ASSESSMENT OF POLYETHYLENEPIPELINESUNDER LANDSLIDE

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ABSTRACT

With increasing global demands for energy resources, pipeline systems, called as lifelines, play a significant role in urban processes. For safety considerations pipeline systems in urban areas buried in soil. Therefore, landslide is one of general problems in water conducting pipelines which occurred increasingly within last decade. During landslide, excessive plastic deformations occur in pipeline which lead to local plastic failures in critical parts of pipeline system. In case of landslide it is important to avoid crossing slopes but in practice because of environmental restrictions it can’t be avoided. Generally geotechnical processes, such as landslide, are so complicated so many researches have been focused on landslide and its effects on lifeline systems. This paper has been focused on failure in polyethylene buried pipelines under non-uniform deformations of landslide. Within design process of pipelines, critical problem is to determine allowable strain and stress limits in pipeline under landslide. Here a finite element model of polyethylene pipeline has been prepared in ABAQUS software with a contact element to model interaction of soil and pipeline. Final model include soil profile and pipeline system crosses perpendicular to landslide direction. In this paper variation of surrounding soil and geometry of pipeline have been investigated. This paper tries to investigate failure potential of pipeline under excessive deformations and variation of these parameters. A failure criterion has been proposed based on strain limits of pipeline. Finally failure potential have been assessed by means of fragility curves. Given results in this paper could be used in practical design codes of water conducting pipeline systems.

INTRODUCTION

The term “pipeline” refers to a long line of connected segments of pipe, with pumps, valves, control devices, and other equipment/facilities needed for operating the system. Their purpose isto transport a fluid, mixture of fluids, solids, fluid solid mixture. The term pipeline also includes a relatively large pipe spanning a long distance. Buried pipeline systems are commonly used to transport water, sewage, oil natural gas and other materials. Pipelines are classified as lifelines since they carry materials are essential to support human life.

Permanent ground deformation is a significant hazard for many manmade structures including houses, highways, tunnels, bridges, as well as water, gas, oil and sewer pipelines. The principal forms of this ground deformations are surface faulting, land sliding, seismic settlement and lateral spreading due to soil liquefaction. Landslides are one of the key problems for stability analysis of pipelines. During Landslides, buried pipelines are subjected to forces and deformations imposed on them through interactions at the soil-pipeline interface.

Past design practices for pipelineshave focused on avoidance of areas that have a reasonable probability of experiencing geo-hazards. This approach has been generally successful when there are limited restrictions on selecting a pipeline route. Therefore, many studies have been focused on pipeline integrity management strategies to mitigate geo-hazards and consist of understanding the geo-hazards and propose design measures that improve the pipeline resistance to the geo-hazards

JafarzadehF.,et al. (2012) studied buried steel gas pipes against local slope instability.The pipe having three positions in the slope and is taken perpendicular to sliding. They suggested that the placing pipe in lower parts of the slope could result in more safety for the pipeline system.

BingH., et al. (2012) studied strain-based design of buried pipelines subjected to landslides. The general finite element program ABAQUS is used to analyze the distribution of pipe strain caused by landslide through which the pipeline passes.The resultsindicate that the pipeline is primarily subjected to tension stress when the landslide crosses the pipelineperpendicularly, the pipe strain is a maximum along the central axis of the landslide, and reverse bendingoccurs on pipeline at both edges of the landslide. The pipe strain is in proportional to diameter-thickness ratio of pipeline, D/t, and this means decreasing D/tcan help to improve security of pipelines subjected to the landslide.

ZhengJ.Y.,et al. (2012), studied the failure mechanisms of buried steel pipelines due to non-uniformdeflection of landslide process. An improved finite element model is established to predict theload-bearing ability of buried pipelines under deflection load, and the nonlinear contactinteraction between the pipeline and soil is considered. Finally, a strength failurecriterion based on the maximum principal strain is proposed to determine the safe propertiesof buried pipeline under this special failure issue. This paper focuses on the failure mechanisms of buried HDPE (High Density Polyethylene) pipelines due to non-uniform deflection of landslide process.

