How to Design Geohazard Resistant Steel Pipe in Critical Fault Crossing Areas

Polynikis Vazouras, Ph.D.[1]; Brent D. Keil, P.E., M.ASCE[2]; Richard D. Mielke, P.E., M.ASCE[3]; and Spyros A. Karamanos, Ph.D., M.ASCE[4]

[1]Dept. of Mechanical Engineering, Univ. of Thessaly, Volos, Greece. Email: pvazour@uth.gr
[2]Northwest Pipe Co., Vancouver, WA. Email: BKEIL@nwpipe.com
[3]Northwest Pipe Co., Vancouver, WA. Email: RMIELKE@nwpipe.com
[4]Dept. of Mechanical Engineering, Univ. of Thessaly, Volos, Greece (corresponding author). Email: skara@mie.uth.gr

ABSTRACT

The paper investigates the structural performance and design of large-diameter continuous (welded) buried steel pipelines in seismic fault crossings, which constitute a potential threat to their structural integrity. The buried pipeline should be able to accommodate ground-induced deformations, absorbing the ground-induced deformation in an efficient manner and sustaining the tensile and compressive strains that develop in the pipe wall. The problem is investigated numerically using advanced finite elements, which simulate the steel pipe, the soil, and the soil-pipe interface in a rigorous manner. Results are obtained for two cases, both referring to actual applications in North America: an 84-in. pipeline crossing a 6.55-ft-displacement strike-slip fault and a 108-in. pipeline crossing a 12.2-ft-displacement normal fault. The results show that large-diameter steel welded pipelines, properly designed through a strain-based design procedure, can sustain ground-induced actions from fault movement, while maintaining their operational function. The introduction of the Geohazard Resilient Steel Pipe (GRSP) concept, a novel patented system consisting of a series of pipe wall projections at appropriate locations along the pipeline within the fault zone, assists the pipeline in absorbing the imposed ground-induced deformation, reduces pipeline distress, increases pipeline performance, and constitutes an efficient tool for increasing pipeline safety in seismic fault crossings.

INTRODUCTION

Most of the observed damages in both hydrocarbon and water pipelines during earthquakes are caused by permanent ground movement from near-surface fault offset, landslides, settlements, and liquefaction-induced lateral spreading. Related to such phenomena are large ground movements, which induce severe inelastic deformation in the pipe wall that may lead to pipeline rupture and loss of pressure containment.

The particular case of seismic fault-crossing has been recognized as a serious threat for pipeline integrity, imposing significant deformation to buried pipelines, with large strains, well beyond the elastic limit of material behavior. Towards calculating those strains and assessing pipeline performance, soil-pipe interaction constitutes an essential feature for determining stress and strain in the pipe. In their pioneering paper, Newmark and Hall (1975) were the first to analyze the response of a pipeline crossing a seismic fault using a simplified cable model, which was further refined by Kennedy *et al*. (1977). More refined analytical approaches, considering beam models on elastic foundation were also reported by Trifonov and Cherniy (2010) and more recently by Sarvanis and Karamanos (2017). However, analytical methodologies may not be suitable for describing the key features of pipeline response to large ground movements in a detailed and reliable manner, particularly the interaction with the moving soil. On the other hand, finite element modelling of the pipe-soil interaction provides a more efficient tool for investigating this complex problem. Most existing finite element models proposed for this problem use springs to simulate soil behavior and either beam or pipe elements for simulating the pipeline (Liu *et al*. (2008); Odina and Tan (2009), which offer a reasonable yet approximate representation of the actual case. Apart from numerical simulations, a series of experimental works have also been reported on HDPE and steel pipelines, contributing to better understanding of pipeline behavior under permanent ground deformations (Ha *et al*., 2008; O'Rourke *et al*., 2008).

The European GIPIPE project has been a milestone contribution on "geohazards and pipelines," with emphasis on permanent ground-induced actions. In GIPIPE, a series of novel experiments have been performed (Vazouras *et al*. 2015b), and a pioneering finite element modelling approach was developed for simulating the response of buried steel pipelines underground-induced actions. These state-of-the-art models account rigorously for the inelastic behavior of the steel pipe, the variable material response of the surrounding soil, the soil-pipe interaction (including frictional contact and separation), the distortion of pipe cross-section, the formation of local buckling, and the effects of internal pressure (Vazouras *et al.*, 2010, 2012, 2015a; Tsatsis *et al*. 2019). It has also been recognized that the strains developed in the pipe wall because of severe permanent deformations are well beyond the elastic limit of the pipe material and therefore, a strain-based design approach should be used for the safe design of buried steel pipelines against geohazards.

The present work presents the basic features of large-diameter steel welded pipeline design and performance in fault crossing areas. The study employs the state-of-the-art finite element tools developed in GIPIPE (Vazouras *et al*. 2015b) for the analysis of buried pipelines in geohazard areas, subjected to excessive axial stretching and bending deformation. It also describes the application of a patented novel system, aimed at improving pipeline performance, by reducing the strains developed at the pipe wall caused by bending and stretching. This patented novel system (Keil and Karamanos, 2024), referred to as the Geohazard Resistant Steel Pipe (GRSP) system, InfraShield®, was introduced recently by the authors (Keil *et al*., 2020b). It consists of introducing a series of pipe wall projections in appropriate locations along the pipeline, within the fault zone and offers an efficient tool for accommodating ground-induced deformations acting as "strain-relieving" devices, decreasing pipe wall strains outside the projections, and safeguarding pipeline integrity. The numerical results are obtained for two characteristic cases, one strike-slip fault and one normal fault, which impose significant stretching or bending deformation to the buried steel pipeline.

