CABLE PRESSURE SYSTEMS

GRADIENT METHOD OF APPROXIMATE LEAK LOCATION

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1. GENERAL

1.01 This section covers the gradient method of locating leaks and restrictions in continuous feed pressure systems. A method of computing the indicated location of an air leak also is described. Computations are made to verify the accuracy of the plotted leak location before excavating to clear leaks in buried or underground cables.

1.02 This section includes information formerly contained in Sections 637-411-500, 637-411-501, 637-411-503, 637-413-503, 637-413-505, and 637-500-500.

1.03 This method requires the following:

- Positive pressures existing in the cable or applied from auxiliary sources.
- Use of precision instruments to read pressures to an accuracy of at least 0.025 psi. Although the C pressure gauge is only graduated to 0.05 psi, interpolated readings of 0.025 can be obtained with this instrument.
- Information such as cable size and length, conductor insulation and gauge, cable interlacing, location of valves, plugs, and associated bypasses.
- A clipboard or suitable hard surface, straightedge, and hard lead pencil. It may be desirable to have a triangular scale having 10 or 20 divisions to the inch.

**Reprinted to comply with modified final judgment.

- Form E-1017, Air Pressure Testing—Graph of Pressure Readings (Fig. 3), or other graph paper having 10 or 20 spaces to the inch. Form E-1017 has 20 spaces to the inch and is conveniently laid out for gradient plotting. When using other than Form E-1017 for gradient plotting, the accuracy of the graph paper should be checked.

2. MAKING PRESSURE READINGS

2.01 Pressure readings for leak location purposes usually are made with a C pressure gauge or an instrument of greater accuracy, such as a mercury manometer. The hose on the instrument should be kept as short as practicable in order that the air withdrawn from the cable to charge the instrument and make the readings will not seriously affect the pressure readings.

2.02 Pressure readings for a leak location test should be taken by the same person, using the same instrument, to eliminate possible differences in reading methods and instrument characteristics.

A. Preparation

2.03 Leak locating measurements should not be undertaken without a thorough knowledge of the physical arrangement of the cable plant in question. This information should include types and sizes of cable, locations of junctions of different type cables, and locations of valves, plugs, bypass connections, branch cables, air filled load cases, etc.

2.04 In addition, the employee should be familiar with the general condition of the cable section and the history of the cable, such as electrolysis conditions, incidence of damage by outside parties, location and cause of previously cleared leaks, etc. Such knowledge is necessary to analyze the overall pressure condition in the section, the possibility of other leaks or restrictions, or of other work activity on the cable such as open splices and pressure charging operations by other employees. This information is of value in selecting the values where pressure readings will be taken and deciding on the most advantageous method to be followed in making the pressure readings.

2.05 Any known restrictions or stoppages in the cable should be cleared or bypassed before starting leak locating tests.

2.06 If it is necessary to install temporary valves or to make valve repairs that would disturb the pressure gradient, allow sufficient time (several hours may be required) for the pressure to stabilize.

2.07 When pressure readings are too low to plot a gradient, auxiliary sources of pressure should be applied by either the one- or two-source method described in Part 7.

B. Selecting the Reading Valves

2.08 Pressure readings should be taken over a continuous length of cable that includes at least three evenly spaced valves on each side of the suspected leak location. Evenly spaced valves will minimize errors introduced by substitution of straight lines for the true curve of a leak gradient when plotting pressure graphs (see Part 4).

2.09 Where the leak is near a plug, a reading should be obtained near the plug and, if practicable, at one or more valve points between the suspected leak and the plug. Readings also should be obtained at three uniformly spaced valve points on the side of the suspected leak away from the plug.

2.10 Where the section of cable under test includes two types of cable having different pneumatic resistances, one of the reading valves should be at the junction splice between the two types, and at least one reading valve should be between the junction splice and the suspected leak location to establish the shape of the gradient in that portion.

2.11 Where the section of cable under test includes a junction with a branch cable, one of the reading valves should be located at the junction splice, and at least one reading valve should be between the junction and the suspected leak to establish the shape of the gradient in that portion.

C. Placing Temporary Valves

2.12 Leak locating tests based on pressure readings made at intervals exceeding 1000 feet may not reveal the true shape of the gradient adjacent to the leak, the existence of more than one leak, or restrictions or minor variations in pneumatic resistance in the cable. This may lead to considerable error in leak location, particularly where small leaks are involved.

2.13 The shape of the critical portion of the gradient can be more accurately determined by installing temporary valves, with a uniform spacing of 500 to 1000 feet in the vicinity of the leak. Generally, the distance between the valves should be sufficient to detect small differences in pressure between adjacent valves when small leaks are involved.

2.14 Suitable valve spacing can be determined by inspection of a gradient plotted from readings at the regularly spaced valve points. The C pressure gauge can be used where a relative accuracy of ± 0.05 is adequate. When using this gauge, there is no advantage in spacing temporary valves any closer than that which would result in pressure differences less than 0.05 psi between adjacent valves. For leaks of this size and smaller, consideration should be given to the use of precision leak locating procedures described in Section 637-412-500.

2.15 Typical valve arrangements for underground and buried cables are illustrated in Fig. 1.

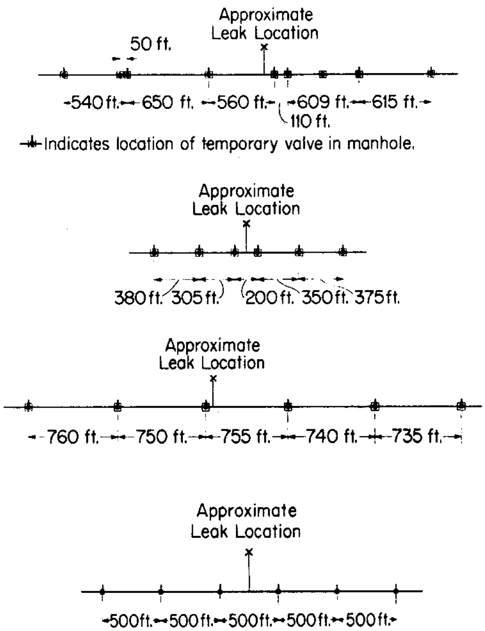


Fig. 1—Valve Arrangements

2.16 For convenience in making readings and to minimize the effects of temperature changes of the cable, temporary valves can be extended to street level at manholes, and to ground level on buried cable installations, by means of a length of suitable tubing, as illustrated in Fig. 2.

3. PREPARATION OF GRAPH

A. Description of Form E-1017

3.01 Form E-1017, Air Pressure Testing—Graph of Pressure Readings (Fig. 3) is available

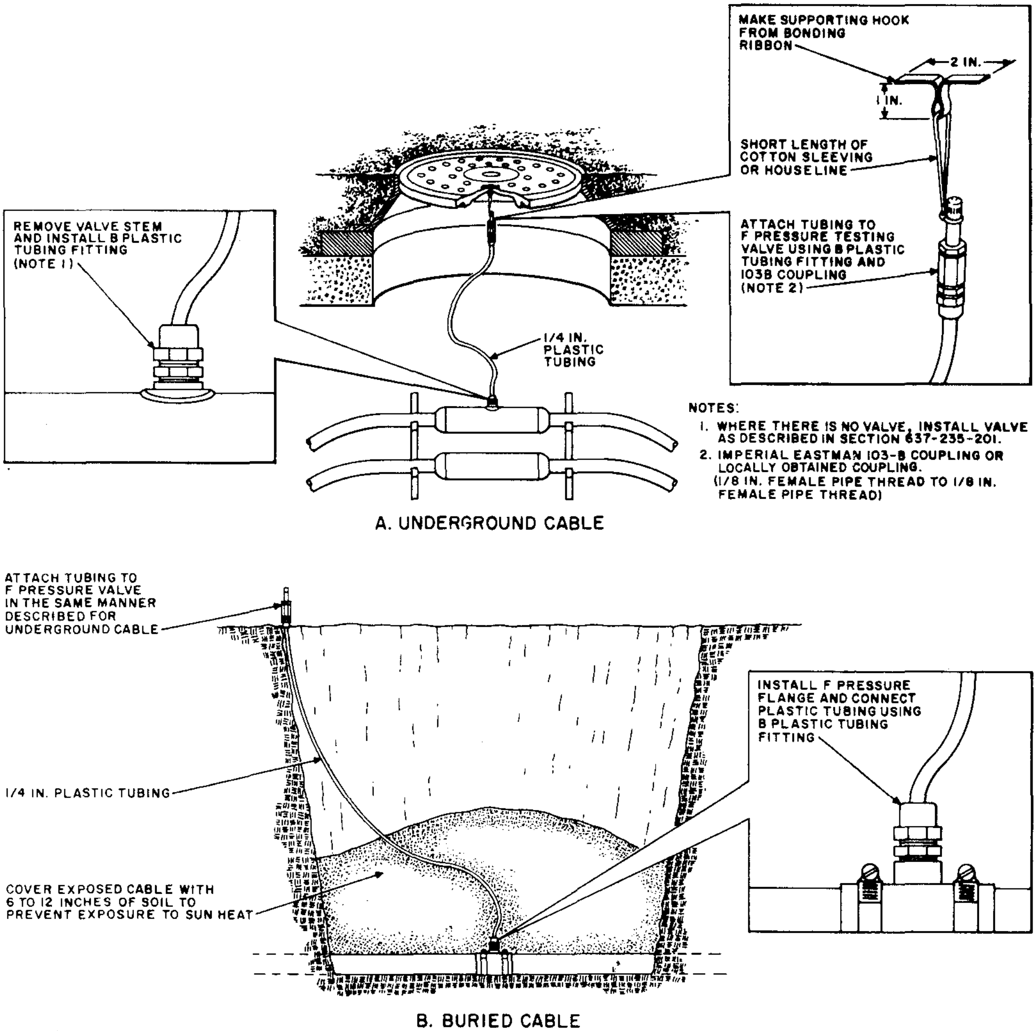
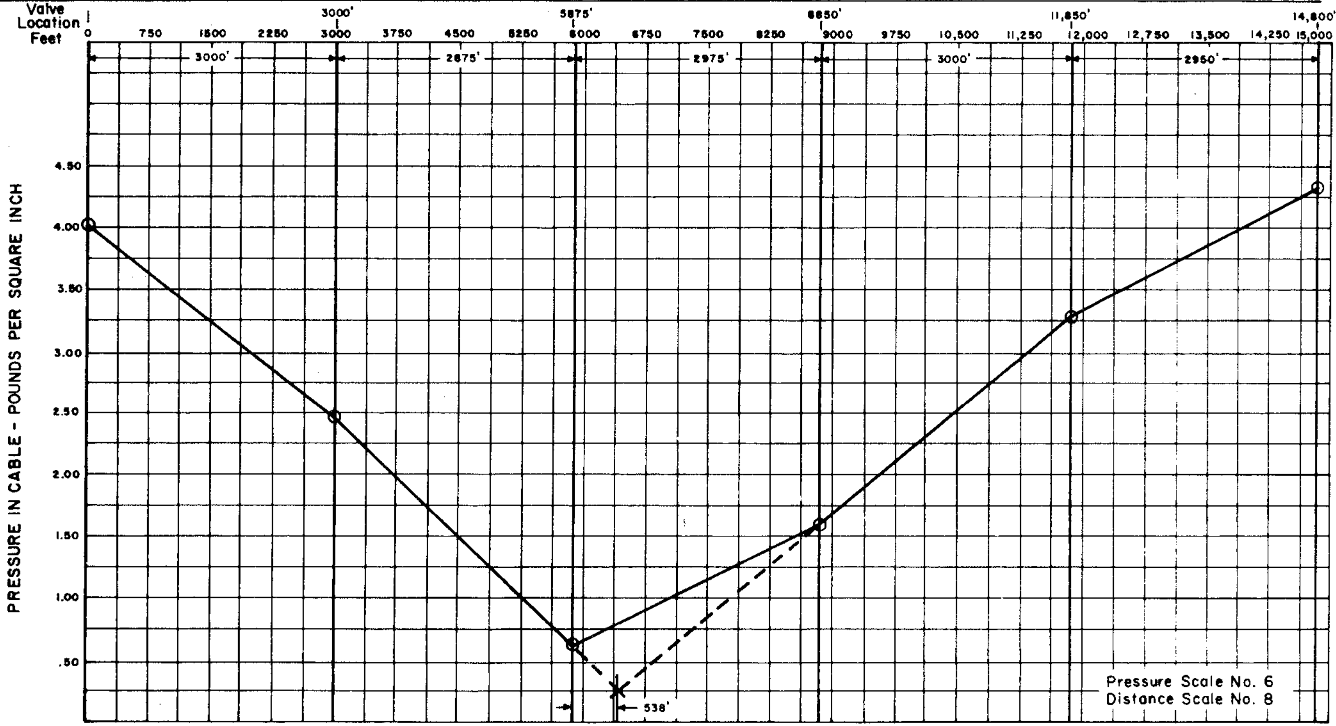


