ANALYSIS OF BURIED PIPELINE OWING TO REVERSE FAULT MOVEMENT ACCOUNTING FOR SOIL-PIPE INTERACTION

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1. INTRODUCTION

Surface faulting has been a major cause of pipe breaks during past earthquakes. Chi Chi earthquake in Taiwan in 1999 caused severe damage to buried pipeline due to rupture of Chelungpu fault. Consequently, seismic analysis of buried pipeline accounting for fault rupture is a critical phenomenon in the field of lifeline engineering. This research study includes the analysis of buried pipeline under reverse fault movement using three dimensional Distinct Element Method (DEM) and Finite Element Method (FEM). Interactions between soil and pipeline during faulting are analyzed in this paper.

2. NUMERICAL MODELING

A three dimensional model has been developed to analyze the response of buried pipeline accounting for fault movement. Soil-pipe interaction is the most critical issue in the modeling.

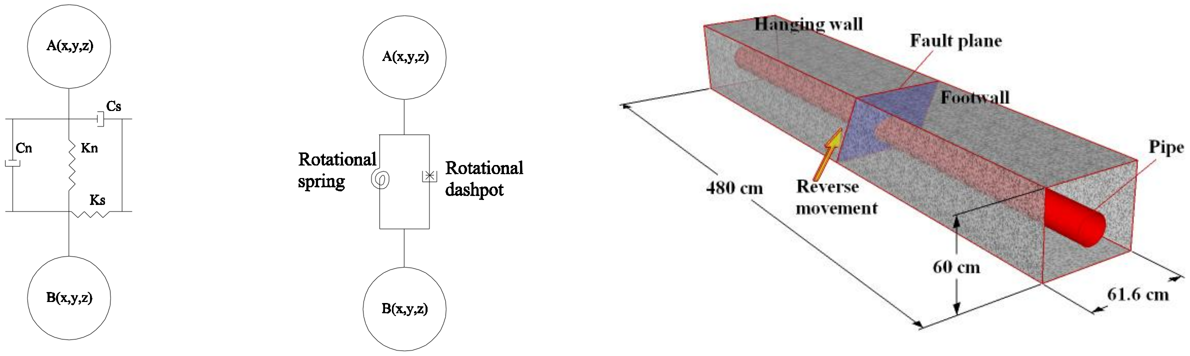
2.1 Modeling of soils

DEM is an important tool in modeling the behavior of granular materials pioneered by Cundall and Strack (1979). Rheological elements of DEM are shown in Figure -1 (a). Iwashita and Oda (1998) proposed an additional rotational spring slider system (Figure-1(b)) in parallel with the normal and shear spring. This research study includes spherical particles with normal, shear and rolling springs and normal and shear dashpots. Normal force is calculated when particle overlap and maximum shear force and moment are given in the following:

$$F_{max} = \mu F_n \qquad (1)$$

$$M_{max} = \alpha B F_n \qquad (2)$$

Where, F_n is the normal force, μ is frictional coefficient, B is diameter of contact area, α is a parameter which determines the rolling resistance.



(a) (b) (c)

Figure-1: (a) Rheological elements of DEM, (b) Rolling resistance in DEM, (c) Layout of proposed model

2.2 Modeling of pipes

Pipe is modeled using three dimensional beam elements. Stiffness matrix, mass matrix and damping matrix are calculated for pipe elements. Dynamic behavior of pipes has been considered in this analysis.

2.3 Proposed model

Around 1.8 million spherical particles having diameter 1.1 cm and density 2.4 g/cm^3 are used to put up the model and packed in the assembly. Typical parameters for particles are given in Table-1. Pipe is placed in the shallow depth of the model and surrounded by the discrete soil particles. 15 cm diameter pipe with elastic modulus 1.6 x 10^{11} N/m^2 and density 7850 Kg/m^3 has been chosen for this model. Initially after defining the position, DEM simulation has been performed for sedimentation of particles. The basement and sidewall particles are remaining fixed during calculation. Periodic boundary conditions are imposed in the strike direction so that any particle goes beyond the boundary placed in opposite side. Size of the model after the preparation process is 61.6 cm x 480 cm x 60 cm.