SHORT DESCRIPTION OF STEEL PIPELINES AND THEIR WELDED JOINTS

Spiral-welded pipes are the main component for constructing large-diameter steel pipelines for water transmission. They are made from coiled steel using a continuous process that involves de-coiling, edge preparation, cold-forming the strip into a cylindrical shape, automatic welding of the inside and outside seam, and cutting to the desired length by an automatic cutoff device. After lining and coating and any necessary fabrication of fittings is complete, the pipes are shipped to the jobsite and welded together to construct the pipeline. Quite often, lap welded joints are employed as an alternative to butt-welded full-penetration joints, because of their lower installed cost and their proven history of use. They require cold forming of a "bell" at one end of each pipe segment, which is manufactured at the pipe mill using a mechanical expander. During on-site construction, the non-expanded end of the adjacent pipe segment (the "spigot"), is inserted into the bell and welded with a single (inside or outside) or double full circumferential fillet weld. Figure 1 shows pipe joints subjected to bending, as part of a large-scale project on the structural resilience of steel welded pipelines. Experimental results from this project, and the relevant numerical calculations (Keil *et al*., 2018, 2020b; Sarvanis et al., 2020), indicated very good structural performance of standard lap-welded joints under axial loading (compressive and tensile) and bending, in terms of both their ultimate strength, and particularly their deformation capacity.

Despite the excellent performance of the lap-welded joints, justified in the above experiments, several specimens exhibited buckling at the bell and through the field-applied fillet weld. Local stresses exist in the bell, mainly because of its cold expansion forming, which introduces some amount of work hardening and residual stresses in the steel material. Local buckling is also likely to occur at the bell due to its geometry and the eccentric stress path (Karamanos, 2022). To increase the resilience of pipeline joints, the authors have proposed the patented GRSP system aimed at providing extra safety to buried welded-steel pipelines subjected to ground-induced deformations well beyond the maximum load, without loss of water pressure containment or flow. It consists of a series of pipe wall projections at appropriate locations along the pipe, capable of absorbing significant amount of deformation without pipe wall fracture and enforcing pipe wall buckling to occur at specific locations (Figure 1b). The projections are installed at the time of pipe manufacturing, and their effectiveness in mitigating pipeline stress and deformation and protecting lap welded joints has been verified numerically and experimentally (Keil *et al*. 2020b).


(a)

(b)

Figure 1. Buckled shapes of lap-welded joints under bending: (a) standard lap-welded joint without projections (Source: S. A. Karamanos, 2017); (b) joint with pipe wall projection, "buckled" at the projection (Source: Northwest Pipe Company, 2019).

PROBLEM STATEMENT

Figure 2 shows schematically the physical problem of a pipeline crossing a strike-slip (horizontal) fault (Figure 2a) and a normal fault (Figure 2b). In each case, the fault may be regarded as a "discontinuity plane" that divides the soil in two parts. When it is activated, one part of soil moves with respect to the other part, causing a differential displacement along the pipeline alignment. Consequently, the buried pipeline is also displaced and deforms in an attempt to accommodate itself within the imposed soil displacement pattern, as shown in Figure 2.

Previous studies in fault crossings indicated that significant deformation develops in the pipeline, mainly because of longitudinal bending and axial stretching. The present work examines whether the steel pipeline, properly designed and constructed, can sustain these ground-induced actions. GRSP projections are placed at defined locations within the fault, aimed at reducing the effects of fault action, absorbing the deformation imposed by the fault movement and acting as "mitigation" devices, alleviating pipe wall strain in a controlled and defined manner. Their function is based on the additional flexibility provided by the projections and their ability to absorb a significant amount of deformation without material fracture.

Two characteristic fault-crossing cases of large diameter steel welded pipelines are analyzed and discussed, based on actual pipeline projects in North America. The first is a strike-slip fault (Figure 2a) with 6.5 ft (2 m) horizontal displacement crossed by an 84-inch diameter steel welded pipeline; the value of horizontal displacement *d* is typical for faults in the West Coast, as described in the publication by Proctor *et al*. (1972) that refers to the 1971 San Fernando earthquake. The second case refers to a normal fault (Figure 2b) at the base of the Wasatch mountains, in Utah, with a total potential displacement *d* equal to 12.2 ft (3.7 m), crossed by a 108-inch steel pipeline.

The key features of pipeline structural response are presented, including the effects of projections in terms of their beneficial effect on pipeline structural integrity. It should be noted that the cases of strike-slip and normal faults are examined, however the conclusions can be extended to other types of ground-induced actions, where the pipeline exhibits a similar type of deformation (e.g., edge of a landslide or a liquefaction zone).

