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A study of the seismic response of a buried segmented pipeline crossing a fault

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ABSTRACT: A buried segmented pipeline crossing a fault is usually damaged by earthquake. Based on buried continuous pipelines' model, the Finite Element Model for a buried segmented pipeline crossing the fault is established in this study. Considering the non-linearity of joint, joint spring elements are composed by axial spring, bend spring and shear spring in three directions. Joint spring elements are applied to link up the pipe segment elements. To study the failure mechanism of segmented pipelines under fault movement, the analysis model is applied to simulate an experiment of buried concrete segmented pipelines crossing the fault. Damage location of concrete segmented pipelines always occurs near the fault. For segmented pipeline, failure mechanisms mainly include joint pull-out, joint contraction, joint rotation and pipe failure.The results show that fault displacement imposes flexural bending and shear on the pipeline accompanied by axial compression or tension, depending on the geometric orientation of the pipeline crossing fault.

1 INTRODUCTION

Buried segment pipeline systems are commonly used to transport water, sewage and other fluids. Theses pipelines carry fluids essential to the support of people's life and maintenance of property. If these buried pipelines are damaged in an earthquake, fire and other disasters could also be caused due to the failure of pipe's service function.

Catastrophic failures of buried pipeline did occur in many earthquakes, particularly under large fault displacements. Based on the investigation of pipeline damage in the 1995 Kobe earthquake, the 1999 Jiji earthquake, the 1999 Kocaeli earthquake, the 2008 Wenchuan earthquake and others. Permanent ground displacements (PGD) pose the greatest damage to a buried pipeline. Simplified design methods have been proposed to obtain the maximum stress or strain in pipelines crossing an active fault (Newmark and Hall, 1975, Kennedy et al., 1977, Wang et al., 1995, Liu et al., 2000, Takada et al., 2001, Eidinger et al., 2001).

Above research papers are mainly about the buried continuous oil or gas pipelines, and the research work of a segmented pipeline is relatively rare. For the segmented pipeline, the mechanism of joint destruction is a key problem. For segmented pipelines, failure mechanisms mainly include joint pull-out, joint contraction, joint rotation and pipe failure. In this study, a Finite Element Model for a segmented pipeline is specially established to study the failure process of pipe under fault movement, and the model is adopted to simulate the behaviour of full-scale concrete segmented pipelines under permanent ground displacements (Kim et al., 2010).

2 FEATURES OF THE ANALYSIS MODEL

Based on buried continuous pipelines' model and considering the non-linearity of joint, the Finite Element Model for a buried segmented pipeline crossing a fault is established, joint spring elements are composed by axial spring, bend spring and shear spring in three directions. At the location of joints, joint spring elements are applied to link up the beam or shell elements to obtain the failure mechanism of segmented pipelines objected to fault, as shown in Figure 1.

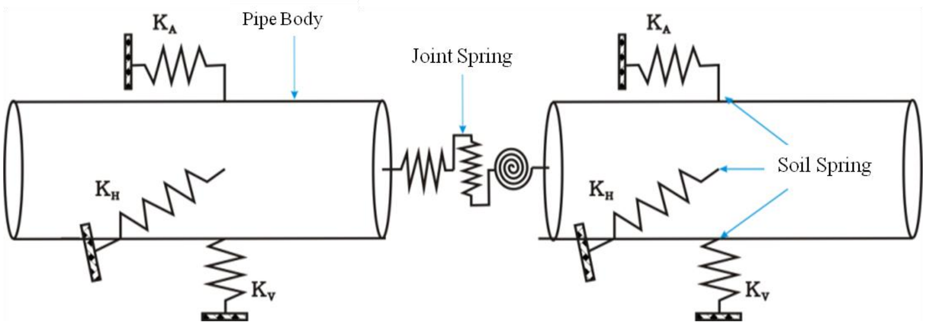


Figure 1. Finite element model for buried concrete segmented pipes

2.1 Modeling of the pipe body

For the steel pipeline, the shell element is usually used to simulate the buckling of the pipe body under the fault movement. Different from the damage of buried continuous pipelines, the segmented pipes always suffer a failure of joints, and the pipe body usually keeps intact. So the beam element is adopted to model the segmented pipe body. Drucker-Prager material model is selected for the concrete pipe and the material constants are listed in Table 1.