HDPE (High Density Polyethylene)

HDPE is known for its large strength-to-density ratio and has been improved to havehigher tensile strength, ductility and fracture toughness than that ofordinaryLDPE(low-density polyethylene). HDPE pipes are used increasingly for water conducting projects in Iran.Pipe material that abrades can result in reduced structural strength due to section losses and a decrease in hydraulic efficiency by roughening the surface. HDPE pipe takes longer to abrade through than concrete pipe or metal pipe. These durability issues result in HDPE pipe having an expected life of over 100 years. Yield stress of HDPE is about that of concrete but is 0.1 of steel’s yield stress. Besides, ultimate failure at HDPE occurs at strains about one half of the steel and 15 times of the concrete. Table.1 shows mechanical characteristics of a typical HDPE material. Therefore, in this paper strain-stress behavior of HDPE material is taken as bilinear curve illustrated in Figure. 1.

Table 1. Mechanical characteristics of a HDPE material

Material	**Density kg/m3**	**Modulus of Elasticity kg/cm2**	**Poisson’s Ratio**	**Yield Strain**	**Failure Strain**	**Yield Stress kg/cm2**
HDPE	950	6000	0.4	4%	8%	240

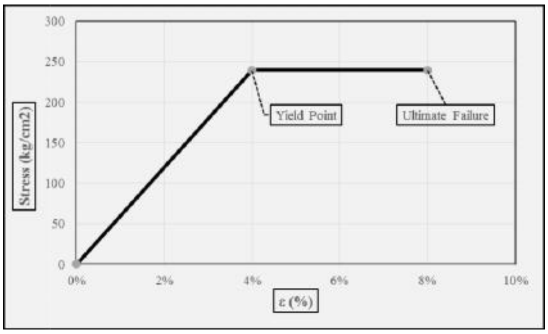


Figure.1. Strain-stress behavior of HDPE material

Land sliding

The problem of landslide hazard in geotechnical construction is ofgreat importance. This geological phenomenon includes a wide range of ground movement, rock falls, deep failure of slopes and shallow debris flows. Sections of the slopes and slants are prone to landslide processes.

Pipelines are often subjected to transverse and longitudinal movements due to displacements in the ground caused by landslides. As landslide movements develop, pipelines can undergo transverse and longitudinal displacements and the resistance offered by the surrounding soil steadily increases depending on the soil characteristics. This resistance reaches an ultimate as the soil reaches failure and develops plastic strains.

When the pipeline crosses a landslide, it is subjected to shearing forces at the lateral edges of the slide.

This can result in bending and subsequent rupture of the pipe. When the pipeline is aligned with the landslide,it will be subjected to compressive and tensile stresses by the downward moving soil. Compressive stresses cause buckling and rupture but tensile stresses rarely cause failures.

Cases of pipeline damage caused by landslide are common in coastal or mountainous regions, where the design of buried pipelines should be improved in order to reduce the risk of damage or failure. In2009, a typical accident of buried pipeline caused by landslide appeared in Ningbo city of China asshown in Figure. 2. The site inspection indicated that the accumulated soil was depositedon the hillside, and the pipeline segment and its surrounding soil were severely pushed away from the original location duringlandslide process in rainstorm days and the pipeline exploded at last.Caption near the fracture location is shown in Figure.3. As indicated in the picture, the pipeline is ruptured circumferentiallyin the butt-welded joint.[ZhengJ.Y.,et al. (2012)]

Figure.2. Pipeline accident in Ningbo city of China, 2009. [Zheng J.Y., et al. (2012)

Figure.3. Captions near the fracture location of accident pipeline.[Zheng J.Y., et al. (2012)]

This paper focuses on the failure mechanisms of buried HDPE (High Density Polyethylene) pipelines due to non-uniform deflection of landslide process. Here, observations based on typical landslide accident of Ningbo city have been used as landslide data. Observations from this accident show that the length of buried pipeline with non-uniform deflection (the width of landslide area) is about 110 m, and the deflection is mainly at the horizontal direction. The maximum deflection displacement is 15.2 m in the middle of this pipeline segment, and the distribution is close to quartic polynomial curve, which is illustrated in Figure. 4.

