Lateral Swelling Pressure on Conduits from Expansive Clay Backfill

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The phenomenon of lateral swelling pressures exerted by expansive clays is well-known. Some structures (piles, retaining walls, conduits, etc.) crack or fail either by action of swelling forces in the horizontal direction or by combinations of lateral with other forces.

This paper deals with a study of the lateral pressures developed along conduits buried in a swelling clay. These pressures originated from the horizontal swelling of the clay backfill during moisture variations.

The study included laboratory investigations of the clay backfill swelling characteristics, as well as field experiments on two pipelines buried at different moisture-density conditions. The pipelines were equipped with strain gages installed in the longitudinal direction of the conduits, thus making possible the determination of the horizontal moment distribution along the pipelines caused by the lateral swelling of the backfill. From the moments, the load distribution diagrams, as well as the elastic lines, were established. The elastic lines were compared with direct field measurements of the horizontal movements of the conduits.

The maximum moments were also computed by assuming various load distributions and statical conditions of the pipe ends. A reasonable correlation was found between the assumed theoretical conditions and the results obtained from the measurements, which may help future prediction of swelling pressures from clay backfills.

● THE PHENOMENON of lateral swelling pressures exerted by expansive clays on structures is well known. Some structures such as piles, retaining walls, and conduits crack or fail either under the action of horizontal swelling forces or by combinations of the lateral with other forces. For example, cases of horizontal shear of piles have been attributed mainly to the lateral swelling of the clay (1), and rupture of conduits has been

1/ On loan from Israel Institute of Technology, Haifa.

found to result from non-uniformity of the swelling forces exerted by the clay (2,3).

Vertical swelling behavior has been the subject of appreciable research and publication (4,5,6), but little has been reported on horizontal action. This paper reports that portion of a research on buried conduits in which lateral swelling pressures were developed from clay backfill placed at two different initial moisture-density conditions. The purpose is to show typical lateral load distributions and the corresponding horizontal movements under the different conditions. A method was developed for the evaluation of the swelling pressures and the resulting maximum bending moments. The limitations of future assessment of pressures by this method are pointed out.

THEORETICAL CONSIDERATIONS

The lateral pressures acting on a conduit laid in expansive clay are dependent on the backfill properties. Upon the ingress of moisture into the clay backfill, opposing lateral pressures develop. If the backfill soil were absolutely uniform and the increase of moisture on both sides of the conduit equal, the pressures would be nullified and only influence ring stresses. However, this is not the actual case, since it is not practicable under field conditions to ensure that the backfill soil will not have some variation in moisture or density along both sides of the pipe. Moreover, even if the backfill is completely homogeneous, non-uniform moisture conditions on the sides might result from accidental flooding, non-uniform irrigation, etc., thus producing inequalities in the opposing pressures.

The pressure on one side of the conduit is partly cancelled by pressure on the opposite side, but such forces are non-uniform along the length of the pipe. As a result the pipe deforms longitudinally under the net differential load. Should measurements of longitudinal deformations be utilized to calculate lateral loads, only the final (not differential) load, under which the structure is statically in equilibrium, would be found. It is not feasible to deduce the original swelling pressure on each side of the conduit from these final loads, because any pair of opposing lateral pressures may yield the same differential pressure. Hence, the following approach was used for the evaluation of the lateral swelling pressure.

A laboratory investigation was conducted on the swelling characteristics of the backfill soil. The results assisted in assuming the magnitude of the swelling pressures that may develop in the field. With these data in hand, the moments under various load distributions and assumptions as to the end conditions of the pipe were determined.

The various load distributions that were tried were as follows:

Case (a). - Distributed load, q, twice as large as the opposing load, acting on the middle portion of an individual conduit ($l = 4.0$ m), hinged at the ends (Fig. 1a). The moments:

$$M_A = 0 \tag{1}$$

$$M_C = M_{max} = \frac{ql^2}{24} \tag{2}$$

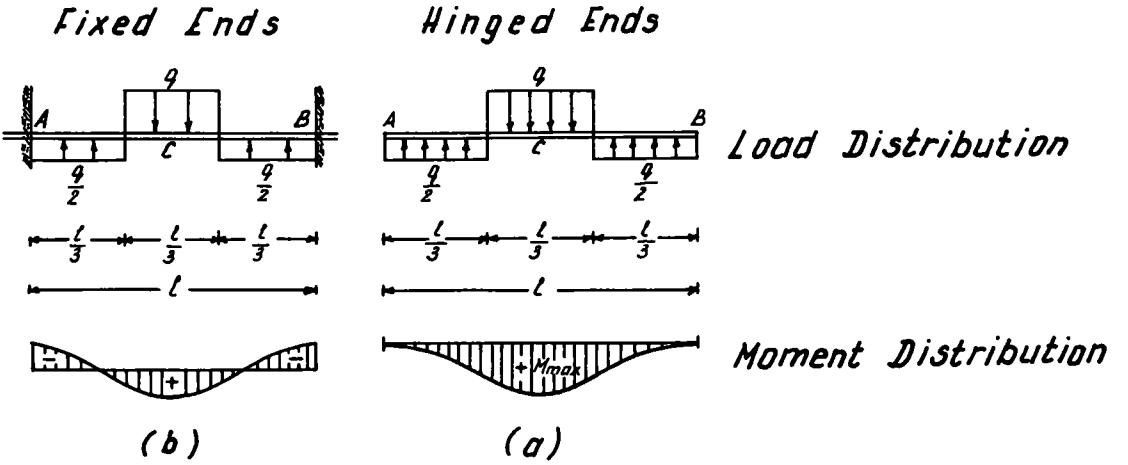

Figure 1. Load and moment distributions of a conduit: (a) with hinged ends, (b) with fixed ends.