Fig. 2—Extending Valves to Ground Level

AIR PRESSURE TESTING - GRAPH OF PRESSURE READINGS

Marker, Pole or M.H. No.	MH#60	MH#65	MH#70	MH#75	MH#80	MH#85
Pressure — As Read	4.02	2.45	.60	1.61	3.30	4.49
Pressure — Corrected	4.02	2.45	.60	1.61	3.30	4.49



Cable 12

Gas Section No. 3

Made By JHS Checked By WEM

Plotted Location MH#70+538'

Actual Location MH#70+510'

Error in Feet 28

Cause of Leak CRACK IN SHEATH

Testboard Report No. 17

Date of Test 10-9-74 Time (Start) 11:00AM (Finish) 2:20PM

Weather CLEAR Temp. 65°F

Fig. 3—Cable Leak in Center of Cable Section

for plotting pressure gradients. This form is 8-1/2 by 11 inches in size, and the graph portion of the form is 5-1/2 inches high by 10 inches long.

3.02 The graph is divided by lightweight lines into 20 small blocks per inch. Every fifth horizontal and vertical line is marked by a medium weight line. Every tenth line is marked by a heavy line to outline 1/2-inch blocks of 10 small blocks. Distances in feet or units of pneumatic resistance are plotted along the horizontal scale. Pressures units are plotted along the horizontal scale. Pressures in pounds are plotted vertically.

3.03 Space is provided at the top of the form for entering valve location, measured pressure, corrected pressure, valve location in feet, and the scale to be used. Sufficient space is provided so that these entries may be made directly above the plotted location of the valve on the graph. At the bottom of the form, there is space for general information such as name of cable, date of test, weather conditions, and results of leak location test.

3.04 Completed forms should contain all data pertinent to the test and retained as part of the history record of the cable for reference during subsequent maintenance work.

B. Information Required for Preparation

3.05 Before preparing the graph, it is necessary to have the following information:

- All valve readings
- Distance between valves
- Size, gauge, type, and length of cables involved.

C. Selecting Pressure Scale

3.06 To select the proper pressure scale, observe the readings taken while isolating the fault and subtract the highest and lowest pressure readings for the length of cable being investigated. Select a scale from Table A so this pressure difference will cover one-half to two-thirds of the total pressure (vertical) range on Form E-1017.

3.07 When the faulty section is being fed from two pressure sources, have the plotting range for pressures start at zero in order to permit projecting the gradients on each side of the fault to a point of intersection within the area of the grid.

TABLE A

PRESSURE SCALE

All Pressures in Pounds per Square Inch, Gauge (psig)

SCALE NO.	PRESSURE DIFFERENCE	PRESSURE RANGE OF GRAPH	ONE-HALF INCH (10 DIVISIONS)	SMALL BLOCK
1	Less than 0.40	0.55	0.05	0.005
2	0.40 to 0.80	1.10	0.10	0.01
3	0.80 to 1.40	2.20	0.20	0.02
4	1.40 to 1.90	2.75	0.25	0.025
5	1.90 to 3.0	4.40	0.40	0.04
6	3.0 to 4.0	5.00	0.50	0.05
7	4.0 to 6.0	8.80	0.80	0.08
8	Over 6.0	11.00	1.00	0.10

3.08 Avoid using pressure or distance scales having fractional values per block, as they are difficult to use and may lead to inaccuracies in plotting.

3.09 If it is necessary to use a distance scale (Table B) greater than No. 8 because of the distance under study, it is recommended that pressure scales No. 6, 7, or 8 be used to avoid exaggerating small differences in pressure and permit easier evaluation of the gradient.

D. Selecting Distance Scale

3.10 The distance scale should be selected to fit the length of cable to be investigated. First, add the valve spacings to determine the total distance involved, and then select from Table B a scale which will provide sufficient range for this total distance. If the total distance falls between two of the suggested scales, use the scale which provides the greater total distance.

> ***Note:*** Normally, it should not be necessary to extend an aerial gradient beyond 3000 feet (generally, six valves at about 500-foot spacings). With valve spacing of 3000 feet on buried or underground cable, gradients normally should not extend beyond six valves or 20,000 feet.

TABLE B

DISTANCE SCALE

SCALE NO.	TOTAL DISTANCE RANGE OF GRAPH (FEET)	ONE-HALF INCH (10 DIVISIONS) (FEET)	SMALL BLOCK (FEET)
1	1,000	50	5
2	2,000	100	10
3	3,000	150	15
4	4,000	200	20
5	5,000	250	25
6	8,000	400	40
7	10,000	500	50
8	15,000	750	75
9	20,000	1,000	100
10	30,000	1,500	150
11	40,000	2,000	200
12	60,000	3,000	300

E. Selecting Pneumatic Resistance Scale

3.11 When the length of cable being investigated contains sections of cables having different sizes and gauges, use pneumatic resistance rather than feet of cable as the horizontal component of the gradient. The plotting of pressure against pneumatic resistance will eliminate changes in gradient slope that result where the cable size or gauge changes and pressure are plotted against feet. This method of plotting will accordingly simplify analysis of the gradient.

3.12 The pneumatic resistance scale (Table C) should be selected so the total pneumatic resistance of the cable being investigated can be accommodated. First, consider the size, gauge, and length of cables involved, and then from Table D (Paper or Pulp) or Table E (PIC), find the units of pneumatic resistance per 1000 feet for the different cables. Calculate the total units of pneumatic resistance. Select from Table C a scale which will provide sufficient range for the total units of pneumatic resistance.

3.13 To find the pneumatic resistance units between valve locations, refer to the example shown in Fig. 8 and proceed as follows:

The cable between P-15 and P-20 is a 500-foot length of 50-pair 22-gauge pulp-insulated cable with a pneumatic resistance of 15 units per 1000 feet. The pneumatic resistance units between P-15 and P-20 are found as follows:

$$(15 \div 1000) \times 500 = 7.5 \text{ units}$$

Follow this procedure for all cables involved.

TABLE C

PNEUMATIC RESISTANCE SCALE

SCALE NO.	TOTAL PNEUM. RES. OF GRAPH (UNITS)	ONE-HALF INCH (10 DIVISIONS) (UNITS)	SMALL BLOCK (UNITS)
1	20	1	0.1
2	40	2	0.2
3	60	3	0.3
4	80	4	0.4
5	100	5	0.5
6	120	6	0.6
7	140	7	0.7

4. PLOTTING GRADIENTS

4.01 Select the proper distance or pneumatic resistance scale and enter these values along the top of the graph. If pressure is plotted against distance, enter the distance for each block of 10 as indicated in Table B, then indicate the distance to the valve locations and the distances between valves. If pressure is plotted against pneumatic resistance, enter the pneumatic resistance between valves and the size, gauge, and length of cable(s) involved along the top portion of the graph. Light vertical lines drawn the full height of the graph at valve locations will simplify plotting pressure values.

4.02 Enter the marker, pole or manhole numbers of the valves, the pressure readings, and the corrected pressures across the top of the form, directly above each valve location.

4.03 Select the proper pressure scale and enter the pressure values along the left-hand side of the graph. The highest value to be plotted should be near the top of the graph in order to

TABLE D

PNEUMATIC RESISTANCE (R_T) PER 1000 FEET
(PAPER- OR PULP-INSULATED CABLE)

SIZE	GAUGE			
	19	22	24	26
11	20.0	50.0	60.0	90.0
16	15.0	40.0	50.0	80.0
25	10.0	25.0	40.0	50.0
50	6.0	15.0	20.0	40.0
75	4.0	10.0	16.0	25.0
100	3.0	7.5	13.0	20.0
150	2.0	5.0	10.0	15.0
200	1.5	4.0	8.0	11.5
300	1.0	3.0	5.0	7.5
400	0.8	2.0	4.0	6.0
450	0.7	1.8	—	—
600	—	1.5	2.5	4.5
900	—	1.0	1.9	3.0
1100	—	0.8	—	—
1200	—	0.7	1.5	2.2
1500	—	—	1.2	1.8
1800	—	—	0.9	1.6
2100	—	—	—	1.3
2400	—	—	—	1.0
2700	—	—	—	0.8
3000	—	—	0.7	9.0
3600	—	—	0.6	9.0

allow ample space for extending gradient lines and making a leak intersection on the graph below the lowest pressure value.