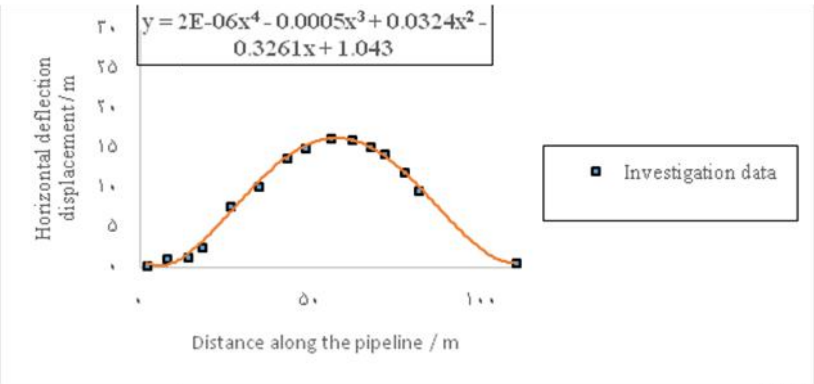


Figure4.Investigation data and the quartic polynomial fitting of deflection displacement.

Numerical Analysis

In order to investigate the landslide process on HDPE pipelines, numerical analyses have been conducted using ABAQUS software. Therefore 3D finite element modelsareprepared to explore the failure mechanisms of buried HDPE pipelines.During the landslide process, the reaction force from the compressedsoil will increase the stress on the pipeline, which effectively reduces the limited deflection displacement. The value of these reaction forces depends on the soil configurations, such as the soil property and soil length in front of pipeline at the horizontal direction and also foundation depth.

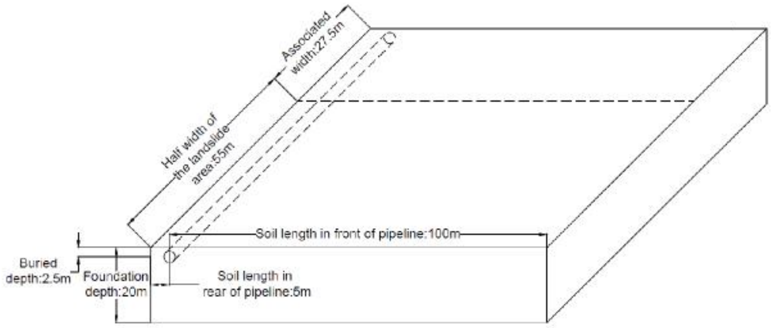
The pipeline is infinite in the axial direction, and as a result the calculation model is established by intercepting one part of the landslide and pipeline in a certain proportion as the analytical object. Parametric investigations from previous work [ZhengJ.Y.,et al. (2012)] show that, the large enough values of soil length in front of pipeline at the horizontal direction and foundation depth may not affect the results of analyses due to landslide.

Geometric features of the finite element model are illustrated in Figure. 5. The mesh of pipeline segment and its surrounding soil are shown in Figure. 6.The mesh density increased until this increase does not change significantly pipe results.During the landslide process, the quartic polynomialdisplacement of Figure. 4 is applied on the soil surface of landslide field (as shown in Figure. 5b), andthe entire piping system will deform under thegiven ground-induced actions.

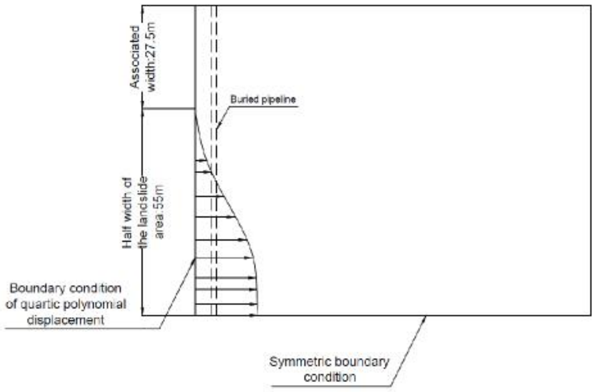
Varying parameters in this paper are surrounding soil conditions and geometry of pipeline section. Therefore four types of soil as Table. 2 have been selected. Also the diameter of pipeline varied between 80 cm to 150 cm with fixed thickness of 2.5 cm.