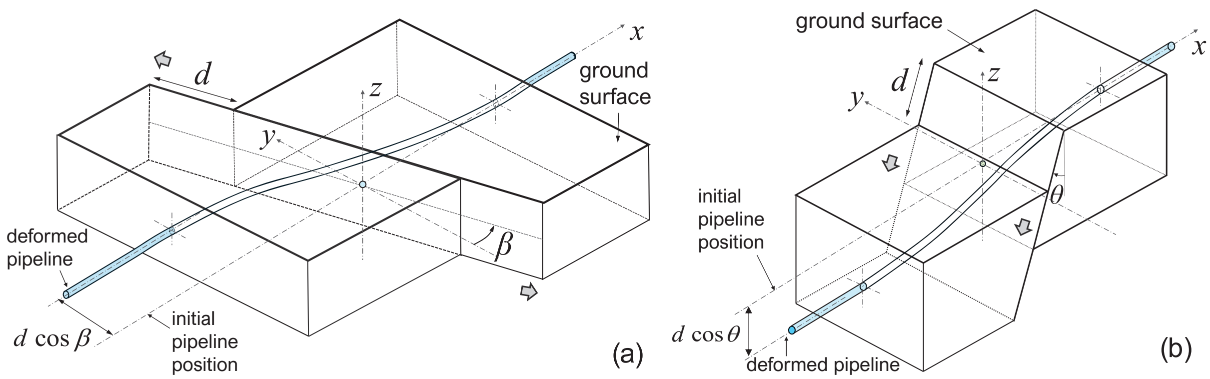

Figure 2. Schematic representation of the pipeline fault-crossing problem; (a) strike-slip fault and (b) normal fault (Source: U. of Thessaly, 2025).

FINITE ELEMENT MODELLING

Nonlinear finite element models have been created in ABAQUS/Standard for analyzing the structural response of buried pipelines crossing active faults. The models follow the state-of-the-art approach developed by the research team at the University of Thessaly during the GIPIPE project (Vazouras *et al*., 2015b) for analyzing soil-pipe interaction problems under permanent ground deformations. The modelling approach is advanced and unique, simulating the pipe and the soil as two interacting continuum systems, representing the actual response of the pipeline within the deforming soil without the use of more conventional and less accurate modelling tools (e.g., pipe elements or soil springs). Using this approach, the pipe, the soil and their interaction are simulated in a rigorous manner, allowing for the calculation of stress, strain and displacement at any location along the pipe and around its cross-section, with a high degree of accuracy. The model consists of the soil block, the steel pipe that is embedded in the soil block, a proper interface between the pipe and the soil, and two end springs that represent the continuation of the pipeline outside the soil block area. The general configuration of the model for the strike-slip and the normal fault under consideration are shown in Figure 3 and in Figure 4 respectively.

The steel pipe is modelled with shell finite elements, capable of simulating local deformations and wrinkling of the pipe wall. Four-node reduced-integration shell elements (denoted as S4R in ABAQUS) are employed, considering an appropriate element size, discussed in a subsequent section of paper. The projections are introduced in the pipe model imposing a radial expansion of the specific cross-section, simulating exactly the manufacturing process of projections. The mesh is shown in Figure 5 for the strike-slip fault (perpendicular crossing).

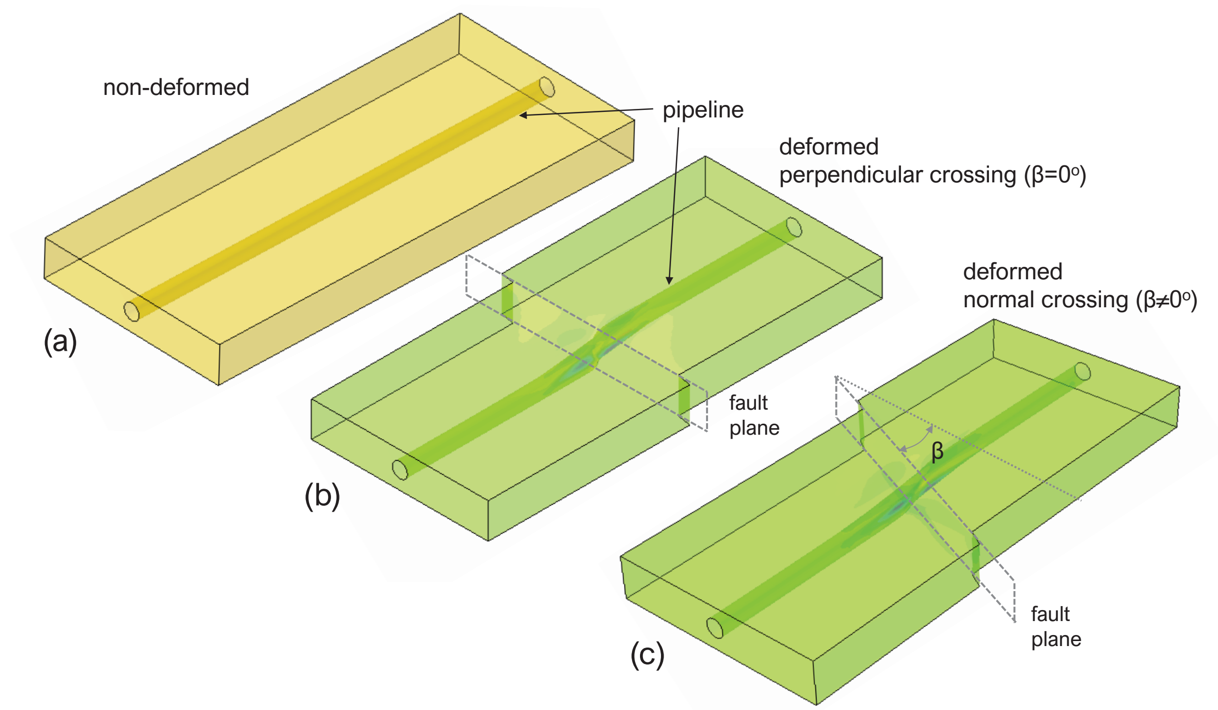

Figure 3. Numerical models for strike-slip fault crossing analysis; (a) initial (non-deformed) configuration of the soil-pipe system; (b) deformed configuration for perpendicular crossing of the pipeline; (c) deformed configuration for oblique crossing of the pipeline (Source: U. of Thessaly, 2025).