4.04 Plot pressure readings with a sharp, hard lead pencil, and mark the dot on the graph exactly at the intersection of pressure and distance or pneumatic resistance for each valve location. Encircle these dots to facilitate reference and connect them with accurately drawn straight lines.

TABLE E

PNEUMATIC RESISTANCE (R_T) PER 1000 FEET
(PIC – PLASTIC-INSULATED CONDUCTORS)

SIZE	GAUGE					
	17	19	20	22	24	26
6	—	6.0	—	—	—	—
11	—	3.2	—	12.0	26.0	51.0
16	—	2.2	—	8.2	17.0	33.0
25	0.4	1.4	2.3	5.1	11.0	22.0
50	0.2	0.7	1.1	2.4	5.1	11.0
75	0.1	0.5	0.8	1.6	3.4	7.4
100	0.1	0.4	0.6	1.2	2.5	5.5
150	0.1	0.3	0.4	0.8	1.7	3.7
200	0.1	0.2	0.3	0.6	1.2	2.7
300	0.1	0.1	0.2	0.4	0.8	1.8
400	—	—	0.1	0.3	0.6	1.4
600	—	—	0.1	0.2	0.4	0.8
900	—	—	—	—	0.3	0.6

4.05 The plotted gradient then should be analyzed for leak location, as described in Part 5.

5. ANALYSIS OF PRESSURE GRADIENTS

5.01 The analysis of pressure gradients requires a thorough knowledge of the cable plant, the conditions under which the tests were made, and the past maintenance history of the section of cable under test. Consideration also must be given to the approximate position of the leak relative to the ends of the cable section and the general shape of the pressure gradient for considerable distances on each side of the leak.

5.02 The procedure for analyzing a graph is the same for both large and small leaks. The location of a fault is indicated by the intersection of the projections of two straight-line gradients, each of which has been drawn through at least two, and preferably three, pressure readings on each side of the fault. If only two readings are used to determine the projection of a straight line, they should be no more than 500 feet apart.

5.03 If existing valves in a cable are spaced more than 500 feet apart, straight-line gradients should pass through at least three readings.

5.04 When analyzing pressure gradients, observe the following rules:

- If three pressure readings for a section of cable lie on the same straight line, the cable between the three valves should be considered as ***not containing a leak.***

- If the midpoint of three readings lies below a line joining the other two points, the length of cable between these two points should be considered as ***containing a leak.***

- If the midpoint of three readings lies above the line joining the other two points, the length of cable between these two points should be considered as having a ***restriction*** (see Fig. 6).

5.05 In analyzing gradients for underground or buried cable, the results should be verified by making computations as outlined in Part 6.

5.06 The procedures outlined in this part are based on the premise that pneumatic resistance rather than distance will be used as the horizontal component of gradients where the cable section under study is not of uniform size and gauge.

A. Typical Gradients

5.07 The examples of pressure gradient graphs given in this section are intended to illustrate the basic principles of gradient work. These examples are intended only as guides. In normal field operations, there will be cases where the faults will not be as evident as illustrated in these examples.

5.08 ***Example 1—Cable Leak—Pressure Plotted Against Distance—Cable of Uniform Size, Type, and Gauge:*** The gradient plotted in Fig. 3 shows the effect of a leak in the center portion of a cable section. On the left side of the low point, the gradient line connecting the plotted points at MH #65 an #70 is steeper in slope than that connecting the points at MH #60 and #65. On the right side of the low point, the line connecting the points at MH #70 and #75 has less slope than that connecting the points at MH #75 and #80. Therefore, the leak is between MH #70 and #75. Projections should be made as shown by the dashed lines. The indicated location of the leak is at the point of intersection of these dashed lines.

> ***Note:*** In the case of a leak which is at or very close to a valve point, the gradient lines connecting the low point to the adjacent points on either side are both steeper in slope than the gradient lines immediately beyond them, and projections to a point of intersection cannot be made.

5.09 ***Example 2—Cable Leak (Near End of Cable Section)—Pressure Plotted Against Distance—Cable of Uniform Size, Type, and Gauge:*** The gradient plotted in Fig. 4 indicates a leak that is very close to a plug. The lines that are to be projected can be found by observing on which side of the low point an irregularity in slope occurs.

5.10 If a leak is near the end of a single feed cable section, the pressure at the plug is practically the same as that at the leak, and the gradient has the general shape shown in Fig. 4. The slope of the gradient line joining the plotted pressures of the plug and the valve at MH #20 is less steep than that of the gradient line between MH #14 and #20. To locate the leak, a horizontal line is drawn through the plotted plug pressure and projected to its point of intersection, with a line drawn through the point at which the change to lesser slope occurs.

> ***Note:*** In the case of a leak which is at an end plug of a cable section and the line connecting the plotted pressures of the plug and the adjacent valve is steeper than the adjoining gradient line, projections to a point of intersection cannot be made.

5.11 ***Example 3—More Than One Cable Leak—Pressure Plotted Against Distance—Cable of Uniform Size, Type, and Gauge:*** The gradient plotted in Fig. 5 illustrates a length of cable with two leaks. Knowing that the slope of the gradient should increase as the leak is approached, the shape of the gradient indicates the existence of one leak between MH #17 and #29, and a second leak between MH #29 and #34. No leak intersection was obtained because of the influence of the second leak on the gradient.

AIR PRESSURE TESTING - GRAPH OF PRESSURE READINGS

Marker, Pole or M.H. No.	MH#4	MH#7	MH#14	MH#20	MH#26
Pressure As Read	7.42	7.39	7.33	7.23	7.17
Pressure Corrected	7.42	7.39	7.33	7.23	7.17

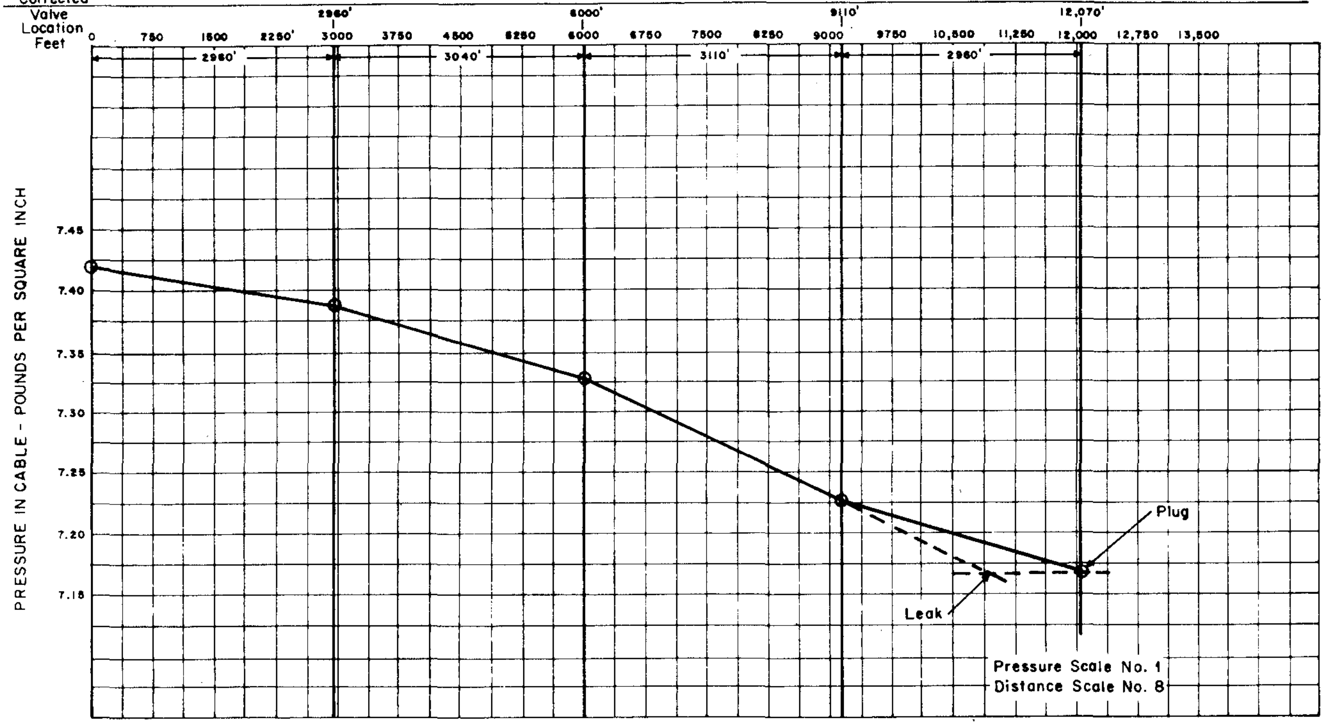


Fig. 4—Cable Leak Near End of Cable Section

AIR PRESSURE TESTING - GRAPH OF PRESSURE READINGS

Marker, Pole or M.H. No.	MH#7	MH#12	MH#17	MH#29	MH#34	MH#39	MH#45
Pressure: As Read	6.37	5.32	4.03	4.18	4.27	5.37	6.19
Pressure: Corrected	6.37	5.32	4.03	4.18	4.27	5.37	6.19
Valve Location Feet		3020'	6010'	9130'	12,005'	14,955'	17,965'