Mohr-Coulomb behavior model was selected to account the stresses and strains in soil. Also to avoid the box effect in boundary planes with regard to propagating stresses, viscous absorbent boundary elements using dashpots have been implemented.The relative sliding on the interface between the pipeline and soil should not be ignored especially when the buried pipeline develops large deflections. Therefore, Contact property of the interface between pipeline and soil is finite sliding to account relative sliding between the pipeline and soil.

The arc-length algorithm and non-linear stabilization algorithm are two effective methods topredict the deflection displacement. Furthermore, the non-linear stabilization algorithm exhibitsbetter efficiency than the arc-length algorithm.Therefore, non-linear stabilization algorithm is used in this paper.



(a) Main view



(b) Top view

Figure.5. Geometric features of the investigated model

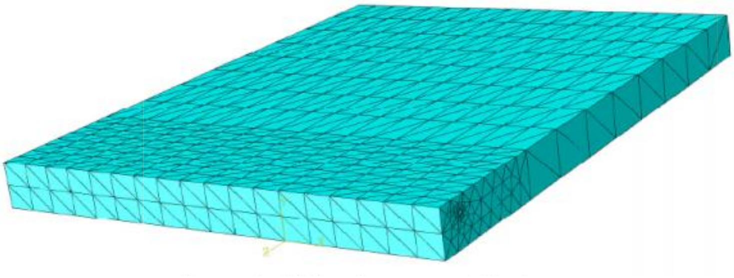


Figure.6. Finite element model view

Table 2.Properties of surrounding soil types

SoilType	Density kg/m3	Modulus of Elasticity kg/cm2	v	Angle of Friction	Cohesion kg/m2
1	2000	150	0.3	30	1
2		300			
3		450			
4		600			

Analysis Results

During the landslide process, the stress/strain of pipeline arises with the offset increasing. The buried pipeline develops excessive plastic deformationsthat finally lead to local plastic collapse at the critical location. When the deflection displacement reaches a critical value, the stress/strain of pipeline at the critical location will exceed the limitation, which leads to ultimate failure of this pipeline segment.

Since the direction of maximum principal stress/strain (MPS) is longitudinal, the MPS along the pipeline can be approximately described as the longitudinal strain. The maximum points represent that the pipe comes into the stage of plastic collapse, which indicates a sudden transition from material hardening to softening. Figures. 7 through 10 show lateral displacement of pipeline along its length when strainreaches its maximum value for different soil types. This figures also illustratesstrain and stress development progresswithin location of failure versus maximum lateral deflection of pipeline at every step of analysis. Also results for different pipe diameters at soil type 3are illustrated in figures.11 through 14.

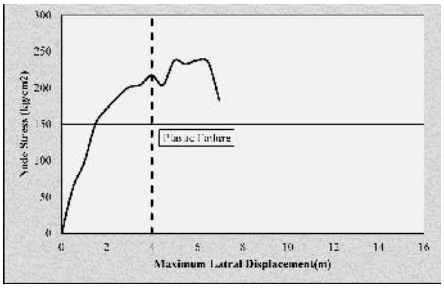
Figures show that, the stress in two edges are always bigger than the middle point and failure always occurs at edges of landslide area. Also soil type has significant effect on the pipeline performance. For stiffer soil types landslide forces develop greater stresses and lateral displacements.Furthermore, it can also be concluded that the maximum MPS of buried pipeline as plastic collapse is very different for selected soil types and could vary from 0.02–0.03.

