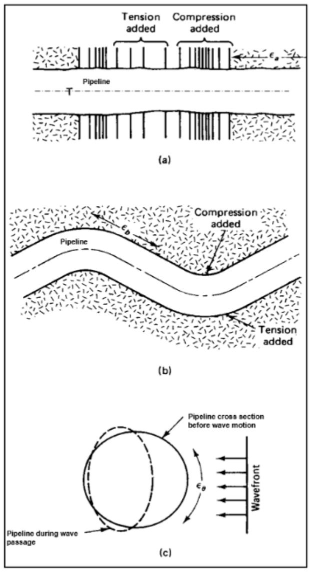
Const-Vibration Listserv Newsletter #23

Stresses in Buried Pipe with Large Diameter to Thickness Ratios Can Be Calculated from Ground Strains for Comparison with Allowable Levels of Specified Minimum Yield Stress (SMYS)



Longitudinal Stress, Axial Component

$$\varepsilon_{aL} = \frac{V_{max}}{c_c}\cos\theta$$

where V_{max} = Peak particle velocity of the ground; and
c_c = Propagation velocity of a compression wave.

Longitudinal Stress, Bending Component

$$\varepsilon_{bL} = \frac{V_{max}(2\pi f)\,D}{2\,c_s^2}\cos\theta$$

where f = Dominant frequency of shear wave;
c_s = Propagation velocity of a shear wave; and
D = Pipeline outside diameter.

Hoop Stress, Bending Component

$$\varepsilon_h = \frac{V_{max}}{c_c}\left(1+\frac{3t}{D}\right)\sin\theta$$

where c_c= Propagation velocity of a compression wave; and
t = Pipeline wall thickness.

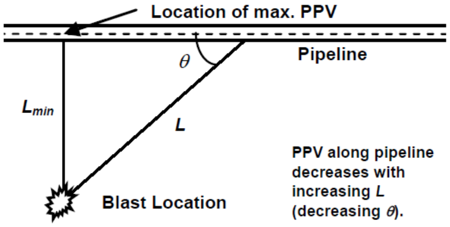


Figure 1 (left) (a) axial strain, caused by compressive wave propagating parallel to long axis; (b) bending strain caused by shear wave propagating parallel to pipeline axis; and (c) circumferential deformation caused by compressive waves propagating perpendicular to pipeline; (above) angle, Θ, between nearest blast hole and location of interest (Nyman, et al, 2008)[1]

Blast vibrations radiate outward from a blast or other source with a propagation velocity while producing a particle velocity wave train. The propagation velocity can be distinguished from particle velocity by considering a cork bobbing on a pond with a passing water wave produced by a dropped stone. The speed at which the wave approaches the cork is the propagation velocity and the speed at which the cork bobs up and down is the particle velocity. A single transducer position can measure particle velocity, whereas several time-synchronized transducers are required to measure propagation velocity. To further complicate matters, there are several different types of waves, (compressive, shear, surface waves, etc.) each of which has its own propagation velocity.

As shown in Figure 1 a buried pipeline subjected to the passage of these vibratory ground waves will incur strains equal to the ground strains when the pipe is relatively flexible compared to the ground in which it is located. As described in Newsletter #22 many continuous steel and plastic pipes are comparatively flexible. With reference to the equations in Figure 1, ground strains and thus strains in flexible pipe will be induced by: a) longitudinal strains, ε_{aL}, from a compressive wave component traveling parallel to the longitudinal axis of the pipeline; b) longitudinal bending strain, ε_{bL}, from a shear wave component traveling parallel to the longitudinal axis of the pipeline; c) hoop strains in the pipe wall from a compressive wave component passing through the pipe cross-section perpendicular to its longitudinal axis.

Hoop strains will dominate for close-in blasting where the incidence angle, Θ, between the nearest blast hole and the pipe approaches 90°, since the longitudinal strain by Equations (a) and (b) is zero. Maximum hoop strain can be estimated from the maximum compressive ground strain plus a relatively small amount of bending strain due to the ovalling deformation of the pipe cross-section as given by the Equation (c). Strains will be highest at points of maximum through-wall bending. See Nyman[1] et al (2008) for additional details.