Eight-node reduced integration “brick” finite elements, denoted as C3D8R in ABAQUS, are used for the soil block. The size of the soil block and the corresponding finite element mesh density depends on the pipe size, the type of fault (e.g., strike-slip or normal) and its orientation with respect to the pipeline direction (crossing or dip angle). Continuity of the pipeline at the two ends of the model is simulated adding a spring at each end of the model oriented in the longitudinal direction that simulates the stiffness of the buried pipe outside the soil block. For a straight pipeline continuation, the value of this stiffness can be obtained from Vazouras *et al.* (2015). The presence of nearby pipe elbows should be accounted for in the spring stiffness, using a special-purpose analysis. Furthermore, to avoid numerical difficulties at the fault location, because of the abrupt discontinuity on the displacement field in the soil, the fault movement is considered to occur gradually within a narrow zone of width equal to 1.08 ft (0.33 m), also considered in the previous works of the authors (Vazouras *et al*. 2010, 2015a).

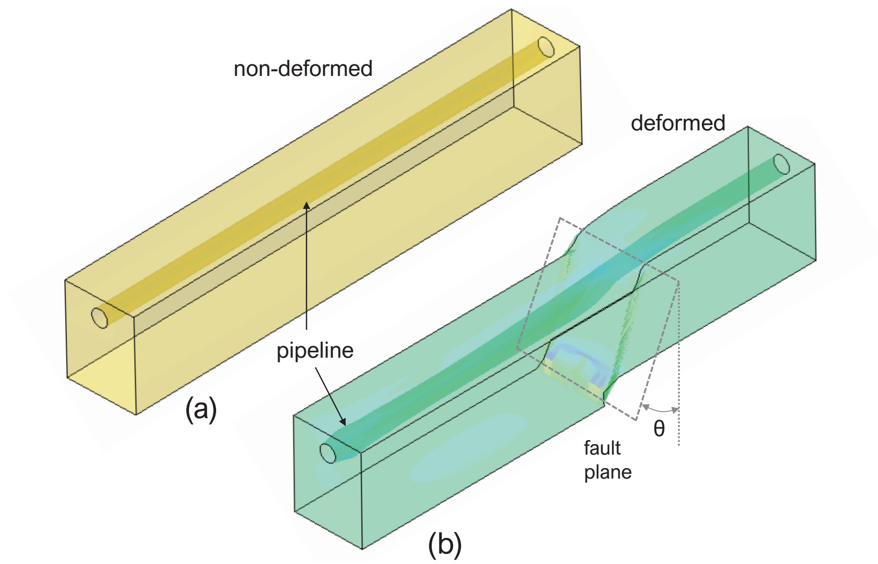

Figure 4. Numerical model for normal fault crossing analysis; (a) initial (non-deformed) configuration of the soil-pipe system; (b) deformed configuration (Source: U. of Thessaly, 2025).

The constitutive model used for the pipe material is J_2 flow plasticity with isotropic hardening, which is calibrated using a uniaxial tension stress-strain curve of the steel material. The constitutive model for the soil follows the Mohr-Coulomb constitutive model, characterized by soil cohesion, friction angle, elastic (Young's) modulus, and Poisson's ratio.

The interface between the pipe and the soil employs a contact algorithm that employs "hard contact" and a penalty friction formulation, which allow for pipe-soil separation, while preventing the penetration of the pipe into the soil mass, and account for interface friction, through an appropriate value of friction coefficient μ.

The fault movement analysis procedure follows a sequence of steps. The first step refers to the formation of pipe wall projections (if present), using a uniform radial expansion process. Subsequently, gravity is applied, followed by the increase of internal pressure at a prescribed level. Finally, soil displacement is applied incrementally, increasing the fault offset displacement, until a target value of fault displacement is reached. In each step, stresses, strains and displacements are recorded at any desired location along the pipe, and around the pipe cross-section.

NUMERICAL RESULTS

The two fault-crossings considered herein are modelled with the simulation tools described in the previous section. The first refers to an 84-inch nominal diameter pipe crossing a strike-slip fault with 6.55 ft (2 m) of horizontal movement. It has an outer diameter of 86.25 in (2,190.8

mm) and wall thickness 0.625 in (15.8 mm), corresponding to a diameter-to-thickness ratio $D/t =$ 138. The size of the soil block is 196.7 ft × 85.2 ft × 17 ft (60 m × 26 m × 5.2 m). The longitudinal dimension of the block (~200 ft) is chosen on the basis that a distance of ±100 ft from the fault is adequate for the bending deformation of the pipe to vanish, so that outside this distance the pipe is under pure tension. The shell element size in the longitudinal direction of the pipe is equal to 2 in (5 cm) in areas of the pipe where local buckling is expected to occur, and increases gradually to 19.7 in (50 cm) in the areas where no local phenomena are expected to occur (Figure 5). A finer mesh in the longitudinal direction is used in the area where projections are imposed, so that localized deformation is adequately simulated. The pipe element size in the circumferential direction in "critical" areas of the pipe is equal to 3.9 in (10 cm). The typical soil element size within the fault zone is 0.33 m, and a coarser mesh is used away from the fault.