Also ratio of diameter to thickness (abb. as D/t) has a little less effect on the pipeline performance. The maximum deflection displacement decreases with the growth of D/t ratio. Therefore, soil type variation has greater effect on the limited deflection displacement than the D/t ratio. Furthermore, it can also be concluded that the maximum MPS of buried pipeline as plastic collapse is almost independent of the D/t ratio, which stabilizes at 0.024–0.027.

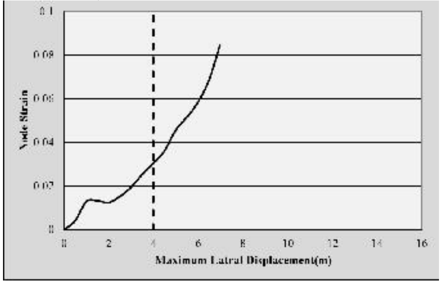
From a series of finite element analysis, the maximum MPS at the critical location is appropriate to assess the safe properties of in-service pipeline during landslide process. In order to ensure the safety of buried pipeline under this special failure issue, the maximum MPS should be less than the allowable value of each material.

Since the pipeline coming into the strain softening stage is not permitted in engineering, the maximum deflection displacement at the top of node-force curve (plastic collapse) can be defined as the allowable displacement, and the corresponding MPS can be served as the allowable strain. The maximum MPS of buried pipeline as plastic collapse is independent of the D/t ratio, but highly differ with soil type variation. The results of finite element analysis indicate the corresponding value of HDPE is close to 2.5%.Therefore, the buried pipeline under the maximum MPS of 2.5% can reserve sufficient ability for the safety operation.

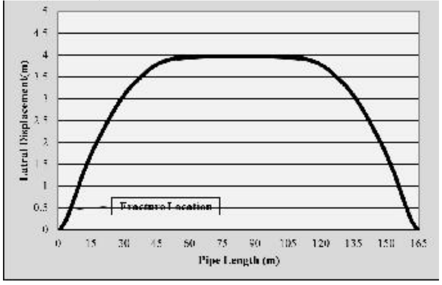
For evaluating landslide hazard in buried HDPE pipelines, fragility curves are a useful tool. With this mean we can characterize the relationships among failure probability and maximum lateral displacement in HDPE pipeline. In this paper average 2.5% strain is proposed as the failure criterion for evaluating the failure prevention at HDPE pipeline.Alsostandard deviation for the naturallogarithm of maximum lateral displacementsthat result inplastic failure is 0.23. Based on given results from analysis cumulative log-normal distribution is used to estimate the fragility curve for probability of plastic failure in HDPE pipeline which is illustrated in Figure. 15.



a) Stress in failure location.

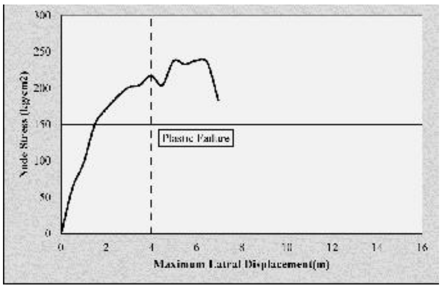


b) Strain in failure location.

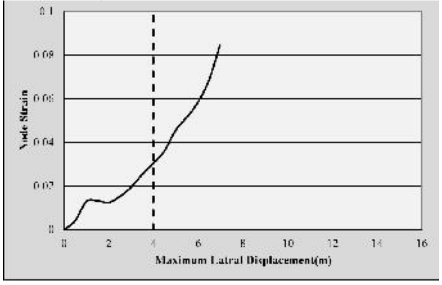


c) Pipeline lateral displacement at plastic failure.

