Strength Requirements for Round Conduit

By G. F. WEISSMANN

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Underground conduits are subjected to external loads caused by the weight of the backfill material and by loads applied at the surface of the fill. These external loads will produce circumferential bending moments in the conduit wall. The magnitude and distribution of the bending moments have been determined by measurements of the circumferential fiber strains in thin-walled metal tubes subjected to the external loads. The effects of different backfill materials, different trench width, and trench depth have been investigated. Bending moments caused by static and dynamic loads have been compared. The bending moments are finally expressed in terms of the required crushing strength.

INTRODUCTION

For many years, vitrified clay has been the principal material for underground conduit used as cable duct by the Bell System. Vitrified clay conduit has, in general, given excellent service. It has more than adequate strength and durability for the wide variety of conditions under which it must be used and for the long service life expected of it. For this reason, relatively little attention has been given to the formulation of special strength requirements for this type of conduit during the period in which it has been standard for Bell System use.

For some time other types of conduit, mainly in the form of single duct, have appeared on the market. Many of their properties make them attractive enough to be considered for Bell System use. However, to prevent possible failure or excessive deformation of the conduit under field conditions each type of conduit should meet minimum strength requirements, in order to provide the same reliable service that clay conduit has given. The main purpose of this investigation was to determine the minimum strength requirement for round conduit under various field conditions.

An extensive investigation of the effects of external loads on closed conduits has been conducted at the Iowa Engineering Experiment Station.[1,2] However, due to the large diameters of the conduits used and the particular test conditions employed, the test results obtained were not directly applicable for the determination of strength requirements for conduits for the Bell System.

Underground conduits under service conditions are subjected to external loads. These external loads are caused by:

a. The weight of the backfill material.

b. The loads applied at the surface of the fill.

The magnitude and distribution of the external loads around the conduit are affected by:

1. The properties of the backfill material.
2. The magnitude of the applied load at the surface of the fill.
3. The height of the backfill over the conduit.
4. The trench width.
5. The bedding condition.
6. The diameter of the conduit.
7. The flexibility of the conduit.
8. Impact.
9. Arrangements of conduits in the trench.
10. Consolidation and compaction of the backfill material.
11. Auxiliary protection of the conduit.

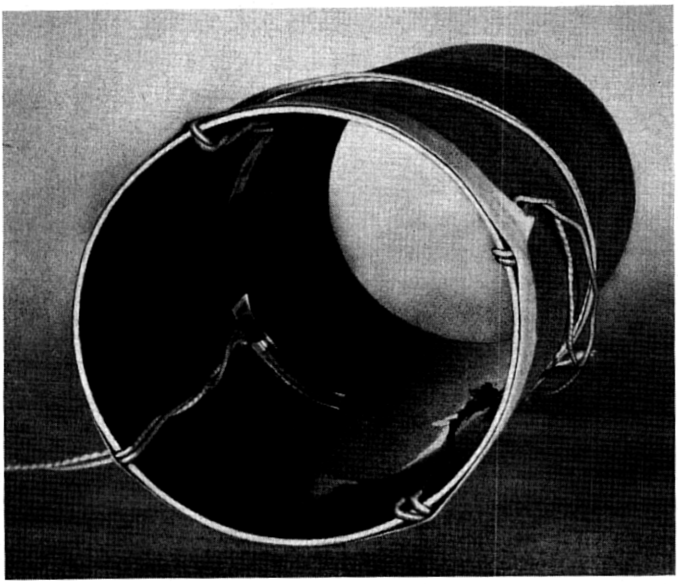

Fig. 1 — Thin-walled tube with SR-4 strain gages.

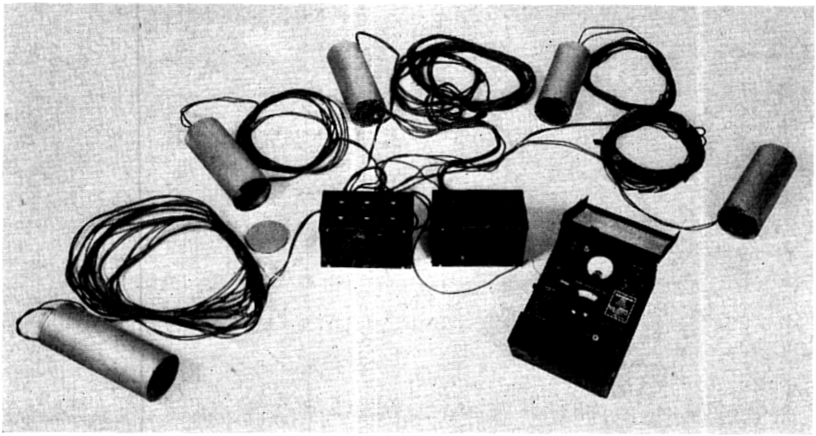

Fig. 2 — Test set.

External loads acting upon the conduit produce circumferential bending moments in the conduit wall. The magnitude and distribution of these bending moments have been determined in tests conducted recently at the Outside Plant Development Laboratory, Chester, New Jersey, and at Atlanta, Georgia. These tests were made with gravel, sand, and clay as backfill, in trenches of various width and depth and under conditions simulating, as nearly as possible, those encountered in the field.