Table 1. Concrete parameters.

Cohesive force (kPa)	Inner friction angle (°)	Expansion angle(°)
167	25.2	0

2.2 Modeling of soil-pipe interaction

The soil surrounding the pipeline is modeled by three directional nonlinear springs: the axial direction of the tube axis, the horizontal direction and the vertical direction. Each pipe body element is connected with three soil springs. These soil springs are used to simulate the axial friction and soil pressure in the horizontal and the vertical directions, as shown in Figure 2.

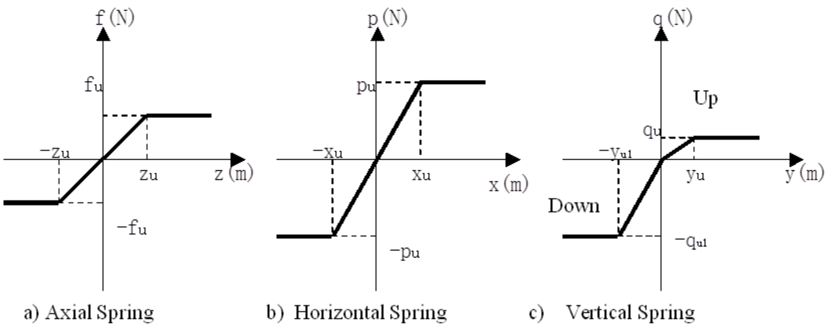
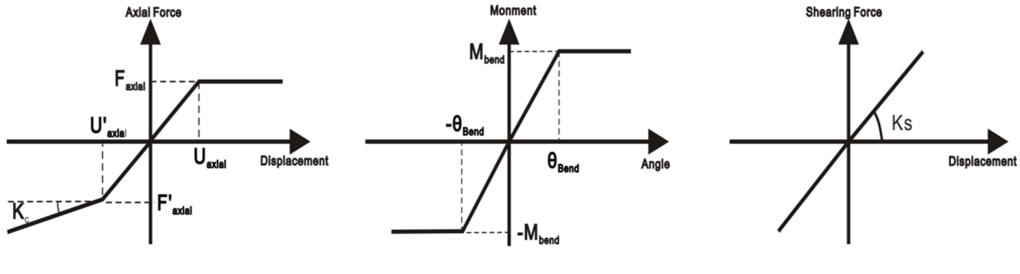


Figure 2. Soil spring in three directions

2.3 Modeling of joints

For segmented pipelines, failure mechanisms mainly include joint pull-out, joint contraction, joint rotation and pipe failure. Fault displacement imposes flexural bending and shear on the pipeline accompanied by axial compression or tension. According to the bell-spigot joint of segmented concrete pipe or cast iron pipe, the joint behaviour is simulated by an axial spring, a Rotational springand a lateral spring as shown in Figure 3.



a) Axial Spring of Joint b) Bending Spring of Joint c) Lateral Spring of Joint

Figure 3. Three springs of the joint

3 VERIFICATION

3.1 Experiment and material properties

Concrete segmented pipe is one the most widely used pipe constructions due to their low cost, high strength, and resistance to deterioration. To explore the behaviour of a segmented concrete pipeline during PGD, experimental testing of a concrete segmented pipeline section is performed at the NEES Lifeline Experimental and Testing Facilities at Cornell University (Kim Junhee, 2010). The pipeline is exposed to PGD created by a 50 degree fault plane exposed during displacement-controlled movement of the facility test basin. A dense array of sensors is installed along the length of the pipeline to measure its response to PGD introduced during fault displacement.

The reinforced concrete pipe cross-section consisted of a 30.48 cm inside wall diameter with a 6.3 cm wall thickness. The pipe walls were reinforced with steel bars using a reinforcement ratio of 0.07. The compressive strength of the concrete material was equal to 27.58 MPa. A full-scale segmented pipeline consisting of five full pipe segments and one partial pipe segment was tested under PGD in the large basin at Cornell University, as shown in Figure 4.