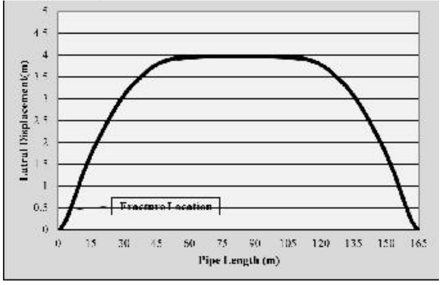
Figure. 7. Results for pipeline, D=80 in soil type 1.



a) Stress in failure location

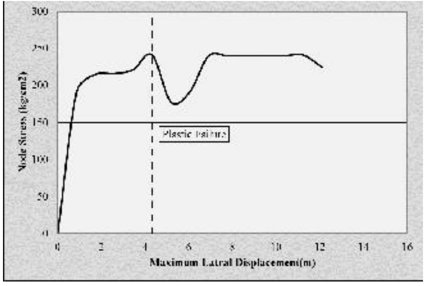


b) Strain in failure location.

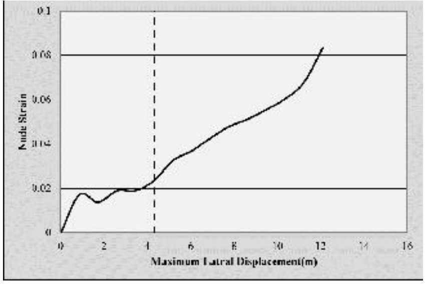


c) Pipeline lateral displacement at plastic failure.

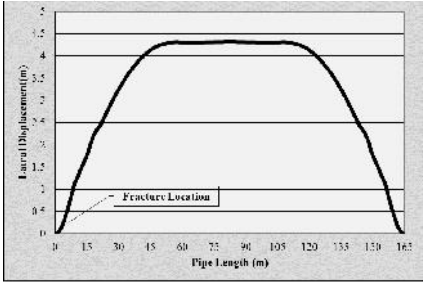
Figure. 8. Results for pipeline, D=80 in soil type 2.



a) Stress in failure location.

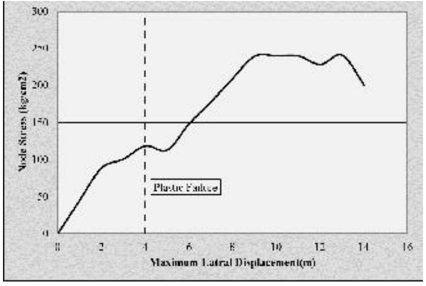


b) Strain in failure location

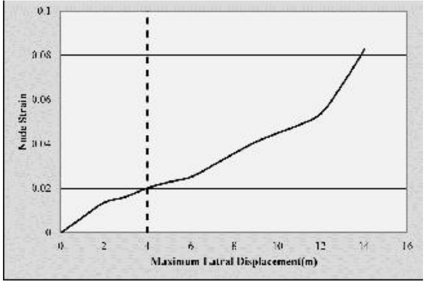


c) Pipeline lateral displacement at plastic failure.

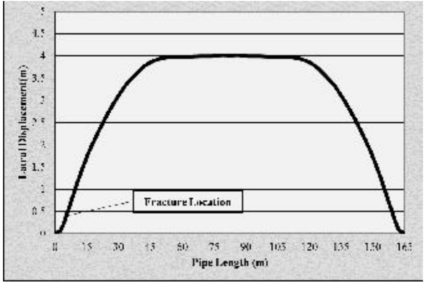
Figure. 9. Results for pipeline, D=80 in soil type 3.



a) Stress in failure location.

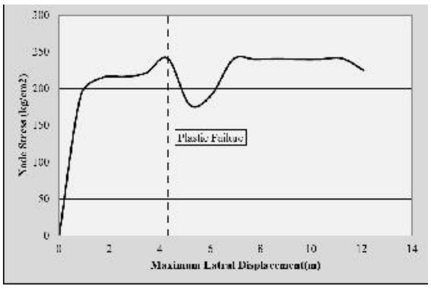


b) Strain in failure location.

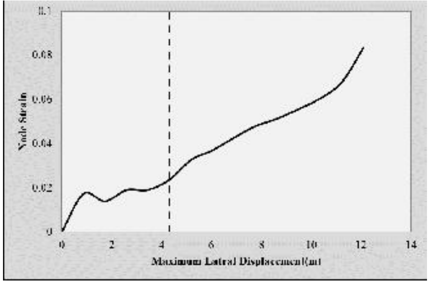


c) Pipeline lateral displacement at plastic failure.