TEST APPARATUS AND PROCEDURE

A test method was developed which permitted the determination of the circumferential bending moments in thin-walled conduits under field conditions.

The test device consisted of thin-walled aluminum or steel tubes of one foot length. The steel tubes used had an outside diameter of 4 inches and a wall thickness of 0.062 inches; the aluminum tubes had an outside diameter of 4.5 inches and a wall thickness of 0.065 inches. SR-4 strain gages were attached to the inside surface of the tube. Each tube was equipped with four equispaced SR-4 strain gages (type A-5), (Fig. 1). One aluminum tube contained, in addition, sixteen SR-4 strain gages (type A-8), which were equally distributed around the internal circumference of the tube. By means of an SR-4 strain indicator and an Edin brush recorder it is possible to measure the strains caused by static, as well as by dynamic loads. The strains could be measured with an accuracy of $\pm 10 \times 10^{-6}$ inch per inch.

TABLE I — LIST OF TESTS AND TEST CONDITIONS

Undisturbed Soil	Backfill Material	Height of Cover	Trench Width	Applied Load	Test Tube
A — Field Tests					
		(inches)	(inches)	(lbs)	
Georgia Clay	Clay	24, 30, 36, 42, 48	18, 22, 30	2250–8500	Aluminum Tube
Georgia Clay	Fine Sand	24, 30, 36, 42, 48	18, 22, 30	2250–8500	Aluminum Tube
Georgia Clay	Clay	24, 30, 36	22	500 lb (dropped 5 and 3 feet)	Aluminum Tube
Georgia Clay	Fine Sand	24, 30, 36	22	500 lb (dropped 5 and 3 feet)	Aluminum Tube
Chester Soil	Clay	18, 24, 30, 36	5	1275–7775	Aluminum Tube
Chester Soil	Fine Sand	18, 24, 30, 36	5	1275–7775	Aluminum Tube
Chester Soil	Fine Sand	24, 30, 36, 40, 48	24	1000–10175	Steel Tube
Chester Soil	$\frac{3}{4}$ in. gravel	24, 30, 36, 40, 48	24	1000–10175	Steel Tube
B — Laboratory Tests					
1. Two-point load					
2. Investigation of bedding					

The test equipment used is shown in Fig. 2. Each tube was laid lengthwise on the trench bottom between two pieces of plastic conduit of the same outside diameter. The tubes were oriented so that one of the strain gages was at the top of each tube. The trench was then filled with the backfill material. The loads at the surface of the fill were applied by using trucks with various measured wheel loads. The trucks were either moved slowly to a stop in position over each tube, or driven at moderate speed across the trench. Additional impact tests were made with a Hydrahammer, which consists of a 500-pound-weight dropped from different heights onto the surface of the fill. Each tube was subjected,

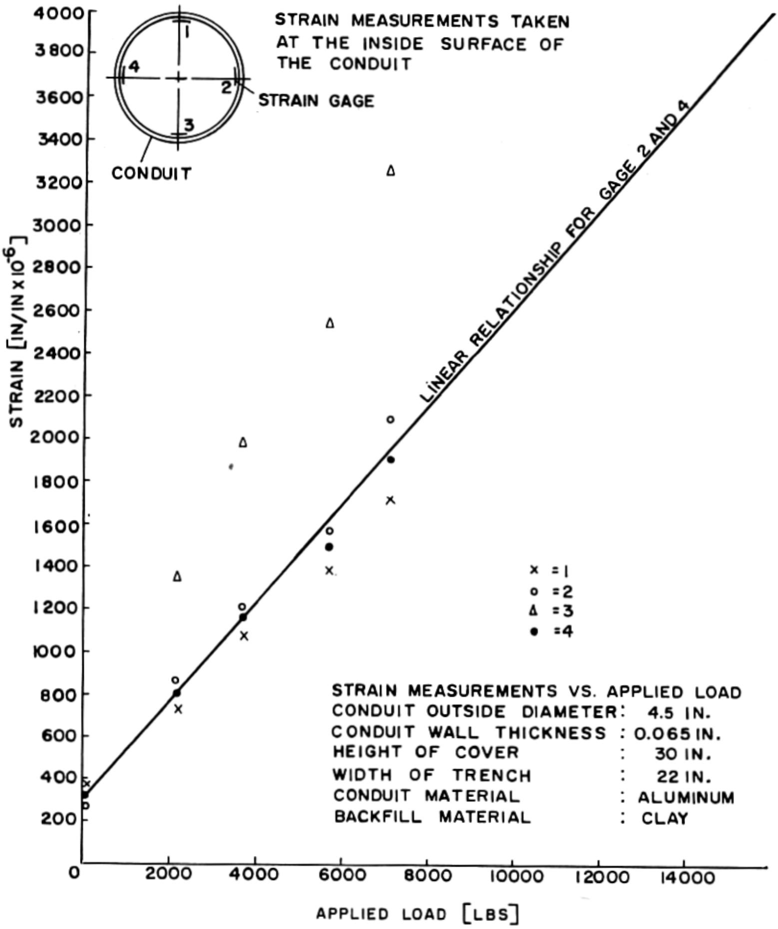

Fig. 3 — Strain measurements versus applied load.

in the laboratory, to various two-point loads (two edge bearing loads). Strain readings were taken during each test.

Table I lists the tests conducted and the test conditions investigated.