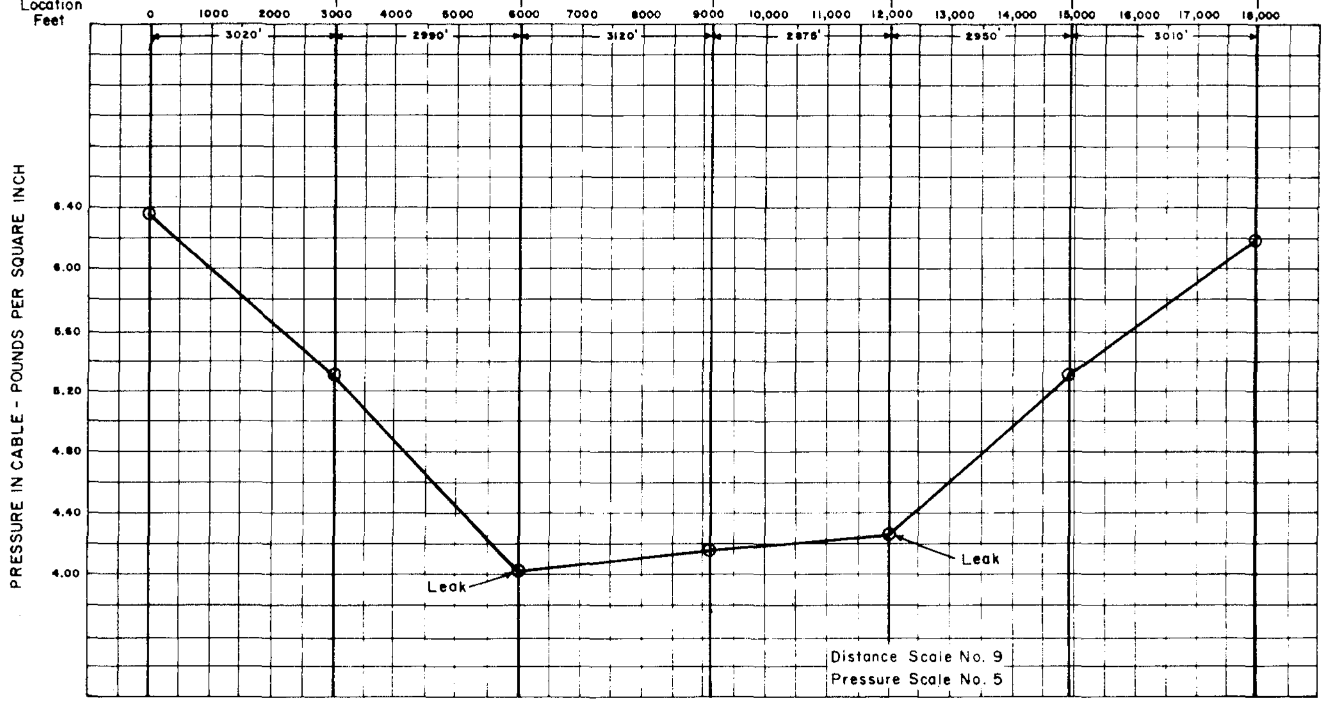


Fig. 5—More Than One Cable Leak

5.12 Where two leaks are relatively close together, the larger leak (the lowest point of intersection) should be located and repaired first. This will require the installation of additional valves in the section between MH #17 and #29 in order that the shape of the gradient adjacent to the leak can be definitely determined. After the first leak is repaired, the location of the second leak can be determined by another set of pressure measurements.

5.13 ***Example 4—Cable Restrictions:*** Two gradients are plotted in Fig. 6. The upper gradient shows the effect of a partial restriction. The lower gradient shows the effect of a complete restriction.

> *Note:* The pressure reading at the 1000-foot valve lies above a straight line joining the 500- and 1500-foot readings. This is a typical indication of a restriction (see 5.04).

5.14 The partial restriction that sometimes occurs at a paraffin-filled splice offers resistance to the flow of air through the splice, and there may be a considerable difference between the pressures on the two sides of the restriction. A pressure gradient graph showing such a condition is illustrated in Fig. 7.

5.15 The solid lines represent the pressure gradient as constructed from pressure measurements. The error in the leak location is due to a distortion in the graph because of a partial restriction in a splice between MH #11 and #14. This restriction obstructed the flow of air and held the pressure on the left side of the low point to a high value. Additional measurements taken on each side of the restriction indicated a difference in pressure of approximately 0.30 psi. The true pressure gradient has the shape of the dashed line shown on the graph.

5.16 ***Example 5—Cable Leak—Pressure Plotted Against Pneumatic Resistance—Size, Type, and Gauge of Cable Not Uniform:*** The gradient plotted in Fig. 8 indicates a leak between P-30 and P-35, approximately 66.5 units of pneumatic resistance beyond P-15 (or 66.5 − 47.5 = 19 units beyond P-30). To convert this resistance to distance beyond P-30, proceed as follows:

> Since a 25-pair 26-gauge pulp-insulated cable has a pneumatic resistance of 50 per 1000 feet, the length of cable required for a resistance of 19 units is (19 ÷ 50) × 1000, or 380 feet. The fault is therefore indicated at 380 feet beyond P-30.

5.17 For purposes of comparison, the same cable condition plotted in Fig. 8 has been illustrated again in Fig. 9 but, in this case, pressure is plotted against distance. The relative difficulty of analyzing this gradient as compared with the pneumatic resistance plot in Fig. 8 is typical of cases where the cable changes in size and gauge.

5.18 ***Example 6—Cable Leak—Pressure Plotted Against Distance—Zero Leak Projection—Effect of Auxiliary Source:*** The gradient plotted in Fig. 10 shows the typical effect of a zero leak and how the leak is located by making a zero projection (leak indicated 142 feet beyond P-10). The dashed line on the right side of the graph shows the effect on the gradient when an auxiliary pressure source (nitrogen cylinder) has been applied for leak locating purposes. In this case, the intersection of the projected solid and dashed lines also indicates the leak to be 142 feet beyond P-10.

6. COMPUTING LEAK LOCATION

6.01 Before excavating to clear leaks on buried and underground cables, arithmetical computations should be made to verify the accuracy of leak location obtained by plotting.

6.02 This method of computing the indicated location of a leak is used to eliminate inaccuracies in plotting the pressure gradient. This method does not compensate for errors in pressure readings or pressure disturbances caused by other than the leak.

> *Note:* Computation of a leak location should not be made without first plotting and analyzing the pressure gradient to determine the reliability of the pressure readings and the possible existence of disturbances or irregularities which may have distorted the leak gradient.

