Property Risk Consulting Guidelines

A Publication of AXA XL Risk Consulting

PRC.14.1.2.4

HYDRAULIC GRADIENT

INTRODUCTION

A hydraulic gradient or pressure gradient is a graphic representation of the residual pressure at selected points along the length of a pipe through which water is flowing at a constant rate.

The flow of water through a pipe is governed by natural physical laws. Its pressure drop under a specific set of conditions, such as type, age and size of pipe, and rate of flow, can be predicted. Occasionally, the flow does not follow the prediction, and it becomes necessary to determine where the actual pressure drop differs from that expected. A hydraulic gradient is one of the most useful tools for analyzing such situations.

POSITION

Obtain hydraulic gradient test data when it is necessary to pinpoint where excessive pressure losses are occurring.

DISCUSSION

If water is discharged from a point on an underground main, the residual pressure is progressively lower as the discharge point is approached. This is a result of the cumulative friction loss through the pipe and fittings. In other words, a certain amount of energy is lost in the pipe overcoming the resistance to flow due to friction. Pressure measurements are obtained during a hydraulic gradient test as follows:

- Calibrated gauges are attached at convenient points along the pipe, such as hydrants and sprinkler system risers. The more points that are used, the more detailed the analysis and the easier it is to pinpoint problems.
- The static pressure at each test point is read and recorded.
- Water is discharged from a hydrant near the end of the line, preferably through Underwriters' playpipes, and accurate pitot readings are taken. The flow corresponding to these pitot readings is obtained from appropriate hydraulic tables and recorded. See PRC.14.1.2.1.2 A, hydraulic calculator.
- While the water is flowing, the residual pressure at each test point is read and recorded.

When the residual pressure at various points along the underground pipe is measured and plotted against the corresponding equivalent length of piping producing the friction, the resulting graph is known as a hydraulic gradient.

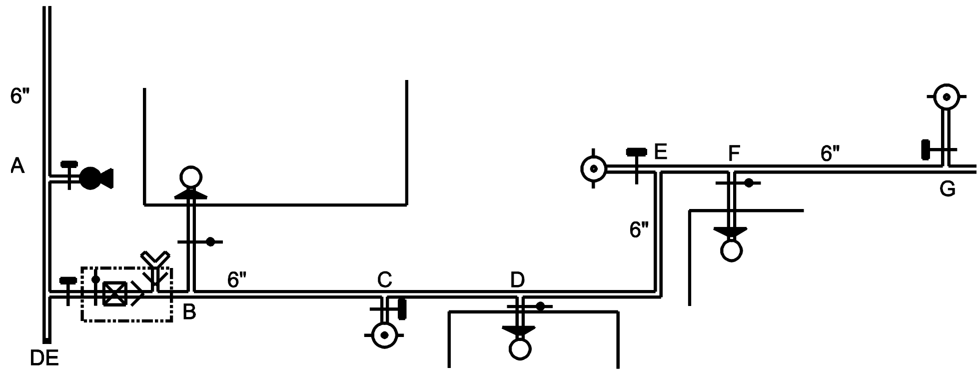


Figure 1. Diagram Of Physical Layout Of Facility Showing Locations Where Pressure Readings Are Taken.

Example

Figure 1 shows the physical layout of a section of underground main feeding several hydrants and sprinkler systems. All reference points are at the same elevation with the exception of Point “A,” which is approximately 14 ft (4.3 m) lower than the others. It is suspected flow is restricted between reference points “A” and “F.” The static pressure readings are taken from gauges on the devices that are attached to the underground main at the various reference points being investigated. Recorded pressure readings are shown in Table 1. Water is then discharged from the hydrant at point “G” and the flow is calculated. While the water is flowing, residual readings are read and recorded.

The distance between each reference point is the actual length of pipe plus equivalent lengths of pipe for the fittings and valves between the points. Use Table 2 for these equivalent lengths, corrected to the appropriate C-Factor. Use Table 3 to determine the equivalent lengths for fire service meters at various flows, corrected to the appropriate C-Factor.