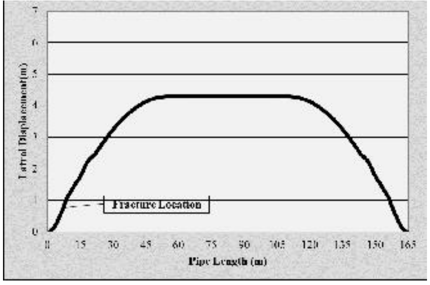
Figure. 10. Results for pipeline, D=80 in soil type 4.



a) Stress in failure location.

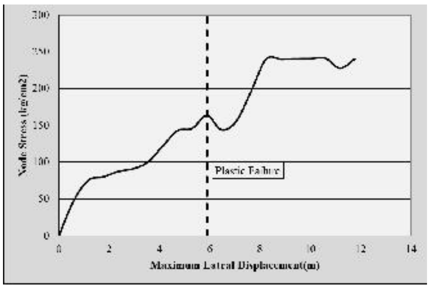


b) Strain in failure location.

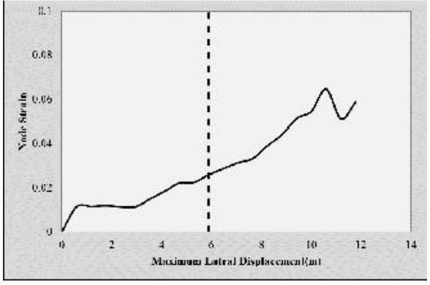


c) Pipeline lateral displacement at plastic failure.

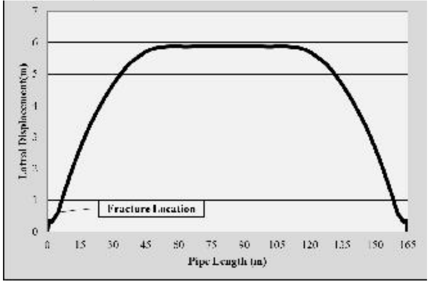
Figure. 11. Results for pipeline, D=80 in soil type 3.



a) Stress in failure location

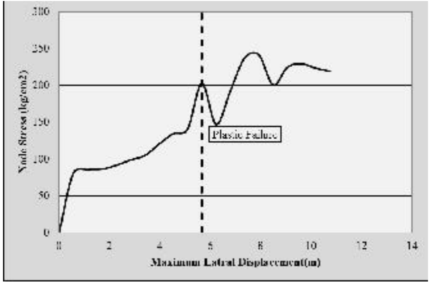


b) Strain in failure location.

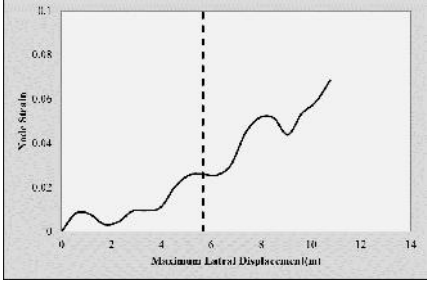


c) Pipeline lateral displacement at plastic failure.

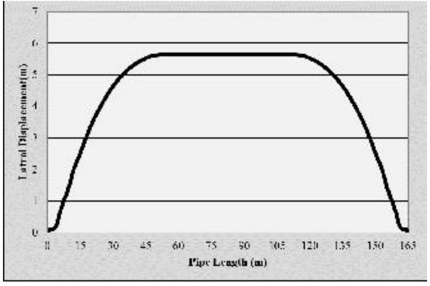
Figure. 12. Results for pipeline, D=100 in soil type 3.



a) Stress in failure location.