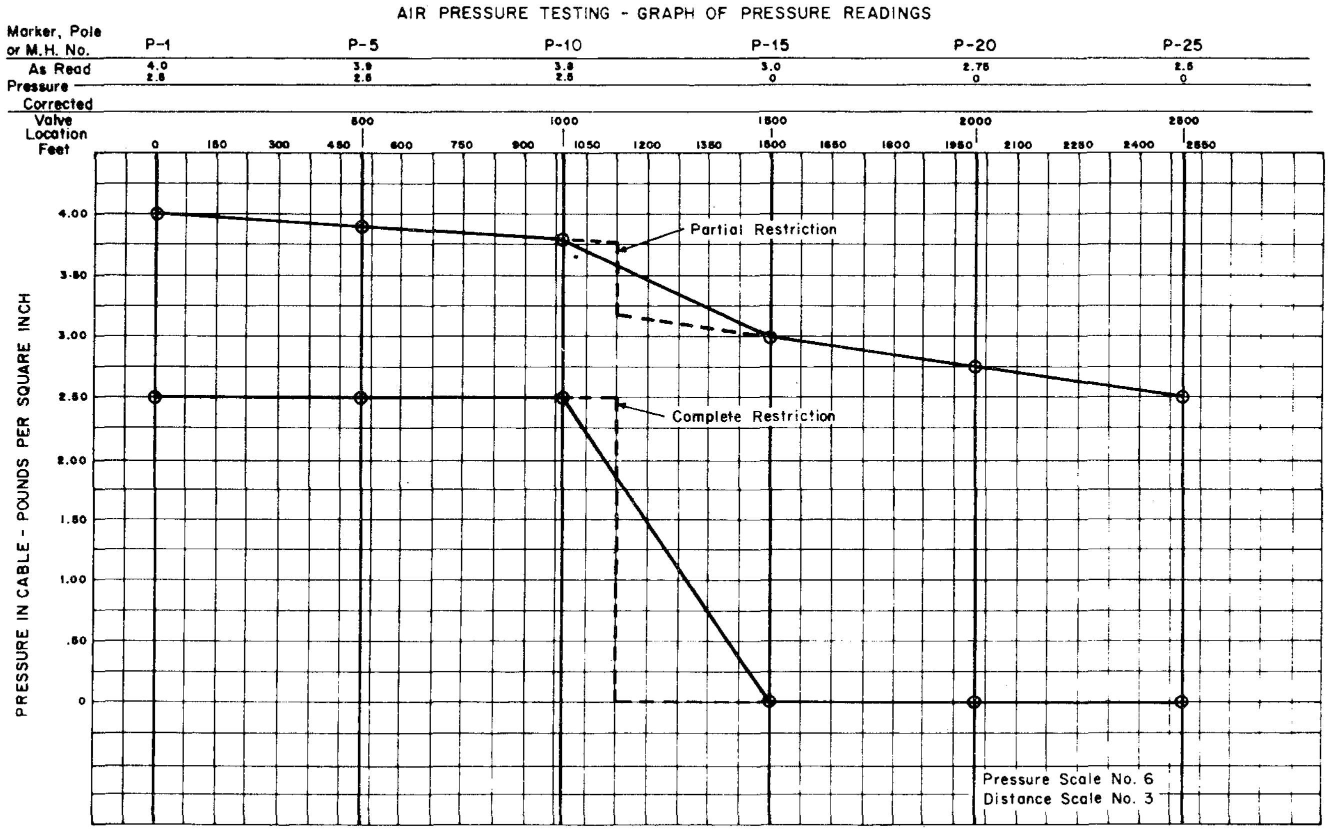


Fig. 6—Cable Restrictions

AIR PRESSURE TESTING - GRAPH OF PRESSURE READINGS

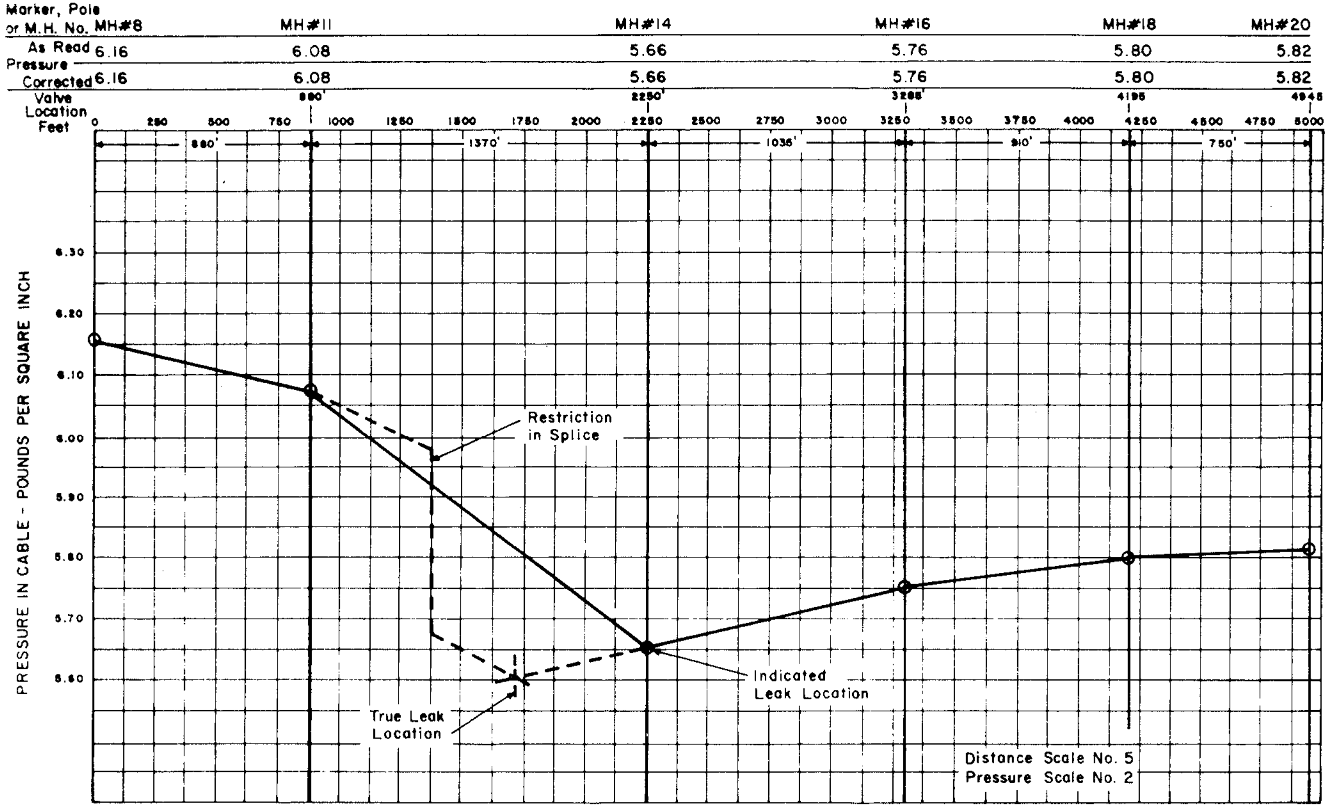


Fig. 7—Graph Distorted by Partial Restriction

AIR PRESSURE TESTING - GRAPH OF PRESSURE READINGS

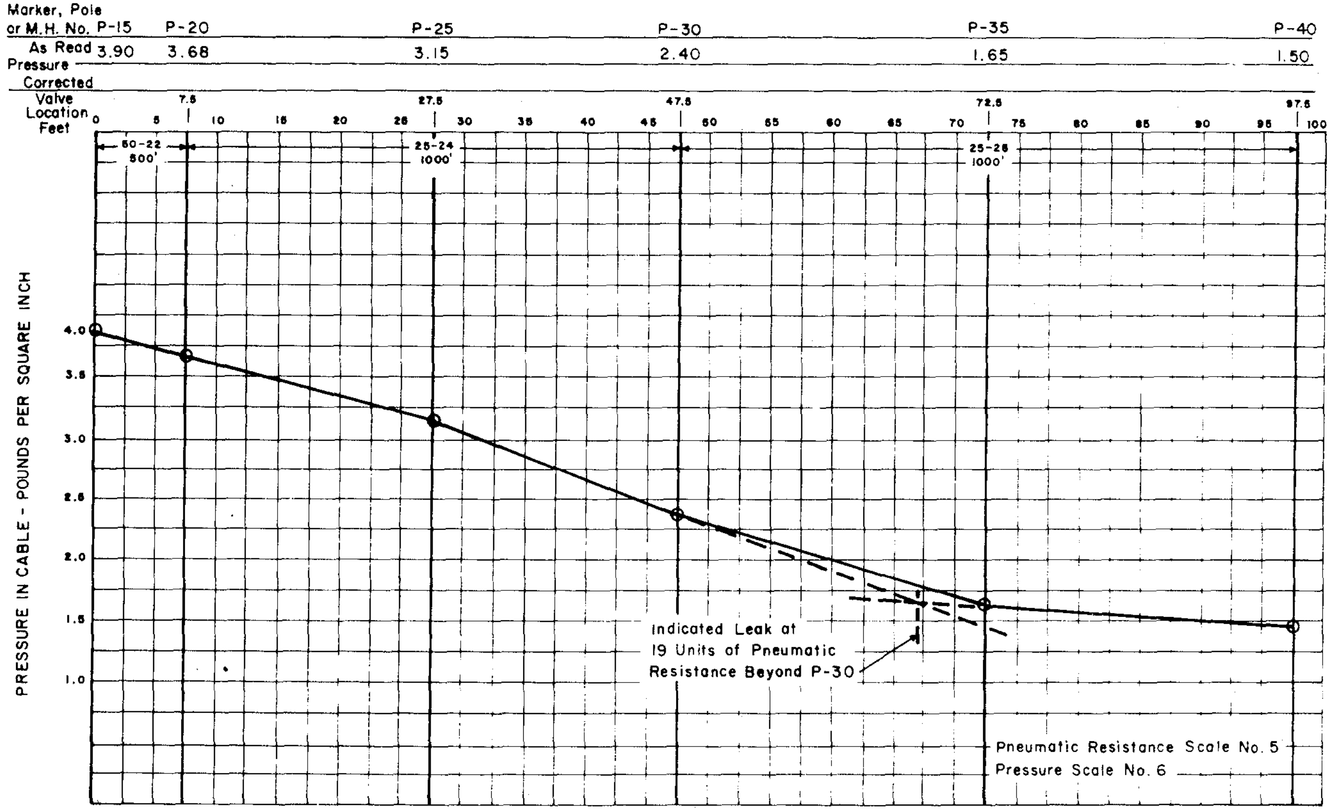


Fig. 8—Cable Leak (Pressure Plotted Against Pneumatic Resistance), Size, and Gauge of Cable Not Uniform

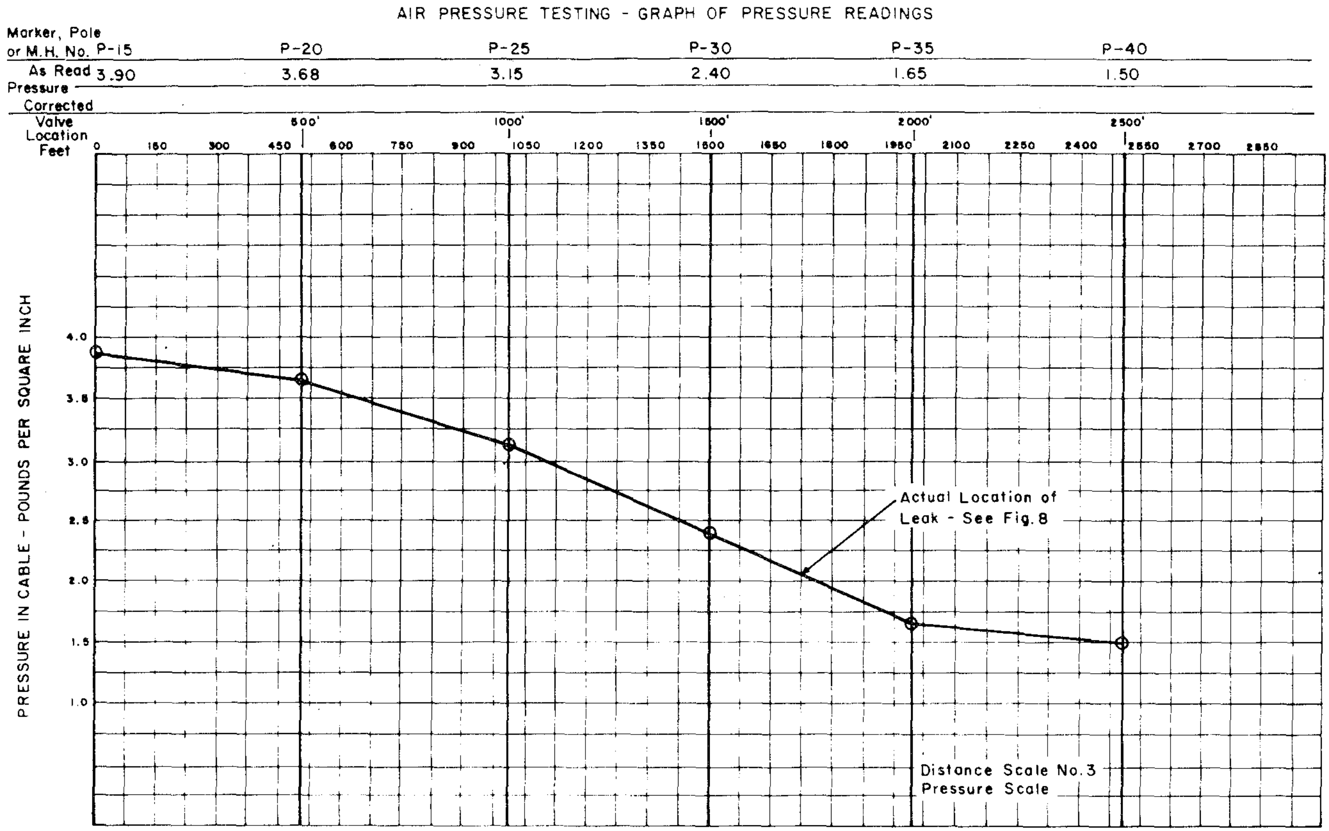


Fig. 9—Cable Leak (Pressure Plotted Against Distance), Size, and Gauge of Cable Not Uniform

