and Table 2. For the analysis, the whole model is divided into two equal parts comprising footwall that remains stationary, whereas the hanging wall moves upward with a velocity of 100cm/sec applied at an inclination angle of 61° and 45° for generating reverse slip. Finally, the size of the model becomes 360cmx1200cmx 80cm shown in Fig. 1(b).

Table 1: Parameters for granular materials

Parameters	Dense sample
Diameter	(2.0~6.0) cm
Number of particles	3,144,000
Normal stiffness constant	1.59×10^6 N/m
Tangential stiffness constant	4.53×10^5 N/m
Normal damping constant	8.53×10^2 N.s/m
Tangential damping constant	4.56×10^2 N.s/m
Coefficient of friction	0.5
Rolling constant	0.5
Time step	0.000004

Table 2: Parameters for steel pipe

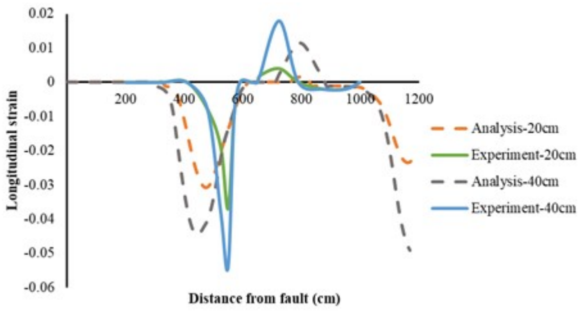
Parameters	Steel Pipe
Pipe length	1200 cm
Element Number	100 nos.
Element Length	12 cm
Pipe external diameter	17.78 cm
Pipe inner diameter	16.90 cm
Density	7.85 g/cm^3
Young modulus before yield	2.0×10^{11} N/m^2
Young modulus after yield	1.4×10^9 N/m^2
Yield stress in Tension	2.41×10^8 N/m^2
Yield stress in compression	-2.41×10^8 N/m^2
Damping constant	α - 1.631, β - 0.1083×10^3
Time step for fault application	0.000004

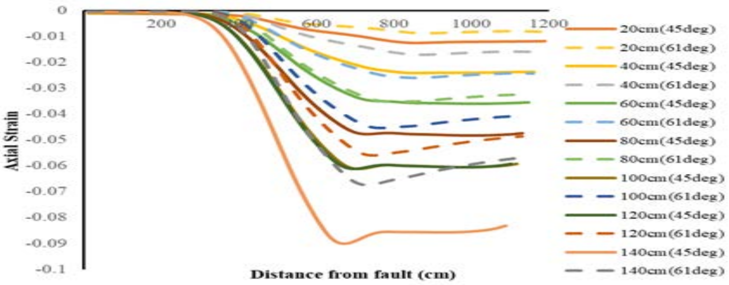
4. VERIFICATION OF MODEL

DEM-FEM model is validated against the full-scale laboratory test that had been done by Jalali et al. (2016) for 16.83cm pipe at 61° dip angle with 20cm and 40cm fault displacement. The strain distribution for the crown section shown in Fig. 2(a) indicates higher compressive strain at the footwall and moderate tensile strain at the hanging wall which was relatively close to the experimental result (Jalali et al. 2016a). At the end of the pipe the strain tends to increase due to fixed end condition and length of the pipe.

5. RESULTS

Responses of pipeline subjected to fault movement for dip fault angles of 61° and 45° have been analyzed and effects of axial strain also investigated in Fig. 2(b). Here the distance from (0-600) cm is considered as the footwall and the remaining part as the hanging wall. The axial strain on the buried pipeline is calculated from the nodal displacement and the deflection angle in the axial direction. At any dip-fault angle, the pipeline experiences increasing compressive strain with the increase of fault displacement. It can also be seen that the axial strain increases gradually as the inclination angle decreases because of stronger compressive force acting on the pipeline at smaller inclination angle.





(b)

Fig. 2: (a) Verification of model with experimental result (Jalali et al.,2016b) (b) Axial strain response

6. CONCLUSION

This research paper created a validated DEM-FEM analytical model that can be used to study the behavior of buried pipeline due to reverse faulting which was compared against a full-scale experimental test result (Fig. 2(a)) of 16.83cm steel pipe. The severity of pipeline behavior was observed at lower fault-dip angle of 45° where deformation and axial strain become higher. A larger model size with small granular assemblies may provide more clear analytical result.

REFERENCES

Cundall, P.A and Strack, O.D.L.: A discrete numerical model for granular assemblies, Geotechnique 29, No.1, 1979, pp. 47-55.

Jalali, H.H., Rofooei, F.R., Attari, N.K.A., and Samadian, M.: Experimental and finite element study of the reverse faulting effects on buried continuous steel gas pipelines, Soil Dynamics and Earthquake Eng., vol. 86, 2016, pp. 1–14.