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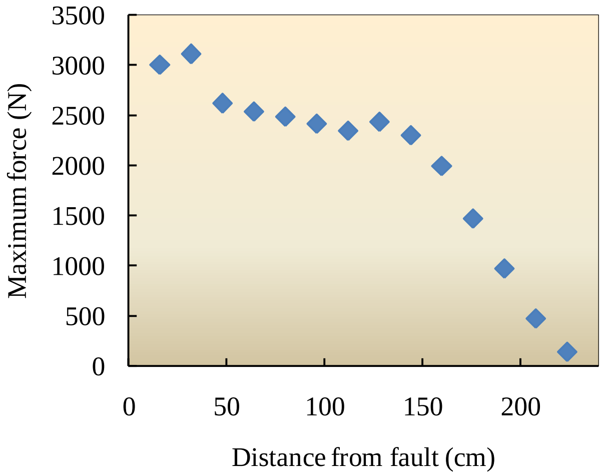
After the sedimentation, reverse fault movement has been applied by moving the basement and sidewall of one side of the model in reverse direction. Fixed boundary conditions are considered at the farthest end of the pipeline and pipe is restrained in the reverse direction. Contact forces between pipes and particles are calculated during rupture and equivalent forces are transferred to pipe nodal points which lead to the deformation of the pipeline. Layout of proposed model is shown in Figure-1 (c).

Table-1: Parameters for particles

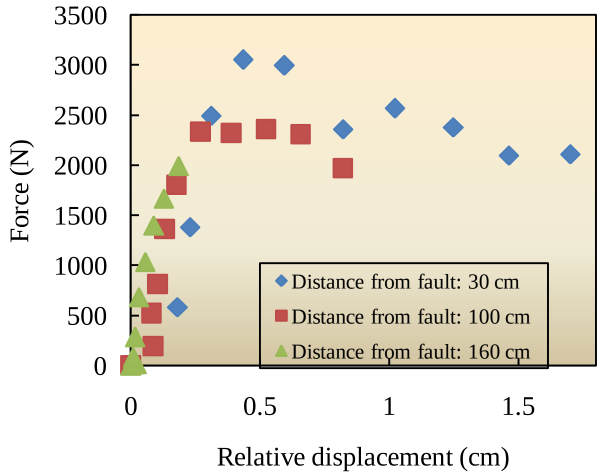
Parameters	Value	Units
Normal spring stiffness	2.5×10^5	N/m
Tangential spring stiffness	7.0×10^4	N/m
Normal damping constant	4.0	Ns/m
Tangential damping constant	2.1	Ns/m
Co efficient of friction	0.25	----

3. RESULTS

Responses of the pipeline under fault rupture are calculated and effects of particles are investigated through this simulation. Forces between pipes and particles are plotted at different points on the pipeline and maximum force are observed near fault position and force effect decreases away from the faulting which corresponds the much belongings of particles at near fault line. Maximum force responses are plotted in Figure-3 (a).



(a)



(b)

Figure-3: (a) Maximum force between pipes and particles in hanging wall zone (b) Force-displacement relation

Force – displacement relation between pipes and particles has also been discussed by plotting F-d relation at different points from the fault line and shown in Figure -3 (b). It has been seen that load-deflection curve increases initially and after yielding subsequent decrement of force occurs. That means, strain softening behavior are observed after the yielding due to failure of particles whereas away from the faulting, yielding is more gradual and particle offers strain hardening nature. Effects of particles are much higher in the vicinity of fault plane and soil – pipe interaction decreases after the yielding of particles. Sufficiently away from the faulting, the trend of the load-deflection curve changes. However, this force-displacement relation comes from the natural contact between pipes and particles and gives more rational soil- pipe interaction during fault rupture.

4. CONCLUSION

This study employed a new methodology for the analysis of buried pipeline due to fault rupture. Soil-pipe interaction at different positions from the fault plane is investigated and the variation of force – displacement relations are observed in this simulation. Effects of particles are more dominant in near fault position and decreases away from the rupture zone. However, limitation of computational time may be an obstacle for more rigorous analysis. Large model size with smaller particle may provide more clear understanding of the soil – pipe interaction.

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