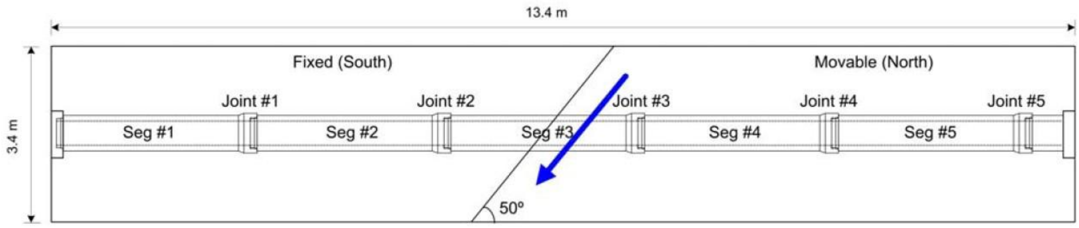


Figure 4. Layout of the segmented concrete pipeline crossing fault (Kim Junhee, 2010)

3.2 Results

The test basin was designed to simulate a transverse fault oriented 50 degrees relative to the longitudinal length of the basin. The north end of the test basin was attached to four hydraulic actuators for controlled displacement while the south end of the basin was held fixed. The test ended after twelve actuation steps with the final PGD measured at 30.5 cm along the fault line. During the 12th actuation step, significant movement was observed at the joints near the fault line. Based on the buried depth of this concrete pipe, the parameters of the soil spring and the joint spring could be obtained as listed in Table 2 and Table 3.

Table 2. Soil spring parameters in three directions.

Spring parameters	Axial Spring	Horizontal Spring	Vertical Spring (up)	Vertical Spring (down)
Force（N/m）	$F_u = 1.181\times10^4$	$P_u = 1.8731\times10^5$	$q_u = 3.823\times10^4$	$q_{ul} = 3.238\times10^5$
Relative Disp. (m)	$Z_u = 0.008$	$X_u = 0.071$	$Y_u = 0.0159$	$Y_{ul} = 0.0375$

Table 3.Spring parameters of joints in three directions

Spring parameters	Axial Spring	Bending Spring	Lateral Spring
F/ M	F'_{axial}=500 N	M_{Bend}=4000 N m	Ks=4.5×10^7N/m
U/ R	U'_{axial}=0.001m	θ_{Bend}=0.1rad	/

Using the finite element software ANSYS, the above analysis model is adopted to simulate the behaviour of this full-scale concrete segmented pipeline under permanent ground displacements as shown in Figure 5 . The finite element analysis results are compared with the experimental results.

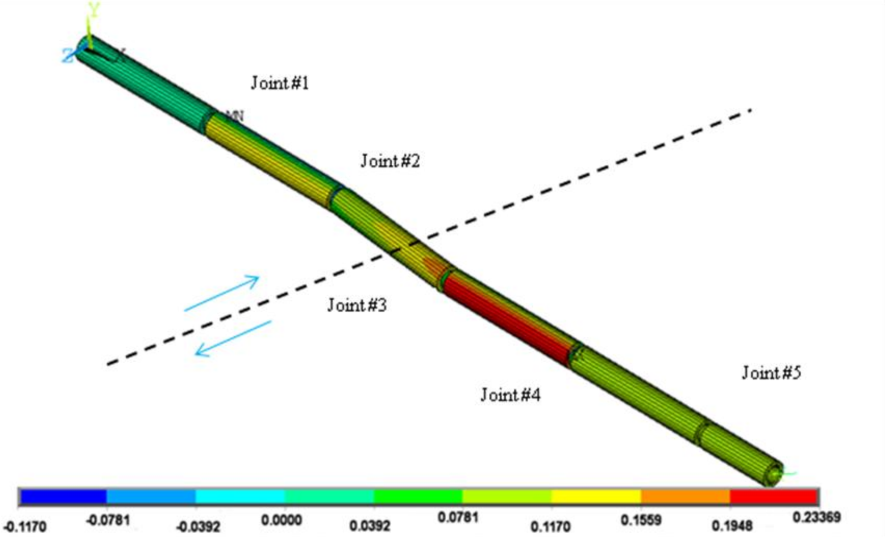


Figure 5. Displacement in Z-Direction along the segmented pipeline (Unit: m)

Table 4. Rotation for pipe joints.