The second fault crossing refers to a 108-inch diameter pipe subjected to normal fault action of 12.2 ft (3.7 m) displacement with dip angle 30 degrees. The outer pipe diameter is 108 in (2,743.2 mm), and its pipe wall thickness is ⅞ in (22.2 mm), corresponding to a D/t ratio equal to 123. The size of the soil block is 262.3 ft × 39.3 ft × 49.2 ft (80 m × 12 m × 15 m). The finite element mesh density of the pipe and the soil have similar density to the one used for the 84-inch pipe fault crossing case described above.

The soil material properties for the 84-inch pipe (strike-slip fault) are: cohesion 7.2 psi (50 kPa), Young's modulus 1,160 psi (8 MPa) and Poisson's ratio 0.45; those used for the soil material surrounding the 108-inch pipe (normal fault) are: cohesion 9.86 psi (68 kPa), Young's modulus 2,600 (18 MPa) and Poisson's ratio 0.45. Both pipes are made of carbon steel according to ASTM A1018 with minimum yield stress 42 ksi. The stress-strain curve used in the analysis is obtained from a laboratory experiment of the pipe, with a 45 ksi stress at 0.2% inelastic strains. The pipes are pressurized with internal pressure equal to 90 psi (6.21 bar), corresponding to standard operating conditions. The friction coefficient μ used in the numerical calculations is equal to 0.3, which is a standard value used in several previous publications of the authors (Vazouras *et al*. 2010, 2015).

Results for the strike-slip fault crossing (84-inch pipe)

Two configurations are considered for the strike-slip fault, corresponding to different values of crossing angle: "perpendicular" crossing (β = 0°) and "oblique" crossing with β = 25°. Both configurations induce a combination of bending and stretching (tension) to the pipeline. In the configuration with β = 0°, the pipeline is primarily subjected to bending, associated with compression at the pipe wall and local buckling. In the β = 25° configuration, tensile deformation is dominant due to axial stretching, preventing the formation of local buckling. In the framework of strain-based design, the main design parameter monitored during the analysis is the value of the maximum longitudinal tensile strain. This value may not exceed a limit value, herein considered equal to 2%, as suggested for lap-welded joints by ALA (2005). It is essential to underline that in order to reach the 2% limit without weld fracture, the girth weld should be constructed and inspected to the applicable welding code so that the weld defects are within tolerance; however, a discussion of the specific requirements is out of the scope of the present paper.

For "perpendicular crossing" of the pipeline (β = 0°), the analysis proceeds until 2 m (6.55 ft) of fault displacement. The corresponding shape of the pipeline is shown in Figure 6 and the main observations are as follows: (a) in the absence of GRSP projections at the pipe wall, local buckling occurs (Figure 6b) at the locations of maximum bending curvature at a fault displacement value of 2.26 ft (0.69 m); (b) in that case, the maximum longitudinal tensile strain of the pipe wall develops at the opposite site of the buckled cross-section, reaching a value of 2.4% (beyond the tensile train limit) at fault displacement equal to 2 m (6.5 ft); (c) large strains occur at the buckle due to pipe wall wrinkling and folding, therefore, if the buckle occurs at a girth weld or the bell of a lap welded joint, this may threaten pipe safety; (d) introducing two GRSP projections at the “critical section” of the pipe, i.e., the pipe section around the local buckle location in the no-projection pipe [see (a) above], 5 meters apart, as shown in Figure 6a the response is significantly improved.

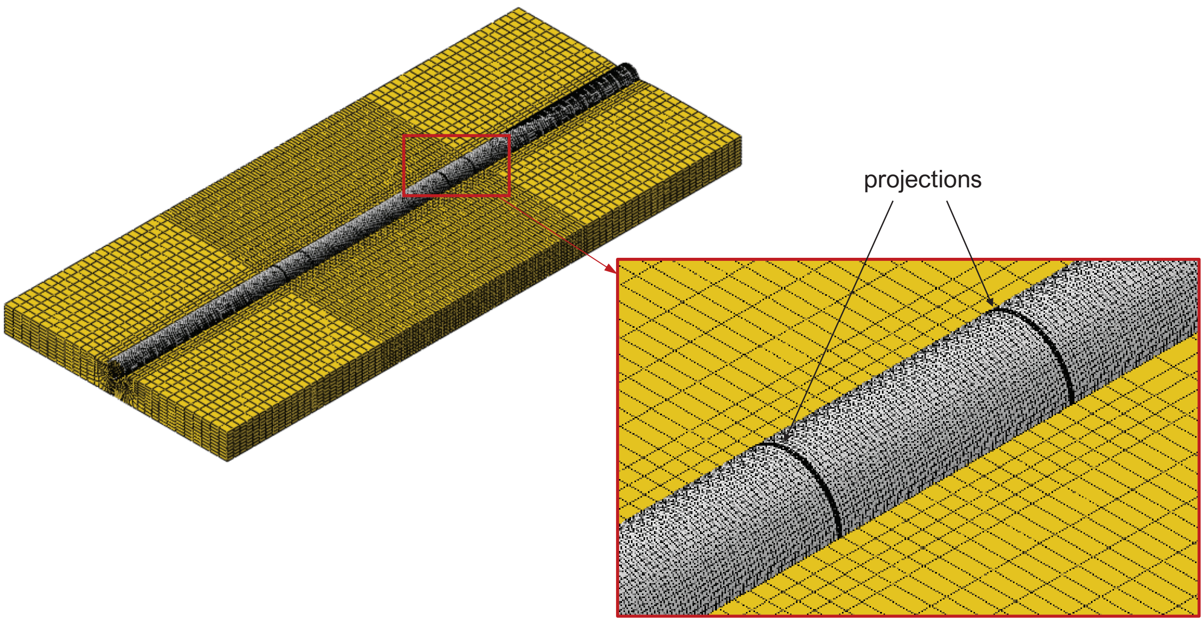

Figure 5. Finite element mesh for the steel pipe and the soil (strike-slip fault); half of the soil block is displayed for visualization purposes (Source: U. of Thessaly, 2025).