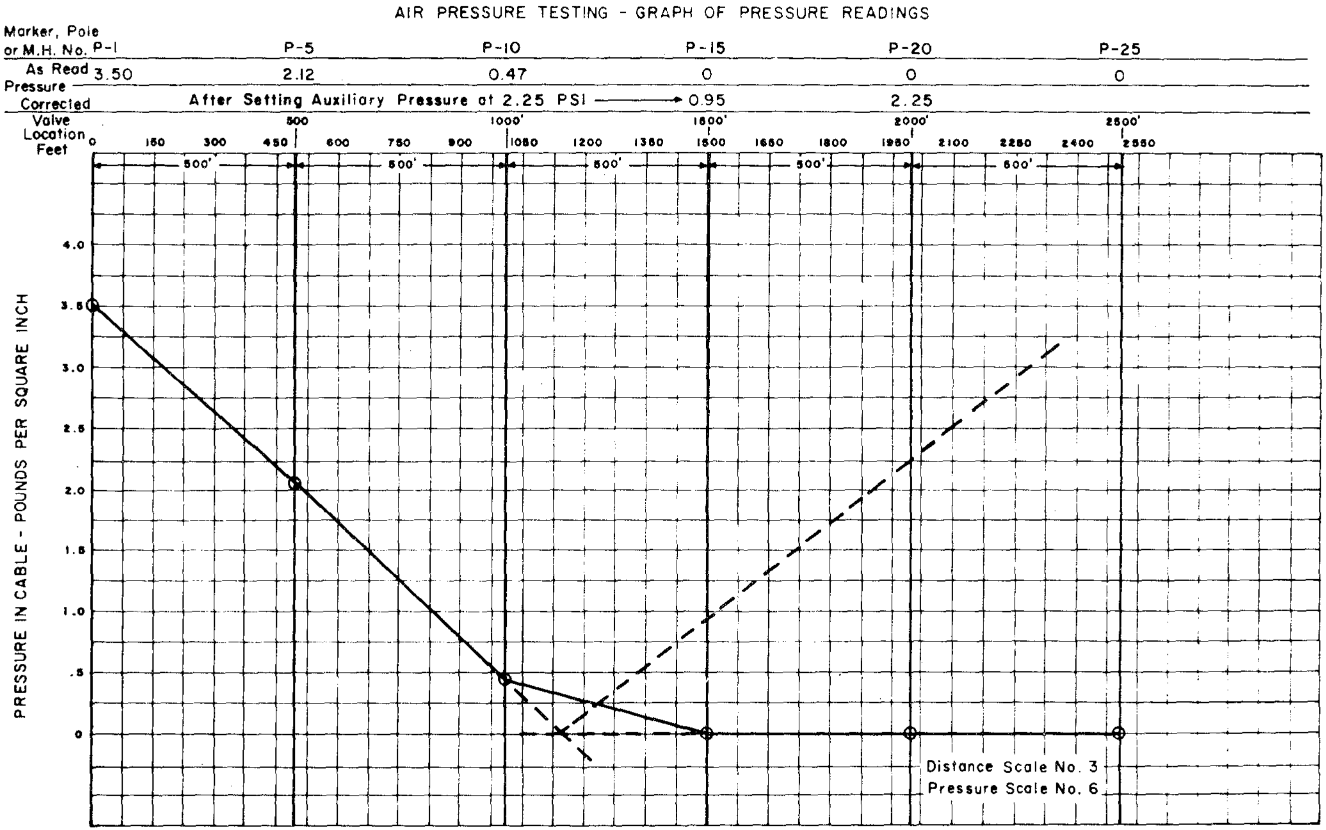


Fig. 10—Cable Leak (Zero Leak Projection)

6.03 An example of the computation for a leak is illustrated in Fig. 11. A typical work sheet that can be used to accomplish this by filling in the blank spaces and completing the indicated computations is furnished in Fig. 12.

1. DISTANCES:
   - A = V1 TO V2 = 610 FT.
   - B = V2 TO V3 = 622 FT.
   - C = V3 TO V4 = 594 FT.

2. PRESSURE READINGS:
   - V1 = 8.39 PSI
   - V2 = 8.19 PSI
   - V3 = 8.14 PSI
   - V4 = 8.33 PSI

3. PRESSURE DIFFERENCES:
   - X = V1-V2 = .20 PSI
   - Y = V3-V2 = .05 PSI
   - Z = V4-V3 = .19 PSI

4. FORMULA:

$$D = \frac{A(BZ \pm CY)}{CX + AZ}$$

WHERE D IS THE DISTANCE FROM V2 TO THE LEAK *

5. COMPUTATION:

BZ	= (B)	622	X (Z)	.19	= 118.2	(1)
CY	= (C)	594	X (Y)	.05	= 29.7	(2)
BZ + CY**	= (1)	118.2	+ (2)	29.7	= 147.9	(3)
A(BZ + CY)**	= (A)	610	X (3)	147.9	= 90,219.0	(4)
CX	= (C)	594	X (X)	.20	= 118.8	(5)
AZ	= (A)	610	X (Z)	.19	= 115.9	(6)
CX + AZ	= (5)	118.8	+ (6)	115.9	= 234.7	(7)
D	= (4)	90,219.0	+ (7)	234.7	= 384	

LEAK IS AT DISTANCE "D" BEYOND V2

NOTES:

* WHEN V2 IS GREATER THAN V3, CY IS POSITIVE. WHEN V2 IS LESS THAN V3, CY IS NEGATIVE.

** SUBTRACT INSTEAD OF ADDING CY WHEN V2 IS LESS THAN V3.

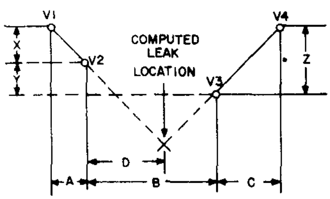


Fig. 11—Example of Computed Leak Location

7. LEAK LOCATION METHODS

7.01 The pressure sources referred to herein are air dryers, nitrogen cylinders, or air pipe manifolds.

7.02 The use of the one- or two-source method is generally sufficient for leak locating purposes. However, if pressure readings for plotting gradient must be taken during unstable pressure conditions within the cable, the use of time pressure curves and the two-direction method, as described in Part 8, may be employed.

1. DISTANCES:
   - A = V1 TO V2 = ______ FT.
   - B = V2 TO V3 = ______ FT.
   - C = V3 TO V4 = ______ FT.

2. PRESSURE READINGS:
   - V1 = ______ PSI
   - V2 = ______ PSI
   - V3 = ______ PSI
   - V4 = ______ PSI

3. PRESSURE DIFFERENCES:
   - X = V1-V2 = ______ PSI
   - Y = V3-V2 = ______ PSI
   - Z = V4-V3 = ______ PSI

4. FORMULA:

$$D = \frac{A(BZ \pm CY)}{CX + AZ}$$

WHERE D IS THE DISTANCE FROM V2 TO THE LEAK *

5. COMPUTATION:

BZ	= (B)	______	X (Z)	______	= ______	(1)
CY	= (C)	______	X (Y)	______	= ______	(2)
BZ + CY**	= (1)	______	+ (2)	______	= ______	(3)
A(BZ+CY)**	= (A)	______	X (3)	______	= ______	(4)
CX	= (C)	______	X (X)	______	= ______	(5)
AZ	= (A)	______	X (Z)	______	= ______	(6)
CX + AZ	= (5)	______	+ (6)	______	= ______	(7)
D	= (4)	______	+ (7)	______	= ______	

LEAK IS AT DISTANCE "D" BEYOND V2

NOTES:

* WHEN V2 IS GREATER THAN V3, CY IS POSITIVE. WHEN V2 IS LESS THAN V3, CY IS NEGATIVE.

** SUBTRACT INSTEAD OF ADDING CY WHEN V2 IS LESS THAN V3.

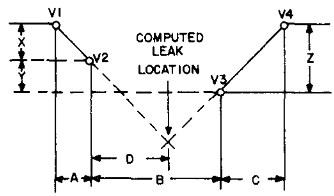


Fig. 12—Computation of Leak Location (Work Sheet)

ONE- AND TWO-SOURCE METHODS

7.03 The one- and two-source methods are applicable in the final location of a leak in underground and buried cable. These methods provide a means of stabilizing the pressure so that the pressure readings at various points in the section of cable under test will become constant and the shape of the gradient will not change.

A. Application

7.04 The use of the one- or two-source method is of particular advantage under the following conditions:

- ***Where the existing cable pressure is low and it is necessary to increase the cable to protect service:*** By connecting a pressure source to the cable on one side (one-source method) or on each side (two-source method) of the suspected leak location, the work of finding the leak can continue, and at the same time protection will be given to service.

- ***In the location of a leak having a relatively flat gradient slope:*** By applying a pressure source to the cable at approximately 10 pounds pressure, the pressure in the cable is maintained at a high level at points close to the leak. This increases the escape of air or gas through the leak and steepens the gradient slope, which permits a more accurate leak location to be obtained.

- ***Where there is more than one leak in the section of cable under test:*** By locating the pressure source so that the section of cable contains only one known leak between sources or between source and the end point, the effect of the other leaks on the gradient is eliminated.

B. Procedure for Making Tests

7.05 Except for the first condition in 7.04, the one- or two-source methods should not be employed without first taking a preliminary set of pressure readings to obtain an approximate location of the leak. Temporary close-spaced valves then should be installed (if necessary) to obtain two, and preferably three, evenly spaced reading points on the side of the leak away from the end of the section being investigated (one-source method) or on both sides of the leak (two-source method). The distance between the leak and the point(s) at which the pressure source is connected should not be any greater than necessary to obtain suitable reading points.

> ***Note:*** At least one reading point is required between the leak and the end of the section if the one-source method is used.

7.06 Two valves are required at each pressure souce location. One valve is used for connecting the pressure source. The second valve should be located on the cable 1 to 2 feet on the leak side of the pressure souce valve. This second valve is used to check the charging pressure and also as one of the pressure reading points for the leak location measurements.

7.07 Adjust the pressure source output to at least 1/2 pound higher than the highest pressure existing in the cable section. This is necessary in order to assure that the regulated pressure at the source(s) and the rate of flow to the leak can be maintained at a constant value during the test.

> ***Note:*** It is recommended that the source pressure be regulated at approximately 10 psi to ensure steep gradients and a more accurate leak location.

7.08 Minor adjustment of the source regulator may be necessary after 5 or 10 minutes of flow to obtain the desired charging pressure. ***Do not change the regulator setting thereafter, as this would disturb the flow and delay stabilization of the leak gradient.***

7.09 The time required to reach a stable condition between the source and the end of the cable section or between sources will vary from 1/2 to 1 hour for each 1000 feet of cable under test.

7.10 To ensure that the cable section is stable when the one-source method is used, first take a set of pressure readings at valve points between the source and the end of the section and a second set of readings between the end of the section and the source. When the two-source method is used, first take a set of pressure readings at valve points between the pressure sources in one direction, and a second set of readings in the reverse direction. If the pressure at any valve differs by more than 0.02 pound between the first and second readings, it is an indication that one of the readings is in error or that the section has not become stabilized, and a new series of readings should be made.

7.11 After the cable section becomes stable, prepare a leak location graph, as described in Part 3.

C. Example of One-Source Method

7.12 The following is an example of the one-source method for the location of a leak in an underground conduit section adjacent to a plug.

7.13 A pressure source was connected at MH #37 at a charging pressure of 8.70 pounds. The pressure was read at intervals at MH #40 at the end of the section until a stable condition was indicated by the 1:10 PM reading, as shown in Fig. 13. Pressure measurements then were obtained at all valve points, as described in 7.10.

7.14 Figure 14 is the leak location gradient plotted from the readings shown in Fig. 13. The indicated leak location is at the intersection of the extension of a straight line connecting the measured pressures at MH #38 and #39, with a horizontal straight line drawn through the measured pressure at #40.