TABLE 1
Static And Residual Pressures At Each Reference Point

Reference Point	Static Pressure (psi)	Residual Pressure (psi)
“A”	90	75
“B”	84	63
“C”	84	55
“D”	84	35
“E”	84	29
“F”	84	26

SI Units: 1 psi = 0.689 bar

TABLE 2
Equivalent Lengths of Fittings in ft For C=120

	Size of Fitting (in.)				
Type of Fitting	4	6	8	10	12
90° Elbow	10	14	18	22	27
90° Long Turn Elbow	6	9	13	16	18
45° Elbow	4	7	9	11	13
Side Tee	20	30	35	50	60
Gate Valve	2	3	4	5	6
Swing Check	22	32	45	55	65

SI Units: 1 ft = 0.3048 m; 1 in. = 25.4 mm

TABLE 3

Equivalent Lengths of Fire Flow Meters in Feet For C=120

	Flow (gpm)							
Type of Meter	250	500	750	1000	1250	1500	2000	2500
4 in. Hersey	111	26	26					
6 in. Hersey	407	276	68	51	41	39	30	
8 in. Hersey	4285	1423	352	109	57	41	39	43
10 in. Hersey	8000	4500	2222	1194	565	215	73	66
4 in. Trident	111	28	26					
6 in. Trident	1074	194	87	51	34	24	17	17
8 in. Trident	4571	692	278	163	107	82	54	43
10 in. Trident	15000	2875	1000	419	261	169	100	72
6 in. Rockwood	74	31	29	24	23	22	28	

SI Units: 1 ft = 0.3048 m; 1 in. = 25.4 mm

Based on a flow of 1000 gpm (3785 L/min) and C = 120, the theoretical losses are calculated as shown in Table 4.

The corrected static pressure at each reference point is determined by adding the recorded residual pressure to the pipe profile pressure. The friction loss between the various reference points can be calculated using the appropriate hydraulic tables or the AXA XL Risk Consulting's Hydraulic Calculator (see PRC.14.1.2.1.2 A). The theoretical residual pressure is found by subtracting the cumulative calculated friction loss at each reference point from the corrected static pressure.

TABLE 4

Theoretical Friction Losses

		Pressure (psi)	
Pipe Segment	**Length (ft)**	**Calc. Loss**	**Totals**
To Point "A"			15.0
"A" to "B" 6 in.			
Actual length	56		
2 Gate Valves	6		
1 Tee	30		
1 Check Valve	32		
Hersey Meter	51		
Total	175	6.1	21.1
"B" to "C" 6 in.			
Actual length	100	3.5	24.6
"C" to "D" 6 in.			
Actual length	100	3.5	28.1
"**D" to "E" 6 in**.			
Actual length	100		
1 90° Elbow	14		
Total	114	4.0	32.1
"E" to "F" 6 in.			
Actual length	52		
1 Tee	30		
Total	82	2.9	35.0

SI Units: 1 ft = 0.3048 m; 1 in. = 25.4 mm; 1 psi = 0.687 bar

TABLE 5
Theoretical Pressure Vs Actual Pressure

Reference Point	Pressure (psi) Theoretical	Actual
A	90 - 15.0 = 75.0	0 + 75 = 75
B	90 - 21.1 = 68.5	6 + 63 = 69
C	90 - 24.6 = 65.4	6 + 55 = 61
D	90 - 28.1 = 61.9	6 + 29 = 35
E	90 - 32.1 = 57.9	6 + 29 = 35
F	90 - 35.0 = 55.0	6 + 26 = 32

SI Units: 1 psi = 0.687 bar

Table 5 shows the corrected theoretical and actual pressures needed for analysis. The results of the hydraulic gradient can be shown graphically. See Figure 2. The analysis consists of four parts:

- A horizontal **reference line** drawn at the point of maximum static pressure;
- A line detailing the **profile** of the pipe, reflecting the pressure due to differences in elevation along the pipe;
- The **actual or measured** hydraulic gradient based on pressure at a particular uniform flow rate;
- The **expected or theoretical** gradient calculated from friction loss tables based on the total equivalent length between gauge connections.