For practical use pipe strains must be translated to pipe stresses because continuous pipe integrity is determined by stress level. Therefore the longitudinal and hoop strains at the locations of interest must be combined to determine blast induced stress levels. Stress in the hoop and longitudinal directions, S_h and S_L can be computed from the biaxial stress relation found in mechanics of materials textbooks as :

$$S_h = \frac{E}{1-\nu^2}\left[\varepsilon_h + \nu\left(\varepsilon_{aL} + \varepsilon_{bL}\right)\right] \qquad S_L = \frac{E}{1-\nu^2}\left[\left(\varepsilon_{aL} + \varepsilon_{bL}\right) + \nu\,\varepsilon_h\right]$$

where E = the Modulus of Elasticity for the pipe material (normally steel)
υ= Poisson's ratio for the pipe material

The strain components ε_{aL}, ε_{bL}, and ε_h computed by Equations (a), (b) and (c), respectively, pertain to locations defined by the angle of incidence, Θ, with the wave front. For a complete evaluation, it is necessary to compute the distribution of longitudinal and hoop strains and then stresses for angles of incidence as demonstrated in Figure 2 below. The steel pipe in this example had a diameter of 36 in and a wall thickness of 0.625 in. Compression and shear wave propagation velocities were assumed to be 9,000 and 4,500 fps respectively, and the shear wave frequency was assumed to be 50 Hz. The peak particle velocity (Vmax in the equations) was assumed to be 17 ips. Calculated maximum longitudinal and hoop stresses shown in Figure 2 were 3.6 ksi and 5.6 ksi, respectively, and occur at incidence angles of about 55 and 80°. These stresses are relatively low, especially for short-term loading for pipe grades of X50 and higher (10% or less of specified minimum yield stress- SMYS).

The combination of maximum longitudinal and hoop stress components without regard to time phasing as well as longitudinal position (based on incidence angle, Θ) and circumferential location generally results in a conservative estimate of strain and stress. In the USBM test report, it was acknowledged that combining the maximum values is conservative and that it would be more appropriate to combine time-related values of the various strain components (Siskind et al., 1995). Strain time histories in the USBM test report indicates that the peak strains are either not closely phased in time or have opposite signs when they are closely phased.

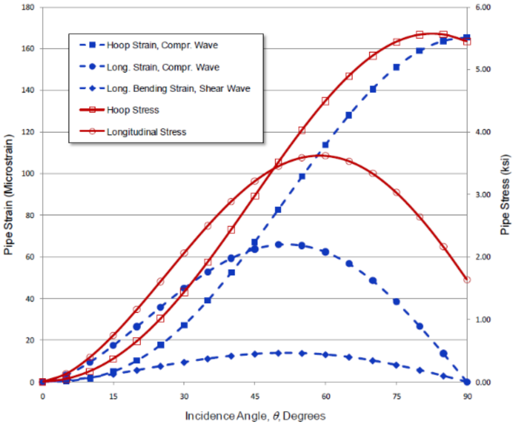


Figure 2. Blast-Induced Longitudinal Stress and Strain in a Buried 36 in. x 0.625 in. Pipeline as a Function of Angle of Wave Incidence, Θ, for a limiting PPV of 17 ips.

References

Nyman, D. J., Dowding, C.H. and Oriard, L.L. (2008) Evaluation of Close-In Blasting Effects on Welded Steel Pipelines, Proceedings of 7th International Pipeline Conference, Calgary, Alberta, Canada.

Siskind, D.E., Stagg, M.E, Wiegand, J.E., and Schulz, D.L. (1994) USBM Report of Investigations 9523, Surface Mine Blasting Near Pressurized Transmission Pipelines. Available through ARblast; https://www.osmre.gov/resources/blasting/arblast.shtm.

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[1] Stress calculation and explanation was supplied by D.J. Nyman for the Nyman et al (2008) article.