D. Example of Two-Source Method

7.15 The following is an example of application of the two-source method of leak location.

TIME OF READING	VALVE LOCATIONS			
	MH #37	MH #38	MH #39	MH #40
9:20 AM	8.70			
9:40 AM				6.23
9:50 AM	8.70			
11:30 AM				7.97
12:00 N				7.97
1:10 PM				7.97
1:20 PM	8.70			
1:30 PM		8.37		
1:40 PM			8.05	
1:50 PM				7.97
2:00 PM			8.05	
2:10 PM		8.37		
2:20 PM	8.70			

Fig. 13—One-Cylinder Method (Data Sheet)

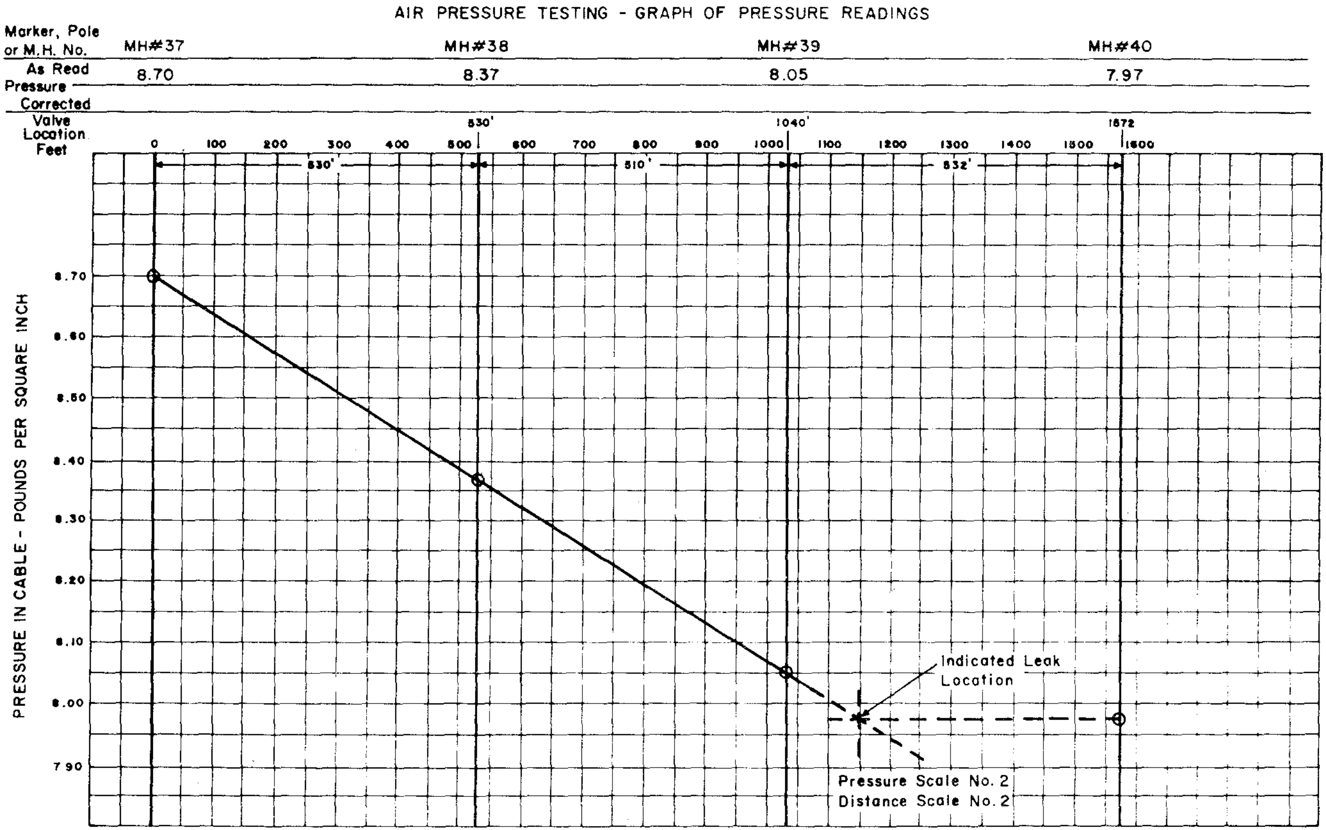


Fig. 14—One-Cylinder Method (Leak Location Gradient)

7.16 Two sources were connected at P #1 and P #6, with a charging pressure of 8.00 pounds. The pressure was read at intervals at P #3 near the midpoint of the section until a stable condition was indicated by the 2:00 PM reading, as shown in Fig. 15. Pressure measurements then were obtained at all valve points, as described in 7.10.

7.17 Figure 16 is the leak location gradient plotted from the readings shown in Fig. 15.

8. OTHER LEAK LOCATION METHODS

TIME-PRESSURE CURVES

8.01 Time-pressure curves provide an accurate method of correcting for the changes in cable pressure during the interval of time required to take a set of pressure readings for leak location purposes.

TIME OF READING	VALVE LOCATIONS					
	P #1	P #2	P #3	P #4	P # 5	P #6
11:10 AM	8.00					
11:20 AM						8.05
11:45 AM			7.26			
12:10 PM			7.45			
1:15 PM			7.47			
2:00 PM			7.47			
2:10 PM	8.00					
2:20 PM		7.74				
2:25 PM			7.47			
2:30 PM				7.44		
2:40 PM					7.73	
2:50 PM						8.05
3:00 PM					7.73	
3:10 PM				7.44		
3:15 PM			7.47			
3:20 PM		7.74				
3:30 PM	8.00					

Fig. 15—Two-Cylinder Method (Data Sheet)

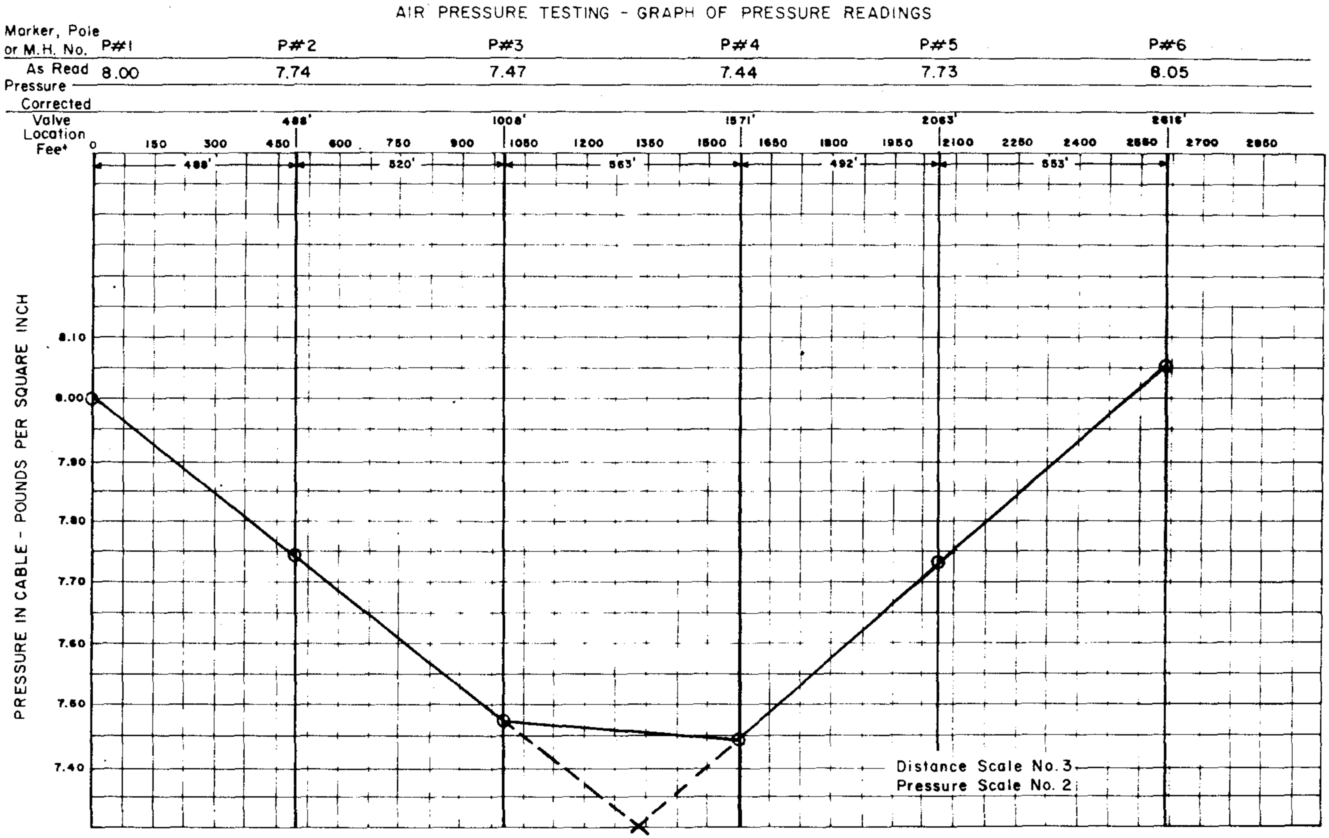


Fig. 16—Two-Cylinder Method (Leak Location Gradient)

8.02 Time-pressure curves require an elaborate measuring procedure initially; however, verified measurements are obtained, and the behavior of the gradient over a period of time is known. This reduces the number of unknown factors that must be considered in analyzing the possible causes of irregularities in the shape of the gradient.

A. Procedures for Making Test

8.03 The time-pressure curves method should not be employed without first taking a preliminary set of pressure readings to obtain an approximate location of the leak. Temporary close-spaced valves then should be installed so as to obtain three evenly spaced valve points on each side of the leak.

8.04 If the preliminary measurements indicate that the cable pressure is low, the cable should be charged to a higher value, using either of the methods described in Part 7.

8.05 The procedures for making the test are as follows:

(a) Starting at the first valve point on one side of the leak, measure the pressure at each valve to the first valve point on the other side of the leak. Record the time of each measurement to the nearest minute. Repeat the measurement three times so as to obtain four sets of readings, as shown in Fig. 17. The direction of travel along the cable should be the same for each set of readings.

(b) Plot the measurements on Form E-1017 or similar graph paper, using the horizontal scale to plot time in minutes. A convenient time scale is obtained by allowing 10 minutes for each 1/2-inch block (see Fig. 18).

(c) Plot the pressure valves for each valve separately and connect the four points with straight lines before proceeding with the next valve. The result will be a series of curves showing the variation of pressure with time for each valve point, as shown in Fig. 18.