TEST RESULTS

Field and laboratory measurements obtained from each strain gage were plotted as a function of the applied load. A typical example for a field measurement is shown in Fig. 3. For this example, as well as for several hundreds of similar measurements, a linear relationship between the measured strains and the applied loads could be observed. For each case this linear relationship was derived from the data using the method of least squares. The straight line in Fig. 3 was plotted by this method and is shown with the data obtained in the test.

MOMENT DISTRIBUTION

Soil pressure acting upon a thin-walled tube will cause circumferential forces and bending moments in the wall of the tube. Furthermore, it is assumed that the strains caused by the compressive forces are small compared with those caused by the circumferential bending moments and are therefore neglected. For pure bending, the following relationship for circumferential bending moments and fibre strains is established.

$$M = \frac{1}{6} h^2 E\epsilon \tag{1}$$

where

M = circumferential bending moment per unit length (in lb/in)
h = wall thickness of tube (in)
E = modulus of elasticity (psi)
ϵ = circumferential fibre strains (in/in)

The circumferential bending moment of a thin-walled tube of unit length subjected to a two-point load is determined analytically:

$$M = \frac{Fr}{2}\left(\frac{2}{\pi} - \sin\theta\right) \tag{2}$$

where

M = circumferential bending moment per unit length (in lb/in)
F = applied two-point load (lb/in)
r = radius of the tube (in)
θ = angle with vertical axis of tube

The calculated circumferential bending moments (2) and those determined by strain measurements and Equation (1) are compared in Fig. 4. The agreement is very close.

Fig. 5 shows the theoretical moment distribution in a thin-walled tube subjected to a uniformly distributed vertical pressure; Fig. 6 is the theoretical moment distribution in the same tube subjected to a uniformly distributed vertical pressure at the top of the tube and a point load at the bottom of the tube.

Fig. 7 shows the typical experimental moment distribution in a thin-walled tube in an 18-inch wide and 40-inch deep trench with a backfill (36-inch cover) of moist Georgia clay subjected to an applied surface load of 10,000 lb. Fig. 8 shows the moment distribution under the same conditions but with a backfill of moist fine sand.

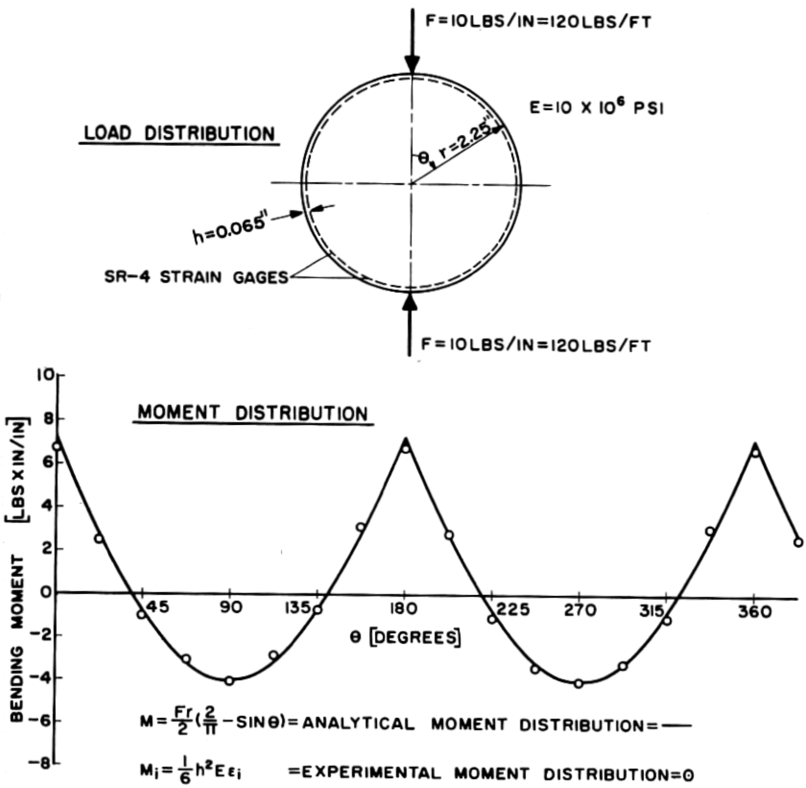

Fig. 4 — Analytical and experimental moment distribution in a thin-walled tube under two-point load.

BEDDING EFFECT

Based on the theoretical considerations illustrated in Figs. 5 and 6, comparison of Figs. 7 and 8 indicates a high load concentration at the bottom of the tube buried in a trench with clay backfill. For a verification of this assumption, a series of additional tests were conducted. The test tube was placed upon (a) a flat steel plate and then covered with moist clay, (b) a flat steel plate and then covered with dry sand, and (c) carefully distributed moist clay and then covered with clay. The external load was then applied. The moment distributions obtained for cases (a), (b), and (c) are shown in Figs. 9, 10 and 11, respectively.

