## Restrained Pipeline Design and Horizontal Bends

In the last forty years, a quiet revolution has occurred in our industry. This revolution is the result of new generations of joint restraint products that make it possible to quickly and safely restrain fittings at bends, dead ends, tees, valves, and reducers without the need for concrete thrust blocks or tie rods. These joint restraint products turn the pipeline into its own thrust block. The key to utilizing these new products is the understanding and proper application of the pipeline restraint design theory.

### The Force To Be Restrained

The first step in any pipeline restraint design is to define the force to be restrained: the resultant thrust force. Defining this force at a particular fitting requires figuratively isolating the piping section containing the fitting restrained, and then summing the individual hydrostatic forces at the fitting joints.

Approached individually, the force attempting to separate any joint in a segmented piping system is equal to the internal pressure at that joint, P, multiplied by the cross sectional area of the pipe, A.
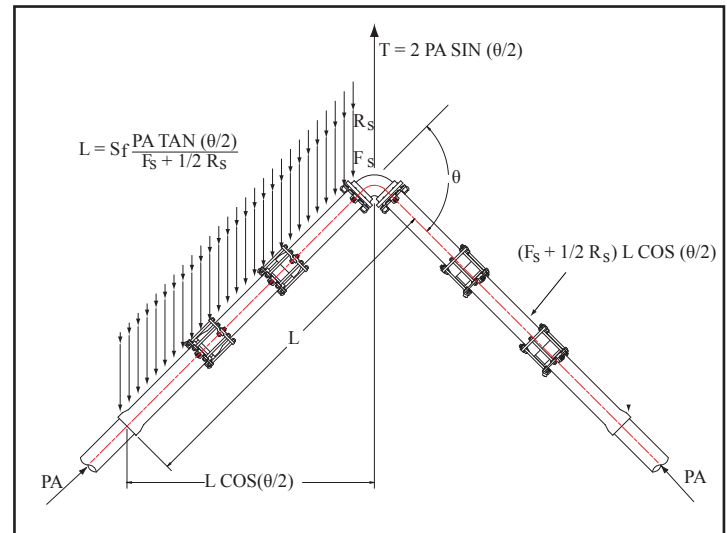
In a continuous straight run of pipe, the forces at one joint are balanced by the equal and opposite forces at the adjacent joints and the weight of the soil friction acting on the pipe. No restraint is necessary. When a bend, tee, reducer, valve, or other flow altering fitting is introduced, the forces no longer balance each other. The hydrostatic forces created at the joints on both ends of the fitting combine to form a single reaction. This reaction is the resultant thrust force, T. This resultant force is the force attempting to move the fitting away from the bend and its attached piping. This is the force to be restrained.

The magnitude of this resultant thrust force is given by

$$T = 2\ P \bullet A \bullet Sin(\theta/2)$$

where T, P, and A are defined above, and $\theta$ is the bend angle.

Factors defining the magnitude of the resultant thrust force on a bend are pipe size, pressure, and bend angle. While pipe size and pressure are usually defined for a given application, the bend angle may vary in some situations. As the bend angle increases, the force restrained increases. A 90 degree bend has a resultant thrust force nearly twice the magnitude of the force at a 45 degree bend. When possible, small bend angles are utilized.



In the figure: $T = 2\ PA\ SIN\ (\theta/2)$; $L = Sf\ \dfrac{PA\ TAN\ (\theta/2)}{F_S + 1/2\ R_S}$; $R_S$; $F_S$; $(F_S + 1/2\ R_S)\ L\ COS\ (\theta/2)$; $L$; $L\ COS(\theta/2)$; $PA$

### The Restraining Forces

The resultant thrust force is identical for a thrust block or a restrained joint system. A thrust block provides a bearing surface to transfer and distribute the resultant thrust to the soil behind the fitting. The critical factor defined in designing a thrust block system is the size of the bearing surface area. Similarly, restrained joints tie available pipe surface area together to distribute the resultant thrust to the surrounding soil along the pipeline near the fitting. The purpose of restrained pipeline design is to define the minimum length of restrained pipe necessary to distribute the resultant thrust to the surrounding soil without exceeding the soil's ability to resist that force.

Restrained pipeline design assumes that two forces resist the resultant thrust force: 1) frictional resistance between the pipe and the soil, $F_s$, and 2) the passive bearing resistance of the soil, $R_s$. Both $F_s$ and $R_s$ are defined in pounds per foot of pipe length.