The presence of GRSP projections has a positive effect absorbing local buckling deformation at a defined location and reducing the tensile strains by a significant amount. More specifically, the pipe wall deforms in a controlled manner at the projection locations, preventing the development of buckles at the girth weld or the bell (Figure 6a). This controlled deformation process also reduces the level of tensile strain developed at the opposite side of the pipeline, increasing pipeline resilience; the maximum tensile strain developed at the pipeline wall at 2 m fault displacement, outside the projection area, is equal to 1.7%, well below the tensile strain limit.

In the case of oblique crossing (β = 25°), due to pipeline stretching no local buckling occurs and therefore, the value of maximum tensile strain should be compared with the limit value (2%). Numerical results have been obtained using four equally spaced projections 3 meters apart, imposed at the pipe section where maximum tensile strain occurs (Figure 7). At fault displacement equal to 6.65 ft (2 m) the value of tensile strain is 2 %, a very satisfactory result.

Results for the normal fault crossing (108-inch pipe)

The normal fault under consideration imposes a total oblique displacement of 12.2 ft (3.7 m) on the pipeline, consisting of two components: a vertical displacement of 10.59 ft (3.2 m) and a horizontal (extension) displacement of 6.14 ft (1.9 m) that correspond to a dip angle θ equal to 30 degrees. This type of extreme displacement induces significant bending and stretching that needs to be accommodated by the pipeline wall. The plan view of the crossing configuration in Figure 8 shows the presence of elbows on either side of the fault area, which are taken into account in terms of their stiffness determined by a special-purpose analysis and incorporated in the end springs of the finite element model.

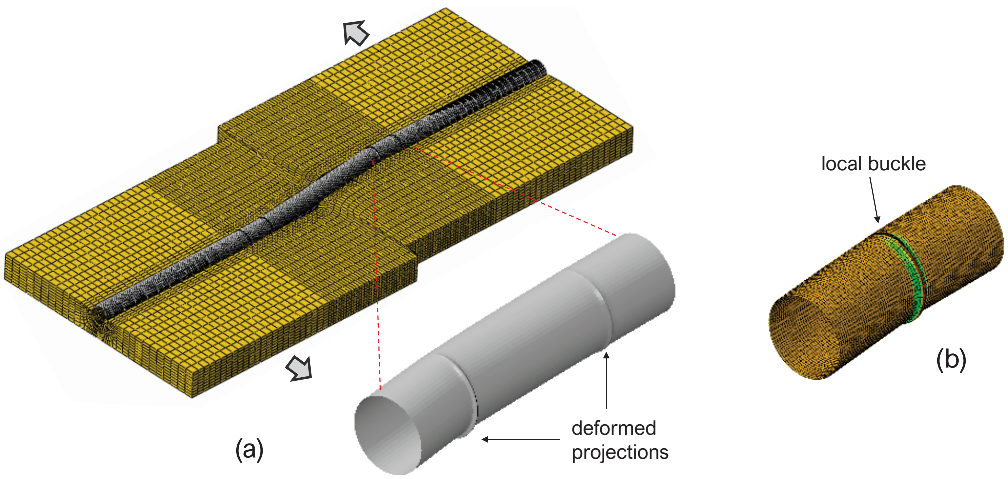

Figure 6. (a) Deflected pipeline under strike-slip fault action without projections (84-inch pipe, perpendicular crossing); (b) local buckling with projections (Source: U. of Thessaly, 2025).

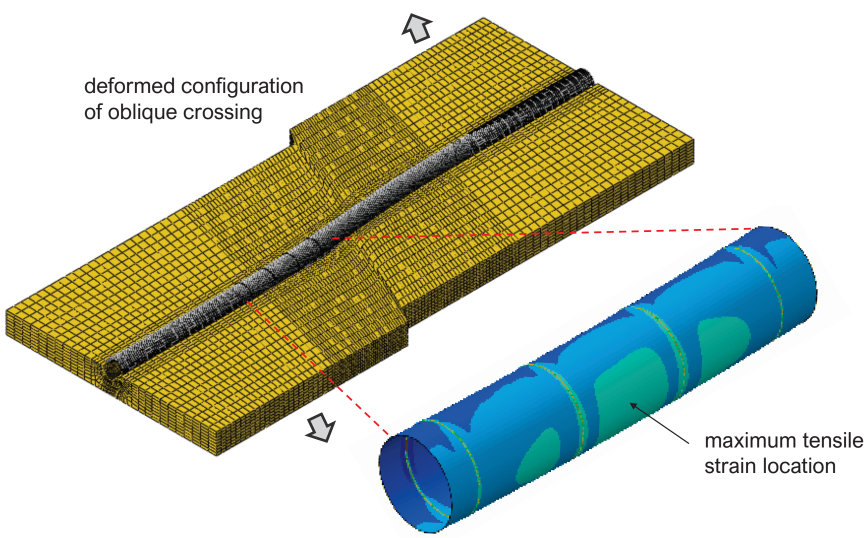

Figure 7. Deflected 84-inch pipeline under oblique strike-slip fault crossing (Source: U. of Thessaly, 2025).