A comparison of the data presented in Figs. 9 and 11 shows the effect of the bedding condition on the moment distribution (steel plate versus clay bedding). These data, as well as theoretical considerations (Figs. 5 and 6), indicate that the bedding condition affects mainly the bending moment at the bottom of the tube and only to a lesser degree the bending moment at right angles to the vertical axis. Due to a change in

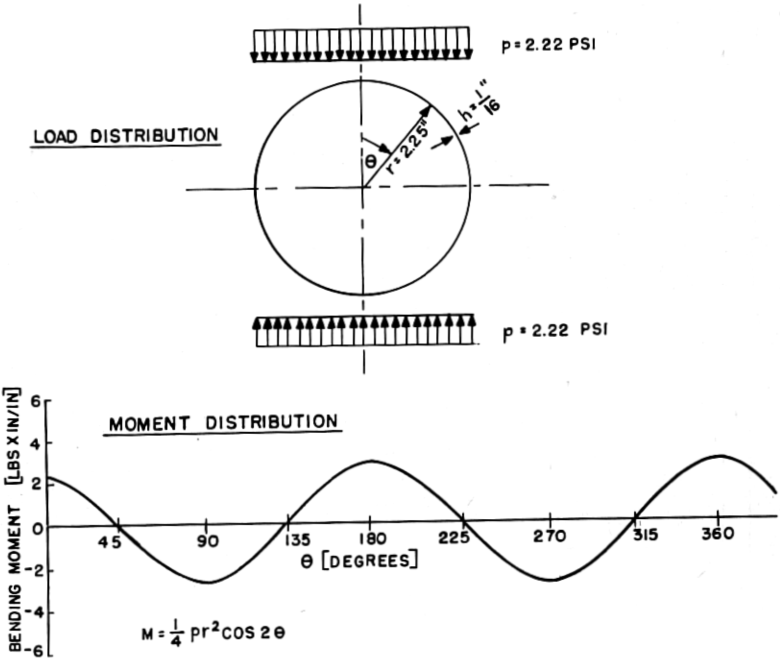

Fig. 5 — Theoretical moment distribution in a thin-walled tube subjected to uniformly distributed vertical pressure.

bedding, the moment at the bottom may vary up to 235 per cent, and the moments at the side points may change a maximum of 12 per cent.[3] The field data indicate that bedding is of particular importance with moist clay backfill, and to a lesser degree for moist fine sand. However, bedding did not appear to affect the moment distribution of the tube for a dry sand or gravel backfill.

TRENCH WIDTH

The effect of the trench width on the magnitude of the bending moments in a conduit has been investigated. The presently available test results indicate the following:

a. No significant difference in the magnitude of the bending moments of the tube (4.5-inch diameter) could be observed for a trench width

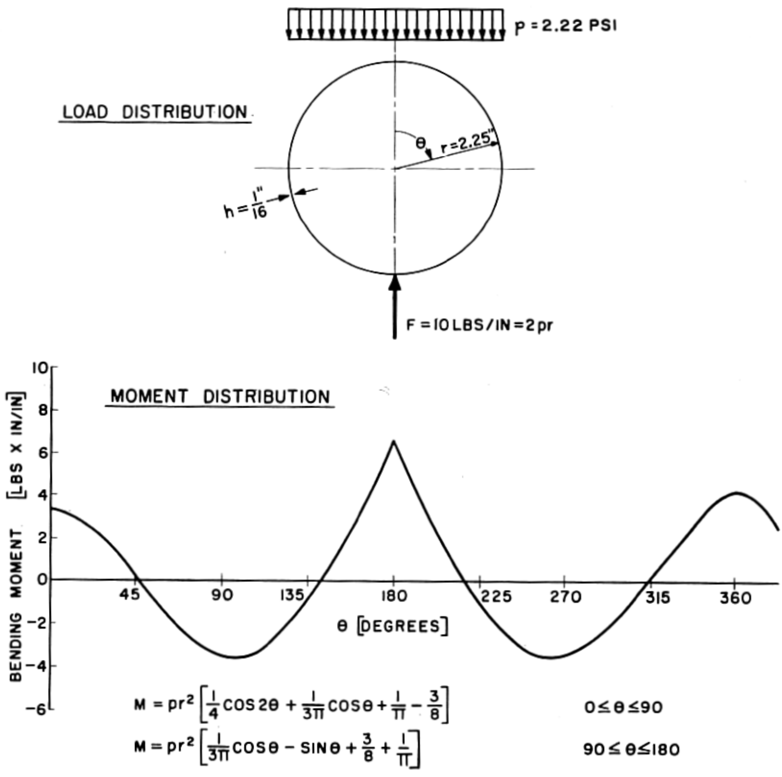

Fig. 6 — Theoretical moment distribution in a thin-walled tube subjected to uniformly distributed vertical pressure at the top and point load at the bottom.

between 18 and 30 inches. The magnitude of the bending moments appeared to be only a function of the backfill material, the applied load, and the height of backfill over the conduit.

b. For a trench width of 5 inches, the bending moments seemed to be independent of the type of backfill material. The same results have been obtained with a backfill of clay, sand, or gravel. This phenomenon indicates that the applied load was carried mainly by the undisturbed soil but deformation of the trench walls together with friction between the backfill material and the trench walls transmitted the load to the conduit. The magnitude of the bending moments in 5-inch wide trenches