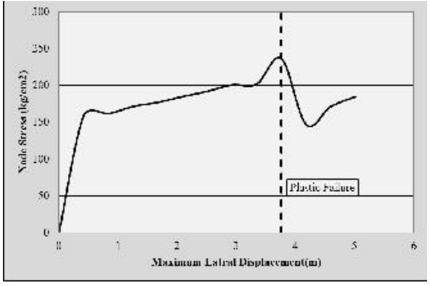


b) Strain in failure location

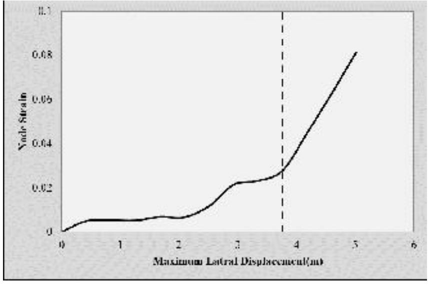


c) Pipeline lateral displacement at plastic failure.

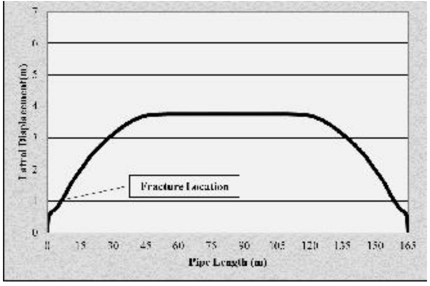
Figure. 13. Results for pipeline, D=120 in soil type 3.



a) Stress in failure location.



b) Strain in failure location.



c) Pipeline lateral displacement at plastic failure.

Figure. 14. Results for pipeline, D=150 in soil type 3.

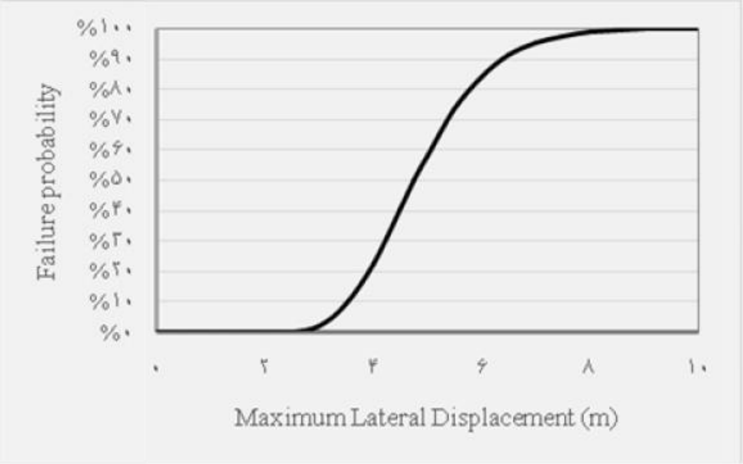


Figure.15. Fragility curve of failure potential for maximum lateral displacement values in pipeline.

CONCLUSIONS

In the pipeline design process, it is significant to determine how much the allowable stress/strain is under the excessive permanent ground deformations. Since most of them in current standards are based on experience, it is imperative that the fundamental research should be developed to obtain the accurate value with respect to each material and specific failure issue. Here, a strength failure criterion based on the maximum principal strain is proposed by a series of finite element analysis.

From previous study[ZhengJ.Y.,et al. (2012)], when the maximum MPS at the critical location reaches about 3%, the buried pipeline of X65 steel will result in the local plastic collapse. The results of finite element analysis indicate the corresponding value of high density polyethylene (HDPE) is close to 2.5%. Therefore, the HDPE buried pipeline under the maximum MPS of 2.5% can reserve sufficient ability for the safety operation. The strength failure criterion proposed in this paper can provide constructive suggestion for the HDPE pipeline design and safety evaluation.

Since excessive permanent ground deformations caused by landslide can easily lead to the failure of buried pipeline, a great amount of work has been concentrated on how to restrict the large deformations. Listed points below can effectively improve the ability of buried pipeline to resist the excessive deformations:

(1) Excessive soil accumulation on the hillside near the buried pipeline should be strictly prohibited or consolidated properly;
(2) To minimize imposed forces to the pipeline, surrounding soil should be selected from loose soil types;
(3) Greater diameters of pipeline improvepipeline performance and could result in failure at higher strains.

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