The new remediation technique for buried pipelines under permanent ground deformation

Une nouvelle technique de pose des conduites enterrées soumises à des déformations permanentes du sol

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ABSTRACT: One part of lifelines is buried pipelines such as gas, water and oil pipelines. Permanent ground deformation such as fault crossing and lateral spreads is one of the more important threats for pipelines. In this research, a new remediation technique for buried pipeline system subject to permanent ground deformation is proposed. Also this new technique has been evaluated by centrifuge modeling of buried pipelines subjected to concentrated PGD. In proposed technique, the high porosity gravels are used as low-density backfill to fill the trench around the pipe near the susceptible area to PGD, thereby reducing soil resistance and soil-pipe interaction forces and also pipeline strains. Previously, the expanded polystyrene (EPS) geofoam proposed to reduce density of pipelines backfill. However, the high porosity gravel is better than expanded polystyrene geofoam from many cases such as workability to construct, environmental effect, durability and cost. In this technical paper, described the proposed technique and also two centrifuge modeling have been done to evaluate its performance. The comparisons of responses of remediated pipeline with unremediated pipeline have been shown that the proposed technique is effective considerably.

RÉSUMÉ : Une partie des réseaux nécessaires au transport du gaz, de l'eau et du pétrole est constituée de conduites enterrées. Les déformations permanentes du sol dues à des tassements ou à des mouvements latéraux sont l'une des menaces les plus importantes pour les conduites enterrées. Dans cet article, une nouvelle technique de pose des conduites enterrées soumises à des déformations permanentes du sol est proposée. Cette nouvelle technique a été évaluée par des essais en centrifugeuse sur des canalisations enterrées soumises à des déformations permanentes du sol. Pour la technique proposée, des matériaux sableux dont la porosité est élevée sont utilisés pour le remplissage des tranchées. Ils réduisent les efforts induits par l'interaction sol-tuyau. Auparavant, c'est le polystyrène expansé geofoam qui était utilisé. Le matériau proposé est meilleur que le polystyrène expansé geofoam en ce qui concerne la mise en œuvre, l'effet sur l'environnement, la durabilité et le coût. Dans ce papier, la technique proposée est décrite ainsi que deux modèles en centrifugeuse réalisés pour évaluer sa performance. Les résultats obtenus montrent que la technique proposée est plus efficace que celle utilisée précédemment.

KEYWORDS: Centrifuge Modeling, Faulting, Lifelines, Pipeline, Earthquake

1 INTRODUCTON

Buried pipelines often serve as lifelines in that they may carry resources that are essential to the support of human life and this is the reason to retain them in serviceable condition in every situation. Among various kinds of natural hazards, earthquakes happen to be the most serious threats for lifelines serviceability. They can damage lifelines through faulting, permanent ground deformation (PGD) and deformations due to seismic wave's propagation. Faulting can affect pipelines in various ways (Fig. 1) and cause severe damages (Fig. 2) depending on faulting movement direction.

Considering mentioned hazards, lots of statistical, analytical and numerical studies have been conducted since 1970s in order to predict pipelines response and vulnerability level and also to investigate methods of damage mitigation; but it has been a difficult and somehow impossible way to evaluate theoretical and analytical research results due to loss of accurate and efficient records about pipelines response to faulting in actual case histories of earthquakes (Choo et al. 2007). In order to compensate such a gap, studies turned towards applying experimental and physical modeling of this phenomenon. Since 2003, significant researches have been started in U.S.A. and Japan with support of companies and institutes such as Tokyo Gas Company, US lifelines Agency, National Science Foundation in U.S.A, Earthquake Engineering Research Center and etc. Most of mentioned conducted studies have been focused on strike-slip faulting. So, still there is lack of studies on normal and reverse faultings' effects and this puts them in prime importance of research priority.

Herein, the authors investigated the pipeline response due to reverse faulting and also investigated the use of high porosity gravel as low-density backfill in pipeline response. It is expected that low-density backfill for will reduce soil-pipe interaction and reduce the pipe train.