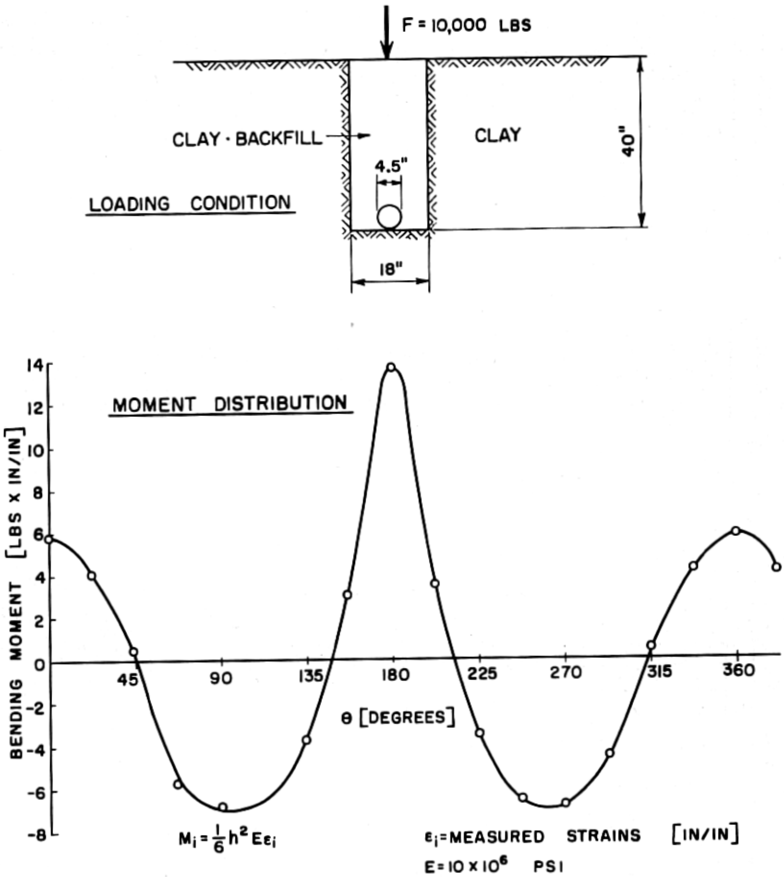

Fig. 7 — Moment distribution in a thin-walled tube, using clay backfill.

depends on the characteristics of the undisturbed soil. A comparison of the values obtained from a 5-inch wide trench dug in sandy clay (typical Chester, N. J. soil) and trenches between 18 and 30 inches wide shows that the values for 5-inch width are greater than for an 18- to 30-inch width when using sand backfill, and less when using clay backfill.

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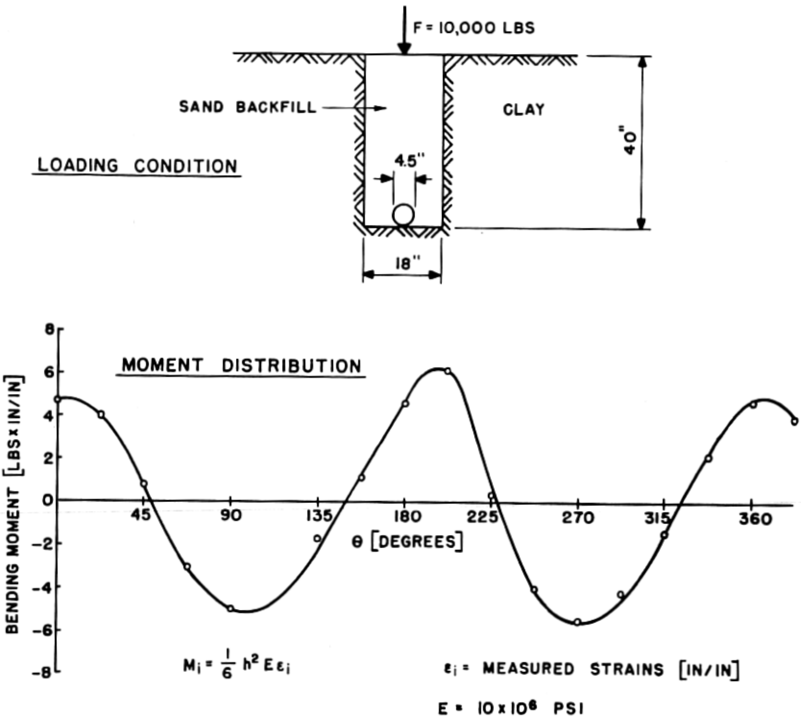

Fig. 8 — Moment distribution in a thin-walled tube, using sand backfill.