Preliminary analyses indicated that the “overbend” area is the most critical area in terms of strain level (Figure 9). This was an expected result, considering that the “overbend” is subjected to significant bending, and the corresponding soil resistance is very large due to the activation of its downward component. To reduce the strain at the “overbend,” a 2.5-feet thick layer of geofoam is assumed underneath the pipe. Three equally spaced GRSP projections, located 3 meters apart, are also imposed within the overbend section and are included in the rigorous finite element model and considered in the fault movement analysis.

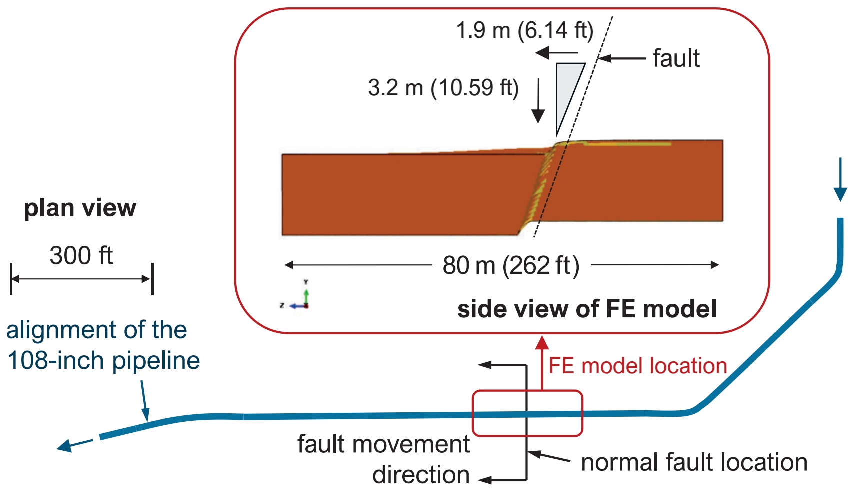

Figure 8. Plan view of the normal fault crossing configuration (108-inch pipeline). (Source U. of Thessaly, 2025)

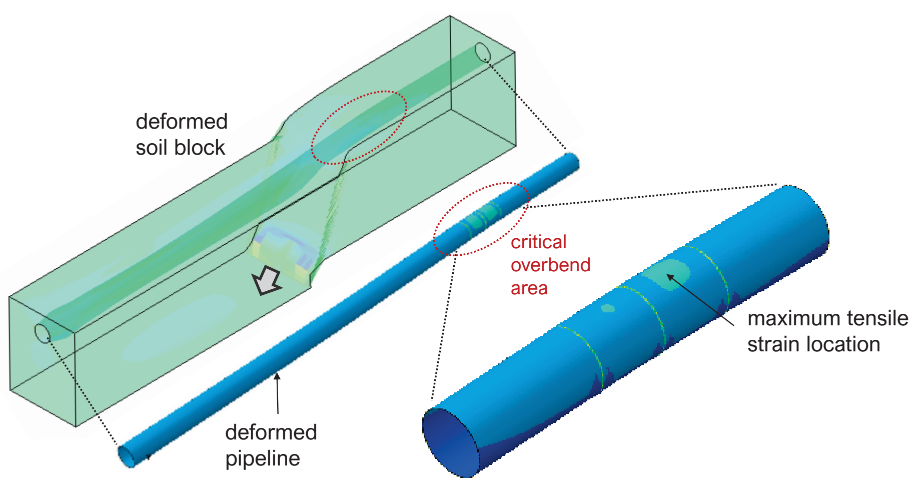

Figure 9. Deflected soil-pipe system under normal fault action with dip angle 30º (108-inch pipe); maximum tensile strain occurs at top of pipe in overbend (Source: U. of Thessaly, 2025).

The finite element results show that the maximum longitudinal strain in the pipe occurs at the overbend, and that the soil movement around the pipe is not uniform in the fault zone, generating varying stress and deformation conditions along the pipeline. Furthermore, in the absence of pipe wall projections, the maximum tensile strain value at the maximum fault displacement is 2.03%, exceeding the 2% limit by a small amount. When the three GRSP projections are employed, the maximum tensile strain reduces to a value of 1.6%, which is well below the limit value. The corresponding strain on the bottom side of the overbend is small and equal to -0.1% (negative sign indicates compressive strain) and can be easily sustained by the ⅞-inch pipe wall of the 108-inch-diameter pipe under consideration.

CONCLUSIONS

Using state-of-the-art numerical simulation tools, the structural performance of large diameter pipes in fault crossings areas is investigated, through a strain-based design approach. The main conclusion from those analyses is that large-diameter steel welded buried pipelines with the use of GRSP, if designed and constructed properly, can absorb a substantial amount of deformation induced by active seismic faults, without loss of their structural integrity and their water transmission function. Two characteristic cases have been examined, stemming from actual pipeline projects in North America: (a) an 84-inch diameter pipeline crossing a strike-slip fault with 6.55 feet displacement and (b) a 108-inch pipeline crossing a normal fault with 12.2 feet displacement. It is shown that the crossing angle plays a significant role in pipeline structural behavior. The use of the GRSP InfraShield® system, consisting of an appropriate number of pipe wall projections within the fault zone, assists the pipe to accommodate ground-induced deformations associated with the presence of local buckles and greatly reduces the tensile strains developed because of longitudinal stretching.

REFERENCES

American Lifelines Alliance. (2005). *Seismic Guidelines for Water Pipelines*.