The amount of resistance provided by pipe-to-soil friction for a given situation is a function of the soil type, moisture content, pipe size, pipe material, depth of bury, and compaction.

Restrained pipeline design approximates these relationships with a series of empirical equations which define $F_s$ in terms of the soil type, pipe size, pipe material, and depth of bury. By definition, this frictional resistance acts in a direction opposite of the resultant thrust force to oppose impending motion.

As the bend attempts to move away from the pipeline, due

to resultant thrust, resistance to the impending movement is generated by the surrounding soil as the soil "pushes" back. According to design theory, this soil reaction is defined as passive bearing resistance, $R_s$. Available passive resistance (lbs/ft) for a given situation is calculated using "Rankine's passive pressure" formula to define the theoretical bearing strength for a given soil, $P_p$ (lbs/ft²), multiplied by the pipe diameter, and trench compaction factor. ($F_s$ and $R_s$ are described in more detail in Connections Bulletin PD-05.)

## The Restrained Length Formula: Horizontal Bends

Passive bearing resistance, $R_s$, is assumed as a maximum at the fitting where potential movement is assumed as the greatest. $R_s$ decreases linearly from the maximum at the fitting to zero at a distance, L, along the pipeline. Frictional resistance, $F_s$, is applied uniformly along the length, L. The total available frictional resistance and the total available passive bearing resistance are defined in terms of the restrained length, L, and the bend angle.

In order for the bend fitting to remain in place, the sum of the total frictional and passive bearing resistances must equal the resultant thrust force. Adding a safety factor, Sf, to this expression and solving for the restrained length, L, the formula for the restrained length at a horizontal bend is given by:

$$L = S_f \cdot P \cdot A \cdot \tan(\theta/2) \,/\, F_s + 1/2 \; R_s$$

where L is in feet.

Every joint along the pipeline within the distance L from the fitting on both sides of the fitting requires restraint.

Failure to restrain any joint within length L may result in joint separation and failure of the system.

## Restrained Length Variables

Eight basic parameters are defined before calculating a restrained length for a horizontal bend:

1. Pipe Type and Material—The magnitude of frictional resistance available to resist the resultant thrust is partially a function of the weight of the pipe and its surface roughness. PVC pipe, because of its lighter weight and smooth exterior, typically requires 15 to 20 percent longer restrained lengths than ductile iron pipe, given the same piping parameters. Wrapping ductile iron pipe in polyethylene will significantly reduce available friction and may increase restrained length requirements by 30 to 50 percent over bare ductile iron pipe lengths.1.
2. Pipe Size—Nominal
3. Bend Angle
4. Test Pressure—The restrained joint system is designed for the maximum sustained pressure that the system is subjected to. Typically, test pressures defined at 1.5 times the working pressure are used to calculate restrained lengths.
5. Soil Type—The soil type is defined as per the Unified Soils Classification System (ASTM Standard D2487).
6. Trench Type—The degree of compaction applied during backfilling greatly affects the available bearing resistance, $R_s$. AWWA C150 details the various bedding conditions recommended for ductile iron pipe. At a minimum, restrained pipelines are bedded on four inches of loose soil with the backfill lightly compacted to the top of the pipe (Type 3 Trench). Increasing the backfill compaction will usually reduce the restrained length requirements. Always test restrained systems with the backfill in place.
7. Depth of Bury—The depth of bury affects both $F_s$ and $R_s$. Measured from surface grade to the top of the pipe, the minimum depth of bury for restrained joint system is two and a half feet.
8. Safety Factor—Normally 1.5:1.

## Summary

Joint restraint products permit restraint of fittings in segmented piping systems without thrust blocking and tie rodding. In a properly designed system, the resultant thrust force at a fitting is balanced by friction at the pipe to soil interface, and by the passive bearing resistance of the soil. Joint restraint design defines the length of pipe that is restrained to a fitting to provide the necessary frictional and passive bearing resistance. For horizontal bends, this length is defined by:

$$L = S_f \cdot P \cdot A \cdot \tan(\theta/2) \,/\, F_s + 1/2 \; R_s$$

where L is in feet.

## Reference
Ductile Iron Pipe Thrust Restraint Design Handbook, EBAA Iron Sales, Inc., 1993.