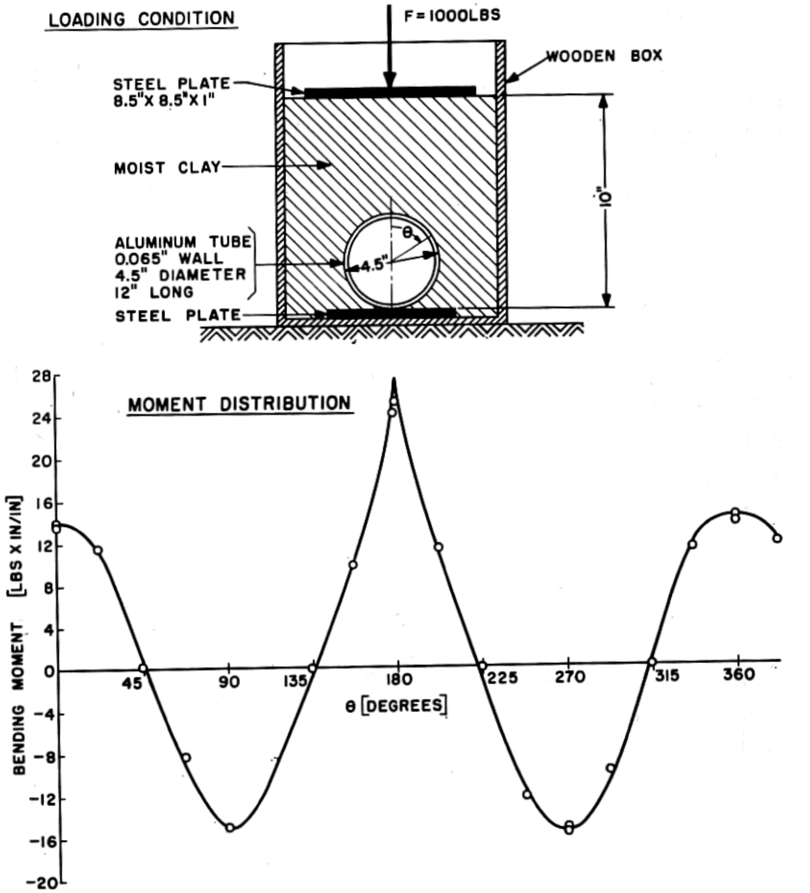

Fig. 9 — Moment distribution in thin- walled tube resting on steel plate and covered with moist clay.

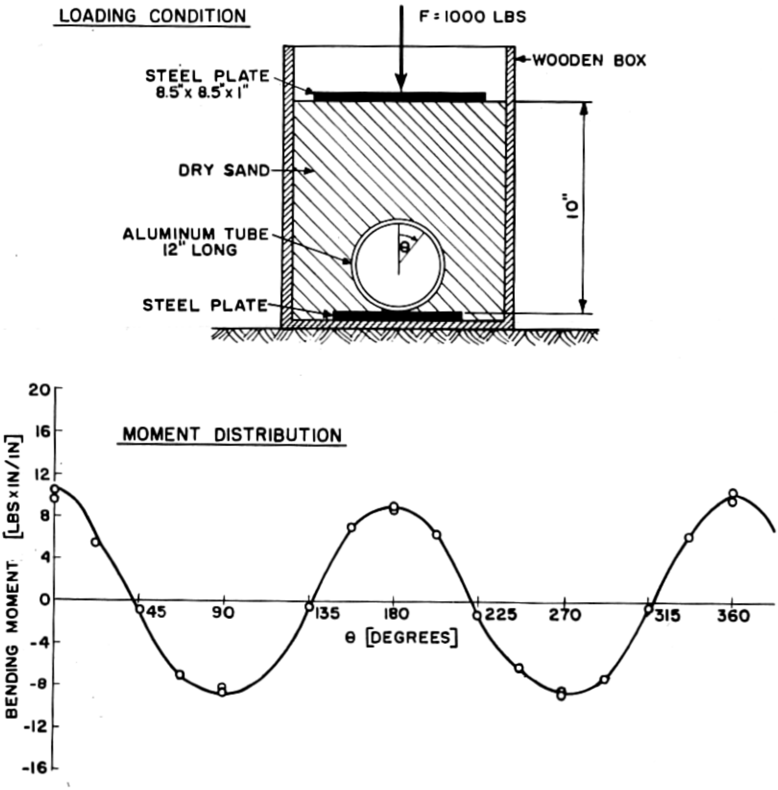

Fig. 10 — Moment distribution in thin-walled tube resting on steel plate and covered with dry sand.

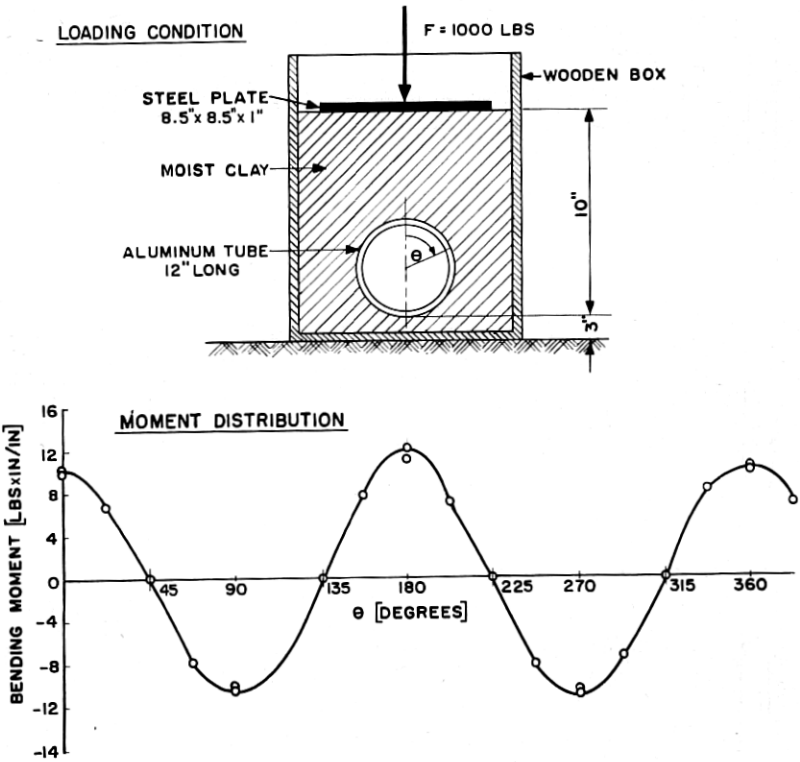

Fig. 11 — Moment distribution in a thin-walled tube in moist clay.