Ha, D., Abdoun, T. H., O'Rourke, M. J., Symans, M. D., O'Rourke, T. D., Palmer, M. C., and Stewart, H. E. (2008b). "Centrifuge Modelling of Earthquake Effects on Buried High-Density Polyethylene (HDPE) Pipelines Crossing Fault Zones.", *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 134, No. 10, pp. 1501-1515.

Karamanos, S. A. (2022). *Structural Mechanics and Design of Metal Pipes, A Systematic Approach for Onshore and Offshore Pipelines*. 1st Edition, Elsevier.

Keil, B. D., Gobler, F., Mielke, R. D., Lucier, G., Sarvanis, G. C., and Karamanos, S. A. (2018). "Experimental Results of Steel Lap Welded Pipe Joints in Seismic Conditions.", *ASCE Pipelines Conference*, paper No. 386906, Toronto, ON, Canada.

Keil, B. D., Lucier, G., Karamanos, S. A., Mielke, R. D., Gobler, F., Fappas, D., Sarvanis, G. C., Chatzopoulou, G., and Card, R. J. (2020a). "Experimental Investigation of Steel Lap Welded Pipe Joint Performance Under Severe Axial Loading Conditions in Seismic or Geohazard Areas", *ASCE Pipelines Conference*, paper No. 744005, San Antonio, TX, USA.

Keil, B. D., and Karamanos, S. A. (2024). SEISMIC PIPE JOINT, US Patent, Application No. 62/884,638; in press.

Keil, B. D., Mielke, R. D., Gobler, F., Lucier, G., Sarvanis, G. C., Chatzopoulou, G., Fappas, D., and Karamanos, S. A. (2020b). "Newly Developed Seismic Resilient Steel Pipe Joint Safeguards Pipeline Structural Integrity during Severe Geohazard Events", *ASCE Pipelines Conference*, paper No. 744041, San Antonio, TX, USA, August 2020 (Virtual).

Keil, B. D., Fappas, D., Gobler, F., Sarvanis, G. C., Chatzopoulou, G., Lucier, G., Mielke, R. D., and Karamanos, S. A. (2022). "A New System for Improving the Structural Resilience of Lap-Welded Steel Pipeline Joints", *Thin-Walled Structures*, Vol. 171, 108676.

Kennedy, R. P., Chow, A. W., and Williamson, R. A. (1977). "Fault movement effects on buried oil pipeline", *ASCE Journal of Transportation Engineering*, Vol. 103, pp. 617-633.

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.

Liu, M., Wang, Y.-Y., and Yu, Z. (2008). "Response of pipelines under fault crossing.", *Proceedings Intern. Offshore and Polar Engineering Conference*, Vancouver, BC, Canada.

O' Rourke, T. D., et al. (2008). "Evaluation of Ground Rupture Effects on Critical Lifelines", NEESR-SG Final Report, Cornell University, Rensselaer Polytechnic Institute, The Sciencenter Discovery Center, NY.

Odina, L., and Tan, R. (2009). "Seismic Fault Displacement of Buried Pipelines Using Continuum Finite Element Methods.", *ASME 28th Intern. Confer. on Ocean, Offshore and Arctic Engineering*, OMAE2009-79739, Honolulu, Hawaii.

Proctor, R. J., Crook, R., Jr., McKeown, M. H., and Moresco, R. L. (1972). "Relation of Known Faults to Surface Ruptures, 1971 San Fernando Earthquake, Southern California", *Geological Society of America Bulletin*, Vol. 83, pp. 1601-1618.

Sarvanis, G. C., Chatzopoulou, G., Fappas, D., Karamanos, S. A., Keil, B. D., Lucier, G., Gobler, F., and Mielke, R. D. (2020). "Bending Response of Lap Welded Steel Pipeline Joints", *Thin-Walled Structures*, Vol. 157, 107065.

Sarvanis, G. C., and Karamanos, S. A. (2017). "Analytical Model for the Strain Analysis of Continuous Buried Pipelines in Geohazard Areas.", *Engrg Structures*, Vol. 152, pp. 57-69.

Tsatsis, A., Loli, M., and Gazetas, G. (2019). "Pipeline in dense sand subjected to tectonic deformation from normal or reverse faulting", *Soil Dynamics & Earthquake Engrg*, Vol. 127, 105780.

Trifonov, O. V., and Cherniy, V. P. (2010). "A semi-analytical approach to a nonlinear stress–strain analysis of buried steel pipelines crossing active faults.", *Soil Dynamics & Earthquake Engineering*, Vol. 30, pp. 1298-1308.

Vazouras, P., Karamanos, S. A., and Dakoulas, P. (2010). "Finite Element Analysis of Buried Steel Pipelines Under Strike-Slip Fault Displacements", *Soil Dynamics and Earthquake Engineering*, Vol. 30, No. 11, pp. 1361–1376.

Vazouras, P., Karamanos, S. A., and Dakoulas, P. (2012). "Mechanical behavior of buried steel pipes crossing active strike-slip faults", *Soil Dynamics and Earthquake Engineering*, Vol. 41, pp. 164–180.

Vazouras, P., Dakoulas, P., and Karamanos, S. A. (2015a). "Pipe-Soil Interaction and Pipeline Performance Under Strike-Slip Fault Movements.", *Soil Dynamics and Earthquake Engineering*, Vol. 72, pp. 48–65.

Vazouras, et al. (2015b). Safety of buried steel pipelines under ground-induced deformations (GIPIPE), Research report, RFCS program, European Commission, Brussels, Belgium.