Bearing and Frictional Resistance: The Building Blocks of a Restrained System

Connections bulletins PD-1 through PD-4 discuss some of the specific applications of the design of a properly restrained pipeline. PD-2 specifically addresses horizontal bends and the various parameters involved in the design process. PD-3 applies those parameters to the design of vertical offsets and tees. Finally, the design of reducers, dead ends, and miscellaneous fittings is discussed in PD-4. This bulletin delves into a more detailed discussion of the bearing and frictional resistance forces at work to balance thrust forces generated in pressurized pipelines. To see how this information relates to the various pipeline elements, please refer to the other Connections bulletins.

Bearing Resistance

The most significant factor used to counteract thrust in a pipeline at horizontal bends and tees is the bearing resistance of the soil. The bearing resistance of the soil is realized as passive pressure and is generated as the pipeline attempts to separate and move into the soil. This is the same resistance as that realized by the back side of a thrust block.

Additionally, there is some bearing resistance that results at the area formed by the diameter difference between the pipe bell and the pipe. In many cases, the calculated minimum restrained pipe length is less than a full length of pipe, and this may or may not include a pipe bell. As a result, it is not prudent for the design to rely on that interaction because the specific conditions that occur in the field are not always known. Therefore, this aspect of the pipeline is not included in the calculations and contributes a slight amount of conservatism to the design.

The maximum amount of resistance or pressure generated by this movement is determined by using Rankin's Passive Pressure Theory:

$$\sigma_h = \gamma H_c K_p + 2c\sqrt{K_p}$$

Where:
- σ_h = horizontal passive soil pressure (lbs/ft²)
- γ = soil density (lbs/ft³)
  for loose soil use backfill density
  for compacted bedding use native soil density
- H_c = mean depth from surface to pipe centerline (ft)
- c = cohesion of the soil (lbs/ft²)
- K_p = Rankin passive pressure coefficent = $\tan^2(45 + \Phi/2)$
- Φ = internal friction angle of the soil (degrees)

The horizontal passive soil pressure is the maximum pressure that the soil will impart, without failing, on a structure moving into it at the prescribed depth. The pipe surface area that is utilized to counter the thrust, caused by pressure in the pipeline, is defined by the restrained length "L" and the outside diameter of the pipe "D", as defined in earlier bulletins. The passive pressure is dependent upon the compaction of the soil. Generally, soils that are compacted to 80% proctor density or greater, require little movement to generate the maximum amount of passive resistance. In order to account for the variances in trench conditions, an empirically derived modifier "K_n" is used to assure that excessive amounts of pipeline movement do not occur.

Therefore, the bearing resistance along the pipeline is denoted by the term "R_s" and is represented as:

$$R_s = K_n \sigma_h D$$

Where:
- K_n = trench compaction modifier
- D = outside diameter of pipe (ft)

Frictional Resistance

Any body moving in contact with another body will encounter a resisting force known as friction. All soils have an inherent friction angle referred to as "Φ". This friction angle is a result of the interaction of the grains of soil as they move relative to one another and is related to the internal shear strength of the soil. This shear strength is also affected by the cohesion of the soil, "c". The Mohr-Coulomb failure law expresses the shear strength of a soil in terms of both friction angle and cohesion.

$$s = c + \sigma \tan \Phi$$

Where:
- s = shear strength of the soil
- σ = effective normal stress on plane of shear

It stands to reason that the friction between the soil and a body is determined. J.G. Potyondy studied this and developed a version of the Mohr-Coulomb failure law that provides coefficients to modify the cohesion and the friction angle. These are based upon the particular soil and the roughness of a surface. This same process is applied to pipe.

Some methods employ coefficients that were developed by Potyondy for "rough steel" surfaces. EBAA Iron has performed hundreds of soil shear tests on actual pipe surfaces to determine conservative and efficient modifying coefficients for ductile iron pipe, ductile iron pipe wrapped in polyethylene film, and PVC pipe. Those coefficients are used in the equations and programs provided, free of charge, by EBAA Iron for our customers. The frictional resistance acting on a pipeline, "F_s", is determined by an adaptation of Potyondy's equation.

$$F_s = A_p(f_c c) + W\tan(f_\Phi \Phi)$$

Where: $A_p = \pi D/2$
Area based on half of the pipe circumference in contact with the soil (ft²/ft)

f_c = cohesion modifier coefficient

$W = 2W_e + W_p + W_w$
normal force acting on the pipeline (lbs/ft)

W_e = normal force due to the vertical prism load of the soil (lbs/ft)

W_p = normal force due to the weight of the pipe (lbs/ft)

W_w = normal force due to the weight of water in the pipe (lbs/ft)

f_Φ = friction angle modifier coefficient

When analyzing horizontal and vertical up-bends, or the runs of tees, the pipe surface bearing area is based on half of the pipe circumference. As the pipe moves into the soil, only the leading surface is affected by cohesion.

When analyzing the branch of a tee, reducers, or dead ends, the full pipe circumference is taken into account because the full surface of the pipe is moving longitudinally into the soil. This modified version of the frictional force is denoted as:

$$F_{sb} = (A_p)_b(f_c c) + W\tan(f_\Phi \Phi)$$

where

$$(A_p)_b = \pi D$$

The friction values for the soil are always based on the soil that is in contact with the pipe. The pipe friction tests also indicated that ductile iron pipeline wrapped with polyethylene film slips inside the polyethylene wrap. This lends itself to conventional friction theory where the coefficient of friction of polyethylene on a ductile iron pipe surface is determined as the tangent of 14 degrees. Therefore, for PE wrapped ductile iron pipe $F_s = F_{sb} = W\tan 14 = 0.249W$

Soils

Soils that are free draining are preferred for pipe bedding materials. These materials are easier to control and monitor during compaction. Compaction of CL and ML soils are closely monitored because of the difficulty to control moisture content.

Pipelines bedded in highly plastic soils are usually bedded in some type of granular material, especially if these soils are subject to high moisture content. In this case, the Fs is based on the bedding material. The R_s value is used based on the cohesion determined by the undrained shear strength of the native soil, according to the "$\Phi = 0$" principle. This principle holds that the shear strength of near saturated and saturated clays, at different moisture contents, is not affected by the normal load.

When the bedding and native soils are different, the frictional values are based on the bedding material. The bearing values are calculated for both soil materials and the smaller value is applied. This is most important when working with highly plastic clays.

Conservative soil values are used when possible. Actual values from the van shear test, unconfined compression test, or standard penetration test are used when possible. A competent soils engineer is consulted to confirm that the soil values used are valid for a particular application.

Summary

The bearing and frictional resistance of the soil are important factors that have a direct impact on the design of a restrained pipeline. In stable soil conditions, considerable economies are realized by utilizing good bedding materials and techniques. The elimination of thrust blocks in a piping system not only makes the installation simpler and more adaptable, it also is beneficial in the long run when other excavations could endanger the ability of a thrust block to operate effectively.

Soil design values are available from EBAA Iron that are used to perform thrust restraint calculations. These are provided along with restrained length tables for your convenience. A thrust restraint computer program is also available, free of charge that incorporates all of the design aspects discussed in this and previous bulletins.

References

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