BACKFILL MATERIAL AND HEIGHT OF BACKFILL

Backfill provides the main protection for conduits against loads applied at the surface of the fill. The type of backfill used and the height of the backfill over the conduit are therefore extremely important. Figs. 12, 13, and 14 show the relationship between the bending moments in the conduit and the height of backfill for different applied loads. Fig. 12 shows this relationship for clay as backfill, Fig. 13 for fine sand, and Fig. 14 for gravel. The maximum bending moment is here expressed in terms of the "equivalent two-point load." The equivalent two-point load is the two-point load that will cause the same maximum bending moment in the conduit wall as the maximum bending moments measured in the field. The relationship between the two-point load and the bending moments in the walls of the conduit was given by (2). The equivalent two point load is obtained for $\theta = 0$ and becomes

$$F_{TP} = \frac{12\pi M_{\max}}{r} \qquad (3)$$

where

F_{TP} = equivalent two-point load (lb/ft)

$M_{\max}$ = maximum bending moment in conduit (in $\times$ lb)

r = radius of conduit (in)

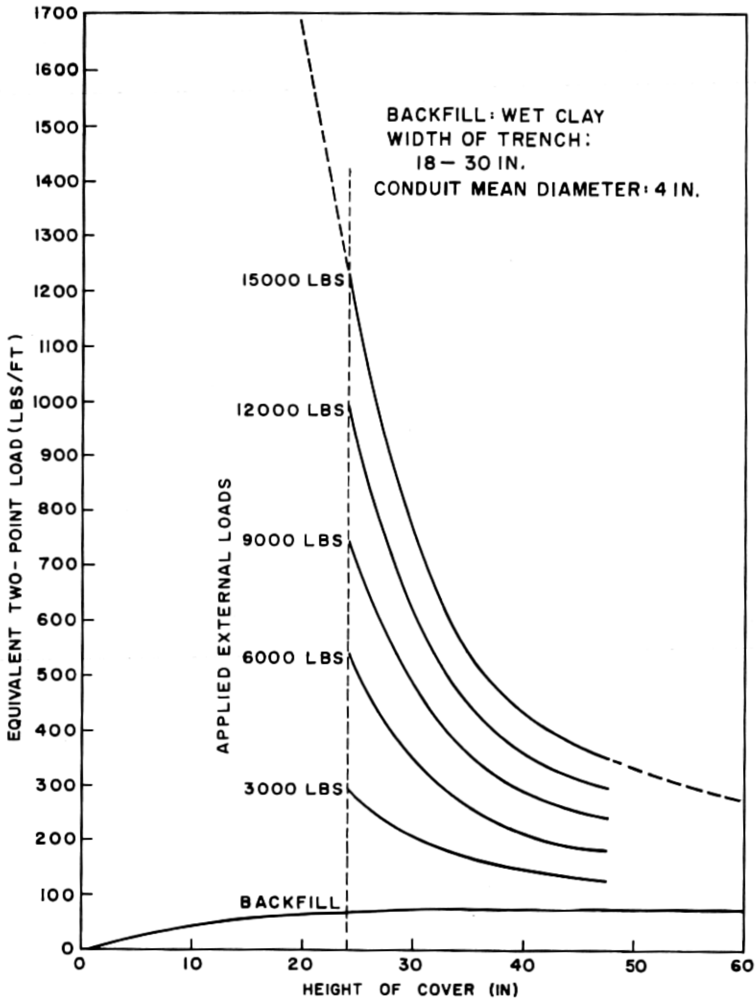

Fig. 12 — Equivalent two-point load versus height of cover for clay backfill.

The two-point load was chosen as a measure of the bending moment for convenience in laboratory testing of new conduits. The two-point load system is undoubtedly the simplest method for testing cylindrical or near-cylindrical shapes in conventional compression testing machines (crushing test). Since most of the supplementary conduit materials are cylindrical in shape, the most obvious requirement would be in terms of minimum two-point loading.

The data in Figs. 12, 13, and 14 were obtained as follows:

The bending moments at points perpendicular to the vertical axis were represented, as a function of the applied load, by a straight line, determined by the method of least squares. This was done for all the investigated depths and backfill materials. The side points were used as a basis of comparison because they were less affected by a change in the bedding conditions. With reference to the considerations of the