Standard graph paper is used. The graph paper is prepared using pressure for the ordinate and the equivalent linear dimensions of the pipe line for the abscissa.

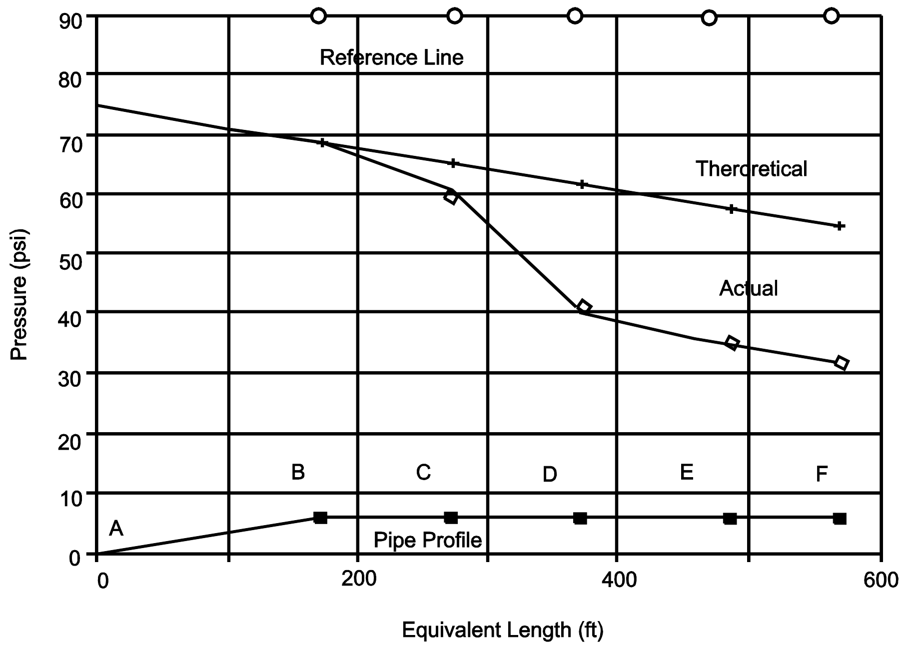
The horizontal reference line drawn is plotted at 90 psi (6.2 bar) using the various reference points representing the hydrants or risers where residual readings were taken. The pipe profile line is drawn by subtracting the static pressure from the reference line at the various reference points, and connecting the resultant pressures by a straight line. The corrected pressures shown in Table 5 are similarly plotted and connected by straight lines.

The actual gradient is approximately the same slope as the theoretical gradient between the various reference points except for the segments from “B” to “C” and “C” to “D.” The minor discrepancy between “B” and “C” can be attributed to accuracy in data collection, assumptions made, and accuracy of calculations. The steeper slope of the actual gradient between points “C” and “D” indicates an abnormal friction loss requiring further investigation.

Conclusions

Hydraulic gradients have the following characteristics:

- For pipe lines with the same diameter throughout and with a constant rate of flow, the gradient should be a straight line of uniform slope.
- Residual pressure, plus cumulative friction loss, is equal to static pressure.
- The vertical distance between two points on a hydraulic gradient is equal to the friction loss between the two points.



SI Units: 1 ft = 0.308 m; 1 psi = 0.687 bar

Figure 2. Hydraulic Gradient Diagram.

If the slope of the actual hydraulic gradient is steeper than the theoretical gradient between two test points, one or more of the following conditions may exist:

- A partially closed valve or dropped valve gate;
- An obstruction such as caulking lead or stones;
- Severe tuberculation;
- Smaller diameter pipe than believed was installed.

Further investigation such as physically checking the pipe interior is then necessary to determine which of these conditions exist. The use of a hydraulic gradient has, however, narrowed this investigation to the portion of the piping between two reference points.