VALVE NO. 1		VALVE NO. 2		VALVE NO. 3	
TIME (PM)	PRESSURE (PSI)	TIME (PM)	PRESSURE (PSI)	TIME (PM)	PRESSURE (PSI)
1:00	7.83	1:08	7.62	1:16	7.29
2:00	7.69	2:08	7.48	2:16	7.15
3:00	7.55	3:09	7.34	3:18	7.01
4:04	7.41	4:13	7.20	4:23	6.87
VALVE NO. 4		**VALVE NO. 5**		**VALVE NO. 6**	
TIME (PM)	PRESSURE (PSI)	TIME (PM)	PRESSURE (PSI)	TIME (PM)	PRESSURE (PSI)
1:26	7.23	1:35	7.50	1:42	7.68
2:26	7.09	2:34	7.36	2:43	7.54
3:27	6.95	3:37	7.22	3:46	7.40
4:32	6.81	4:44	7.08	4:50	7.26

Fig. 17—Data Sheet (Time-Pressure Curves)

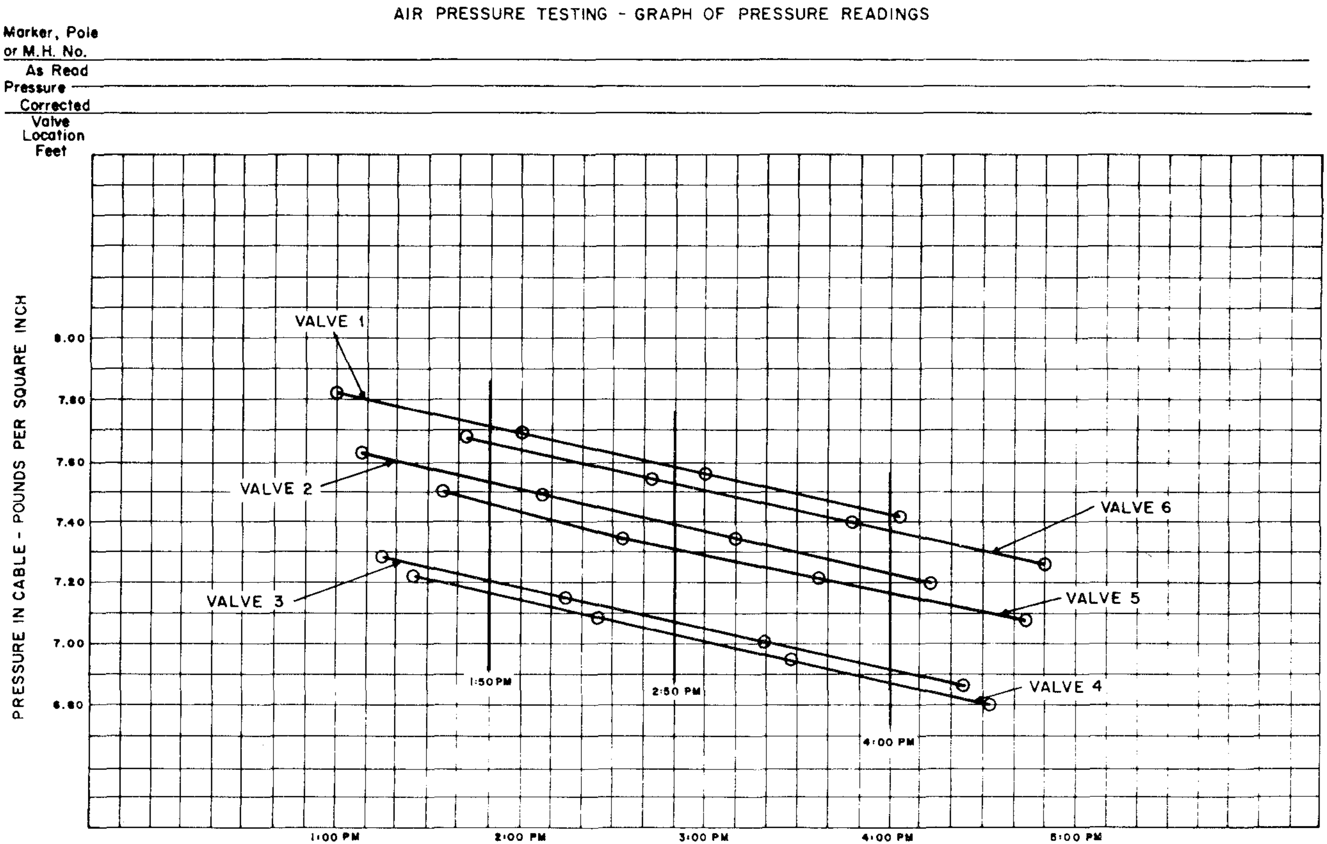


Fig. 18—Time-Pressure Curves

Note: Lack of parallelism or other irregularities in the time-pressure curves is an indication of temperature changes, leaky connections, unequalized pressure, or other disturbances in the pressure gradient. In this case, the cause of the irregularity should be determined and Steps (a) through (c) repeated. If the leak is very small, there may be no measurable decrease in pressure during the time required to take the four sets of readings. In this case, the time-pressure curves will be horizontal straight lines which will nevertheless be helpful in verifying the accuracy dependability of the measurements.

(d) If the time-pressure curves appear consistent, select a time when the curves are parallel and draw a vertical line on the time-pressure curves graph, as shown in Fig. 18. Repeat this procedure for two other selected times.

(e) Pick off and record the pressure values for each valve for the times selected in Step (d), as shown in Fig. 19.

(f) Plot a leak location graph (Fig. 20) from the values listed in Fig. 19. The indicated leak location will be the average of the leak intersections obtained from these gradients.

VALVE NUMBER	PRESSURE VALUES		
	1:50 PM	2:50 PM	4:00 PM
1	7.71	7.58	7.42
2	7.52	7.38	7.23
3	7.21	7.07	6.92
4	7.17	7.03	6.88
5	7.46	7.32	7.17
6	7.66	7.52	7.37

Fig. 19—Pressure Values From Time-Pressure Curves

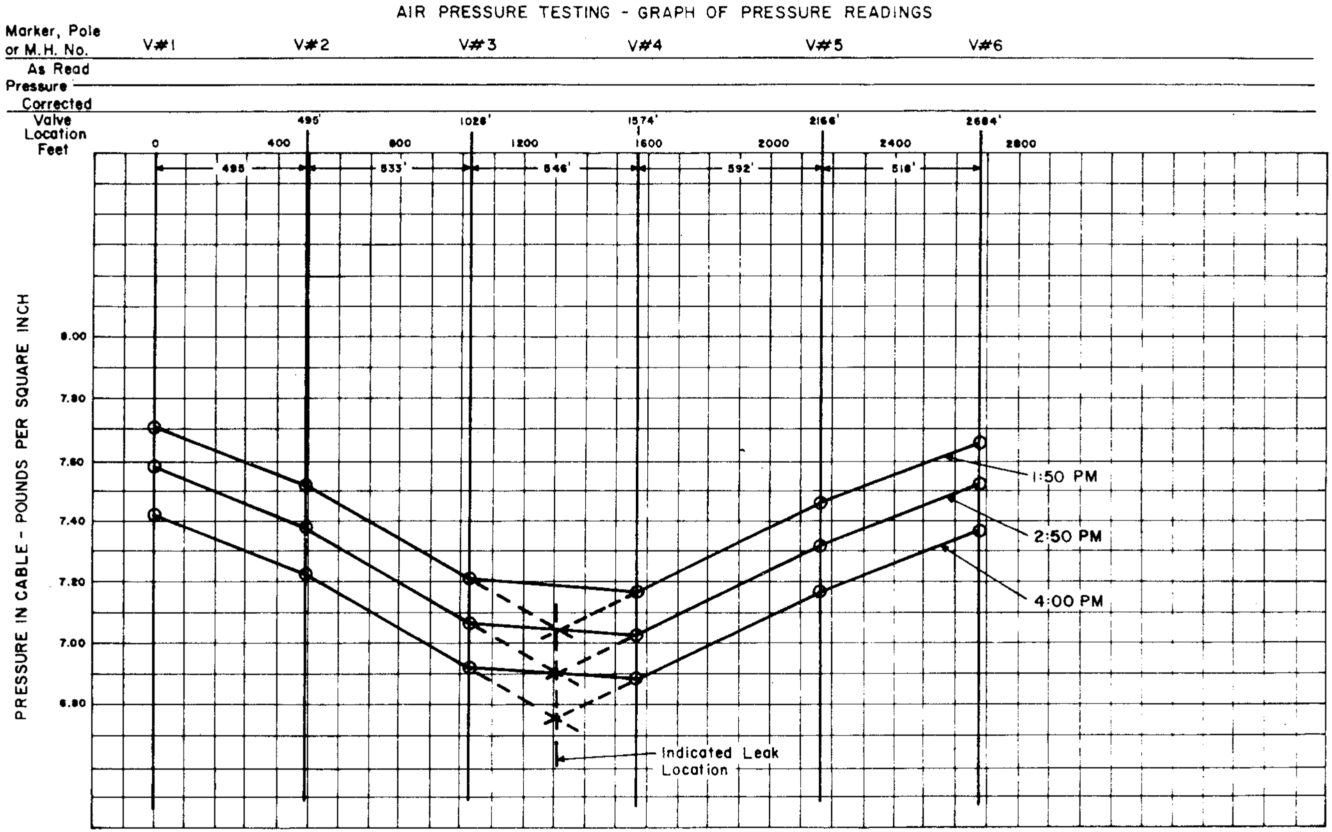


Fig. 20—Leak Location Gradients

TWO-DIRECTION METHOD

8.06 The two-direction method provides an approximate correction for the changes in cable pressure during the interval of time required to take a set of pressure readings for leak location purposes.

A. Procedures for Making Test

8.07 The procedures for making the test are as follows:

(a) Select for the pressure measurements not less than three valve points on each side of the suspected leak location.

(b) Starting on one side of the leak, read and record the pressure along the cable at the selected points on each side of the leak. Record time of each reading, allowing sufficient time between readings to assure being able to take the measurements in the same interval of time on the return trip.

(c) Upon reading the farthest valve, immediately start on the return trip, reading and recording all valves in reverse order. Allow the same interval of time between consecutive readings as required on the first trip.

(d) Average the two readings at each valve and prepare a leak location graph, as described in Part 4, using these average values.

8.08 An example of the Two-Direction Method Data Sheet is illustrated in Fig. 21.

VALVE NUMBER	INTERVAL BETWEEN READINGS (MIN)	FIRST SET OF READINGS		SECOND SET OF READINGS		AVG PRESSURE VALUES TO BE PLOTTED (SEE NOTE)
		TIME (PM)	PRESSURE (PSI)	TIME (PM)	PRESSURE (PSI)	
1	—	1:00	6.56	2:50	6.48	6.52
2	15	1:15	6.52	2:35	6.46	6.49
3	10	1:25	6.47	2:25	6.43	6.45
4	15	1:40	6.45	2:10	6.43	6.44
5	5	1:45	6.49	2:05	6.47	6.48
6	10	1:55	6.52	—	—	6.52

Note: Leak location graph is prepared from the average pressure values shown in this column.

Fig. 21—Data Sheet (Two-Direction Method)