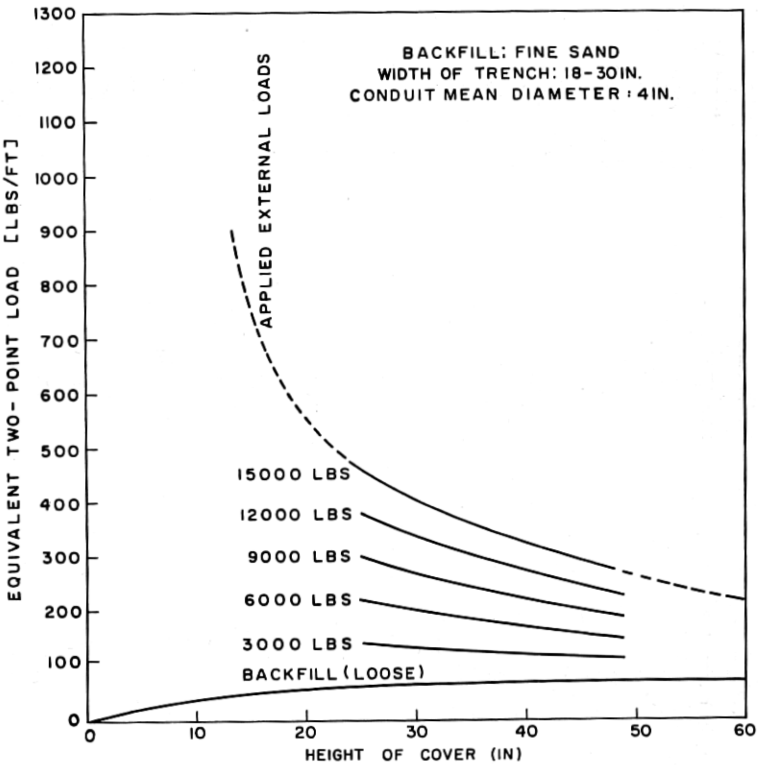

Fig. 13 — Equivalent two-point load versus height of cover for sand backfill.

bedding effect, the possible maximum bending moment at the bottom of the tube was obtained by doubling the values of the side points. Figs. 12 and 14 show clearly that the maximum bending moments occur in wet clay, and also that improvement is obtained by an increase in the height of backfill or a decrease of the applied load. These figures apply to 4-inch diameter tubes. In conversion of results obtained using 4.5-inch diameter tubes, it was assumed that the equivalent two-point load is directly proportional to the tube diameter.

DYNAMIC LOAD

A study was made to determine the effect of moving loads on the maximum bending moment of the conduit. For this purpose trucks were driven over the backfill at a speed of approximately 20 miles per hour, the strains measured and then compared with those obtained by static loads. The results show that for a clay backfill, the bending moments due to dynamic loads were equal to or even smaller than those obtained by static loads. For sand backfill, however, the dynamic loads caused an increase of the maximum bending moments of approximately 10 per cent. These results are in close agreement with dynamic load tests con-

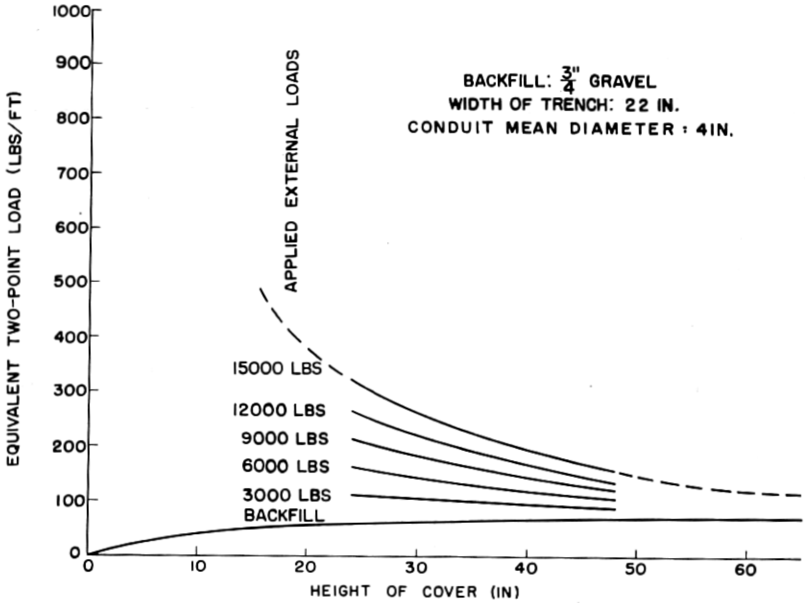

Fig. 14 — Equivalent two-point load versus height of cover for gravel backfill.

ducted by H. Lorenz.[4] Further tests conducted with 500-lb weights dropped from different heights demonstrated that the effect of dynamic loads for clay backfill is of minor importance.

FURTHER INVESTIGATION

The tests previously conducted did not include investigations of the effects of conduit flexibility, various conduit diameters, multiple arrangements of the conduits in the trench, consolidation and compaction of the backfill, and auxiliary protection of the conduit. Studies of these factors are now in progress.

SUMMARY

Strength requirements of underground conduits depend on various factors. The most severe conditions were obtained with wet Georgia clay as backfill for a trench width of 18 to 30 inches. The relationship between the height of backfill, the load applied at the surface of the backfill, and the equivalent two-point load for these conditions is shown in Fig. 12. For example, a round conduit of 4-inch mean diameter under 24 inches of clay cover subjected to an applied load of 15,000 lb should be able to carry a two-point load of 1,250 lb without fracture of excessive deformation. Figs. 12 to 14 can be used to determine the required crushing strength of 4-inch round conduits subjected to different applied loads, buried at different depths with clay, sand, or gravel cover, but only for trench widths of 18 inches or more. Although this investigation is not completed, the results obtained to date may be used, within the indicated limits of application, for the selection of acceptable conduit.

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