Table 1. Centrifuge Facility Properties

Property	Unit	Quantity
Exerted acceleration	g	5 – 130
Acceleration accuracy	g	+ 0.2
Rotational velocity range	rpm	38 – 208
Rotation radius	m	3
Maximum model weight (up to 100 g)	kg	1500
Maximum model weight (up to 150 g)	kg	500

1.1 *Faulting simulator split box*

Experimental setup provision in order to use in centrifuge instrument has its own limitations; for instance, weight and dimensions of the box is thoroughly tied to the used centrifuge facility properties and it is of prime importance for the box to have the minimum weight and dimensions possible together with having enough strength for high magnitude forces caused due to high exerted accelerations. Regarding these limitations, the group-7000 aluminum alloy which has low density and high strength is used to build up the faulting simulator split box in this study. Outer dimensions of the box are 102×76×68 cm (l×w×h) and the inner dimensions are 96×70×23 cm. The split line of the box which is the faulting line itself, makes the angle of 30˚ from the vertical direction. The box setup is assembled and fixed on a 4 cm thick aluminum block of 15 cm width that can bear the hydraulic jack caused 5 ton horizontal force and high magnitude vertical force which is exerted due to high accelerations. Holes have been cut in the two ending walls of the box as the backrests for studied structures such as pipelines. Regarding lack of space in the centrifuge basket, the motivating system and the other constituents of the simulator must occupy the minimum space possible.

Moving mechanism has been designed to be enough stable during the faulting movement and also can bear the high magnitude unbalanced forces derived from soil-structure friction.

A wedge-sliding mechanism has been applied for the box movement to direct the faulting through the 30˚ specified direction and prevent form any strike between fixed and moving parts of the split box. The wedge-sliding mechanism is consisted of two rails installed with the angle of 30˚ from the vertical direction and high level force tolerating ball bearings to guide the movement as desired. Sliding the wedge forward and backward, the moving part of the box would have an upward-downward movement (Fig. 4). Considering the high magnitude forces and weight increase in high order accelerations, the moving system has been chosen of hydraulic type to be strong enough and less space occupying. The velocity and displacement control can be done by means of electronic hydraulic valves with a satisfactory level of accuracy and reliability. The hydraulic pressure generator is installed out of the centrifuge basket to save a significant amount of space and is connected to the inside basket moving system by means of hydraulic pipe and rotary joints.

Figure 4. General View

1.2 *Scaling laws*

The scaling laws used for this modeling are indicated as below (Table 2).

Table 2. Scaling laws for centrifuge testing

Parameter	Model / Prototype	Dimensions
Length	1/N	L
Strain	1	1
Stress	1	ML-1T-2
Acceleration	N	LT-2
Axial Rigidity	1/N2	MLT-2
Flexural Rigidity	1/N4	ML3T-2

1.3 *Soil properties*

Soil material used in first test is chosen to be the granular soil of standard Firoozkouh 161 sand. Soil material used in second test is high porosity gravel with low density. The density of low-density soil is equal to 50% of Firoozkouh soil density. (Table 3)

Table 3. Properties of Firoozkouh and low-density Soil

Sand type	G_s	e_{max}	e_{min}	D50 (mm)	FC	C_u	C_c
Firoozkouh 161	2.65	0.874	0.548	0.27	1 %	2.58	0.88
Low-Density	1.3	-	-	3	~0%	-	-

1.4 *Instrumentation*

Two types of instruments containing strain gauge and linear variable differential transformers (LVDTs) were installed in the model. The strain gauges are installed in axial and circumferential directions on the

pipelines with the number of 26 in 7 stations. Strain gauges are placed in a way that axial and bending strains could be measures separately. Strain gauges are of the high strain type and are connected in the quarter bridge form.

Three LVDTs of the whole 5 ones are installed on the surface of the pipeline to record the deformation profile and the 2 other ones measure the axial displacement of the two endings of the pipeline. Apart from above, colorful grids were being used on the surface and between the soil layers.

2 RESULTS

Two tests were conducted in this study. In the first one, a stainless steel pipe with diameter of 8.0 mm and wall thickness of 0.4 mm which buried in Firoozkouh sand was subjected to a 70 mm reverse faulting with the acceleration of 40g. In the second experiment, the stainless steel pipe with 8.0 mm diameter and 0.4 mm wall thickness which buried in low-density gravel was subjected to the reverse faulting with 40g acceleration. The properties of model and prototype are indicated in Table 4.

Table 4. Properties of model/prototype for conducted tests

	1st Test		2nd Test	
	Model	Prototype	Model	Prototype
Pipeline Diameter (m)	0.008	0.320	0.008	0.32
Pipeleine Wall Thickness (m)	0.0004	0.016	0.0004	0.016
Faulting Magnitude (m)	0.070	2.8	0.070	2.8
Backfill	Firoozkouh 161		High Porosity Sand (Low Density)	
Faulting Type	Reverse (60%)		Reverse (60%)	

Following figures illustrate the deformations of pipeline and soil during the faulting process. In Figs. 9 and 10 bending and axial strains before pipe failure versus distance from the faulting in 2nd test are presented.

