Technical Note PP-840-TN
Polyethylene (PE) Pipes for Seismic Protection

Introduction

PE pipes provide effective, cost-efficient solutions for earthquake pipeline design. The reported survival rates for PE pipes reduce repair costs from avoided pipe damage and reduce the economic impact to society. This technical note addresses:

- How earthquakes impact pipelines
- Material properties that affect pipeline resilience during earthquakes
- Results from recent quake studies

Earthquake Effect on Pipelines

Earthquakes effect on pipes can be either transient or permanent.

Transient Ground Deformation (TGD), or ground oscillation, results in largely axial strain on pipelines. TGD strains result from the soil mass acting to resist movement of the pipeline. Strain levels are largely dependent on the Peak Ground Velocity (PBV) and can be experienced over large areas beyond the fault region. *Toprak, (2006)*

Permanent Ground Deformation (PGD) occurs with differential ground movement across a fault plane when the two sides of the ground move horizontally or vertically with respect to each other. PGD also includes the effects of soil liquefaction.

Examples include:

- surface faulting,
- landslides,
- seismic settling, and
- lateral spreading

PGD typically results in both axial and bending strains on the pipeline. As seen in Figure 1, high strain levels can be experienced along the fault path.

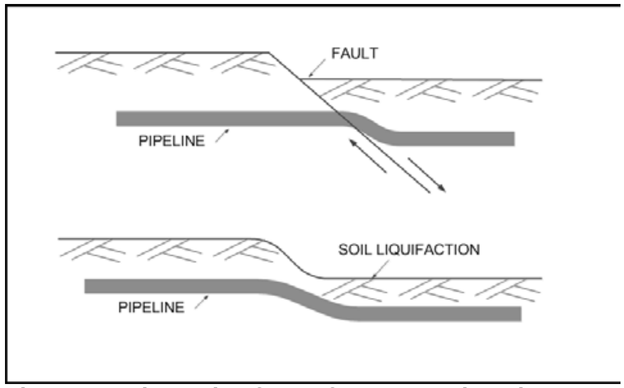

Figure 1 Schematic of PGD for a Normal Fault Displacement (top) and for Soil Liquefaction (bottom)

Laboratory Tests and Comparisons

Axial Strain

Polyethylene pipe can withstand an axial strain approaching ten percent without permanent damage. For a long term strain application, the recommended design strain level is three percent.

Table 1
Polyethylene Yield Strain, short term exposure

Material	Tensile Strain
High Density Polyethylene Pipe	8%

Table 2
Design Strain Levels, long term exposure

Material	Tensile Strain
High Density Polyethylene Pipe	3%
Earthquake Resistant DI Restrained Pipe	1%[1]

[1] Pseudo strain resulting from 1% restrained socket length. *Haddaway, (2015)*

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Lamborn (2011) tested PE pipes with fusion joints at a six percent axial strain with no damage or permanent deformation. After holding the strain for ten hours, the load was removed. The strain reduced rapidly to one percent through stress relaxation eventually returning to the unstrained state.

Bending Strain

Cornell (2007) tested nominal 10" IPS (250mm) and 16" IPS (400mm) DriscoPlex® HDPE pipes in a 63.5° fault slip simulator. The test subjected the pipes to a displacement of 4 feet at 1ft. /minute. The angled displacement induced both tension and bending stress in the pipes similar to the condition depicted in Figure 1. The maximum measured axial strains were eight percent and the maximum circumferential strain was four and a half percent.

In all cases the HDPE pipes withstood the simulated ground deformation with no failure.

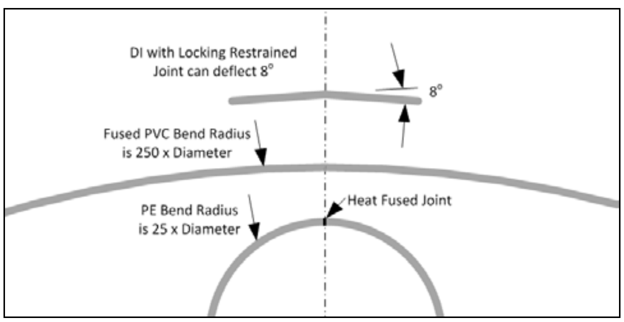

Figure 2 Comparative Bending and Pseudo Bending Capabilities *Haddaway, (2015)* and *Underground, (2013)*

Figure 2 shows two percent strain in bending for PE pipes compared to other piping materials.

Stress Reduction

The lower modulus of PE pipes compared to alternate piping materials reduces the stress applied to connecting structures. The instantaneous modulus of PE pipes is over one hundred times less than metal pipes which results in significantly lower force generation for the same strain.

PE modulus of elasticity is strain rate and time dependent with lower strain rates and longer times resulting in a lower effective modulus. This acts to further reduce the force generated at connections. The Cornell tests generated 118,000lb$_f$ at the pipe ends from the simulated PGD.

$$Force = E\ \alpha\ A$$

where:

$E = modulus, psi$

$\alpha = strain, \frac{in}{in}$

$A = pipe\ cross\ sectional\ area, inch^2$

Field Performance

More recently, the Abruzzo region of Italy suffered an earthquake in 2009 with a moment magnitude (M_w) of 6.3. Esposito (2013) conducted an assessment of the physical impact of the earthquake on the buried components of the gas distribution network. The network included heat fused PE piping and welded steel pipes.

"Regarding HDPE, no repair points occurred in the selected area. This seems to be in-line with the recognized good properties (e.g., ruggedness) of HDPE material and its earthquake performance"

The paper identified the steel pipe system failures as largely due to breaks or leaks in the area of gas welded joints.

Even more recently, New Zealand experienced a series of earthquakes in 2010 and 2011 (Mw 7.1, 6.2, 6.0). The water systems, which initially contained no PE pipes, reported heavy damage. In contrast, the LPG piping systems, which included PE pipes in the same zones of severe liquefaction and ground deformation, required

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only one repair where a service line was tied into a concrete block. See Table 1.

Table 3
Repair Rates 2010/2011 NZ Earthquakes

Canterbury Earthquakes	Repairs Required per Mile
Water Systems[1] Sept 2010 quake (Mw 7.1)	1 per 9.4
Water Systems[1] Feb 2011 quake (Mw 6.2)	1 per 3.4
Water Systems[1] June 2011 quake (Mw 6.0)	1 per 13.7
HDPE piping system in LPG service[2]	1 per 105
HDPE water piping[3]	0

[1] AC, CI, PVC, mPVC, and other pipes
[2] Combined of all 3 earthquakes
[3] 2km of replacement HDPE pipe installed after initial earthquake

Additionally, HDPE pipes used to replace broken water mains after the first earthquake suffered no damage after the remaining three earthquakes despite being subject to large liquefaction induced PGD and lateral spreading of over six feet. The authors attribute the PE pipe high performance levels to the combination of strength and ductility and note that PE pipelines can sustain high levels of tensile strain without rupture. *O'Rourke, (2012)*

Conclusions

The combination of high levels of allowable strain and reduction in force levels generated make the selection of PE pipes for water distribution systems and other critical pipe lifelines a cost effective solution to design for conditions of severe earthquake effects.

PE pipes have withstood large liquefaction induced PGD including lateral spreading of approximately six feet.

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