Rotation	Joint #1	Joint #2	Joint #3	Joint #4
Experiment Result	0.6 °	-5.7 °	5.7 °	-0.6 °
FEM Result	0.0192 °	-5.7009 °	5.4382 °	-0.0223 °

As shown in Figure 5 and Table 4, Joint#2 and Joint#3 suffered large rotation angle and large compressive displacement, the finite element analysis results of these two joints are closed to the experimental results. For the Joint#1 and Joint#4, the joint rotation angles obtained by the finite element analysis are smaller than the experimental results.

As shown in Figure 6, the failure processes of Joint#2 and Joint#3 are studied with the increase of fault displacement. The finite element analysis results are usually larger than the experiment results.

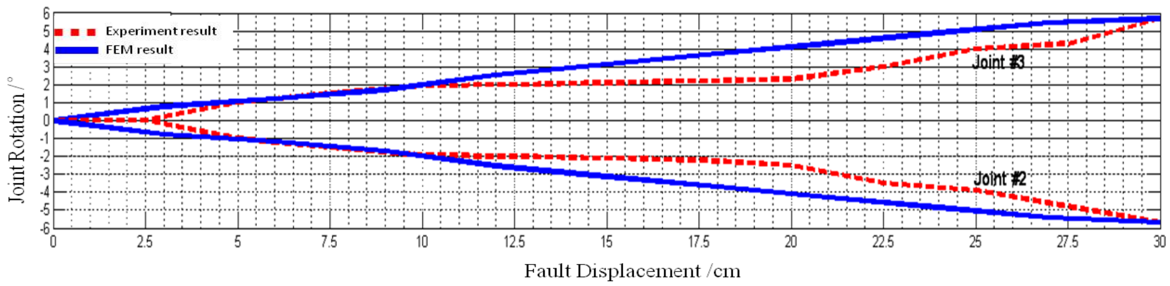


Figure 6. Effect of fault displacement on joint rotation

4 DISCUSSION:

There are many types of joints for the segmented pipes. The analysis model in this study is specially for the bell-spigot joint of segmented concrete or cast iron pipe. Because of strong nonlinearities, it is difficult to completely simulate the joints behaviour under fault movement. The analysis results in this study show that the joint failure mechanism may be strongly related with the crossing angle and the position of pipeline under the fault movement. Fault displacement imposes flexural bending and shear on the pipeline accompanied by axial compression or tension. Joints of those pipe segments near the fault are easy to be damaged.

REFERENCES:

Newmark N. M. and Hall W. J. 1975. Pipeline design to resist large fault displacement, Proceedings of U. S. National Conference on Earthquake Engineering, pp.416-425.

Kennedy R. P. , Chow A. W. and William R. A. 1977. Fault movement effects on buried oil pipeline, Transportation Engineering J., ASCE, Vol. 103, No. TES, pp.617-633.

Wang L. L. R. and Wang L. J. 1998. Parametric study of buried pipelines due to large fault movement, ASCE, TCLEE, No.6, pp.152-159, (1995) and Proceedings of 3rd Trilateral China-Japan-U.S. Symposium on Lifeline Earthquake Engineering, pp.165-172.

Shiro Takada, Hassani Nemat and Fukuda Katsumi. 2001. A new proposal for simplified design on buried steel pipes crossing active faults, Journal of Structural Mechanics and Earthquake Engineering, JSCE, Vol. 668, No. 54, pp. 187-194.

Aiwen LIU, Yuxian HU, Suling ZHANG. 2000. Responses of buried pipelines in large fault movements, Proceedings of Sixth International Conference of Seismic Zonation, EERI.

John Eidinger: Performance of Thames Water 2.2 meter diameter steel pipe at north Anatolian fault crossing, G&E Report 48.01.01, May 9,2001

Junhee Kim, Sean O'Connor, Sid Nadukuru. 2010. Behavior of full-scale concrete segmented pipelines under permanent ground displacements[C]. Proc. SPIE 7650: Health Monitoring of Structural and Biological Systems 2010. Doi:10.1117/12.847735.