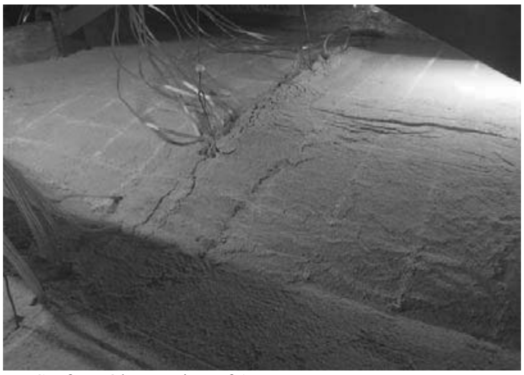

Figure 5. Surface Observation of 1st test

Figure 6. Surface Observation of 2nd test

Figure 7. Section Observation of 1st test

Figure 8. Section Observation of 2nd test

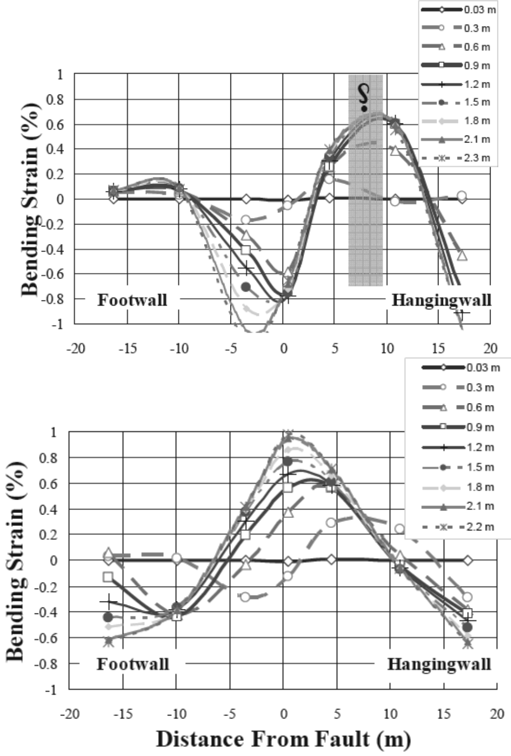

Figure 9. Bending strain during faulting- (Top: 1st test, Down: 2nd test)

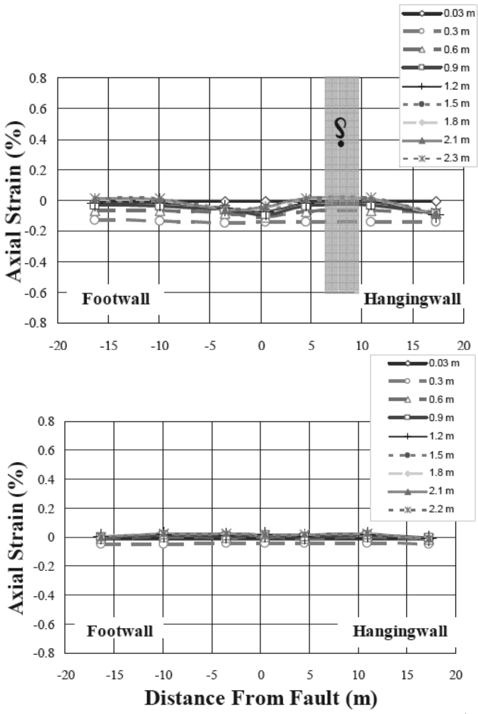

Figure 10. Axial strain during faulting-(Top: 1st test, Down: 2nd test)

3 CONCLUSIONS

In this article the report of establishment of the first geotechnical centrifuge in Iran and its initial application in buried pipelines modeling subjected to faulting are presented. Also, a brief summary of the modeling details, related scaling laws and used facilities and instruments are described. Reported in this experimental study are the axial and bending strains diagrams of steel pipe versus distance from the normal faulting before pipe failure for the first time in the literature. Pipe failure happened almost at 3 cm in model or 1.2 m in prototype offset.

The use of light weight material to fill pipeline trench is an affective technique to improve pipeline response to PGD. This technique changes the pipeline response from wrinkling to beam buckling which is a better deformation mechanism. In this mechanism the deformation of pipeline is distributed along the pipeline, despite of wrinkling mechanism which the deformation concentrated on two points. Also in beam buckling mechanism, the axial strain of pipeline is very small and the maximum bending moment reduced and transferred to the middle of pipeline. Choo et al. (2007) also investigated the use of light weight material (polystyrene blocks) to remediate the behavior of buried pipeline under normal faulting. They found that this technique improved the performance of pipeline under PGD condition.

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