Assuming the ends are fixed, (Fig. 1b) the moments:

$$M_A = M_C = \frac{ql^2}{48} \qquad (3)$$

Case (b). - Distributed load, q, acting on an individual conduit ($l = 4.0$ m) along one side. The conduit is assumed to rest on an elastic subgrade along the other side (Fig. 2) and fixed at the ends, which simulates either rigid connections or a long pipe subjected to moisture changes different from the section analyzed.
The moments according to the formulae of Hétényi (7):

$$M_A = M_B = -\frac{q}{2\lambda^2}\left(\frac{\text{Sin h}\lambda l - \text{Sin }\lambda l}{\text{Sin h}\lambda l + \text{Sin }\lambda l}\right) \qquad (4)$$

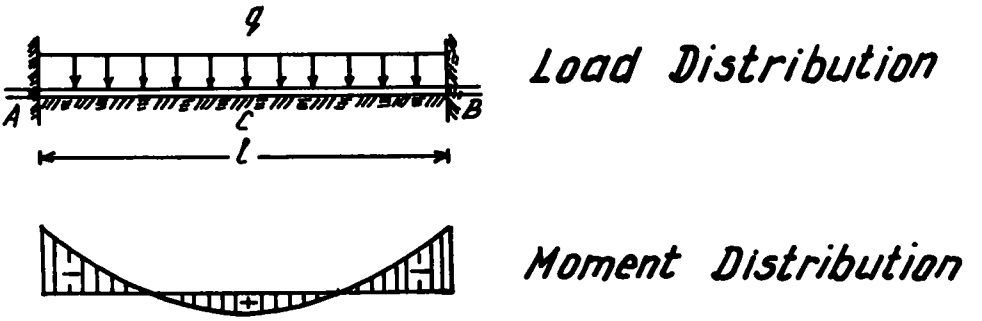

Figure 2. Load and moment distributions of a fixed conduit subjected to subgrade reaction.

$$M_C = \frac{q}{2}\left(\frac{\sin\frac{\lambda l}{2}\ \cosh\frac{\lambda l}{2} - \cos\frac{\lambda l}{2}\ \sinh\frac{\lambda l}{2}}{\sinh\lambda l + \sin\lambda l}\right) \qquad (5)$$

where

$$y = \sqrt[4]{\frac{K}{4EI}} \quad \text{(The characteristic of the beam)}$$

$$K = K_o B$$

K_o is the coefficient of subgrade reaction,

B is the outside diameter of the pipe,

E is Young's modulus of the pipe material, and

I is the moment of inertia of the pipe section.

The maximum deflection takes place at point C and may be computed from

$$y_c = \frac{q}{K}\left[1 - \frac{2\left(\sinh\frac{\lambda l}{2}\ \cos\frac{\lambda l}{2} + \cosh\frac{\lambda l}{2}\ \sin\frac{\lambda l}{2}\right)}{\sinh + \sin}\right] \qquad (6)$$

The calculated moments and displacements were then compared with the maximum values obtained in field measurements and the validity of the swelling pressures assumed was thus examined.

LABORATORY INVESTIGATIONS OF THE CLAY BACKFILL

Classification. - The results of the basic classification tests on the clay, sampled from the experimental site, are summarized in Table 1.

TABLE 1

Clay sizes (% smaller than 5 microns)	65 - 70
Liquid limit (%)	78 - 85
Plastic limit (%)	20 - 22
Plasticity index (%)	58 - 63
Shrinkage limit (%)	9.5 - 11
Activity	1.1 - 1.2
Free swell (%) (8)	130

It is obvious that the clay under study is of a highly expansive nature.

Swelling Behavior. - The swelling characteristics of the remolded clay were investigated for a wide range of moisture and density obtained by varying the energy applied to the Harvard Miniature Compactor. Three compaction curves produced in the laboratory and one obtained in the experimental site in the field served as the basis for the swelling behavior study. It should be noted that the density range tested was well below the maximum density of about 1.4 t per cu m as obtained by A.S.T.M. Standard Compaction test.

Two types of swelling tests were performed on samples prepared at placement conditions corresponding to selected points on the compaction curves: (1) percent swelling under the backfill pressure and (2) swelling pressure with zero movement.

Swell under Backfill Pressure. — The test procedure followed the one suggested by Holtz and Gibbs (8), in which the amount of swelling of a compacted specimen under a certain load and subjected to soaking is determined. The specimens were tested under a pressure of 0.13 kg per sq cm, which corresponds to the backfill load (assuming a depth of 0.9 m and unit weight of 1.4 t per cu m).

The test results were produced in terms of "equal swelling lines" projected on the compaction curves (Fig. 3). The amount of swelling varied under the conditions tested from 1 percent at high initial moisture content to 7.5 percent at the driest conditions. Actually the amount of swelling increased under combined conditions of low moisture and high density.

Swelling Pressure with Zero Movement. — According to the test procedure (8), the clay specimen is restrained from swelling and the maximum pressure required to keep the specimen from moving is measured. The results are presented in Figure 4 in terms of "equal pressure lines" projected on the compaction curves. The swelling pressures were found to vary from 0.05 kg per sq cm to 0.45 kg per sq cm, increasing with combined conditions of low moisture and high density.

THE FIELD STUDY

Program. — The program of the field study included measurements of longitudinal deformations and movements in the horizontal direction of two

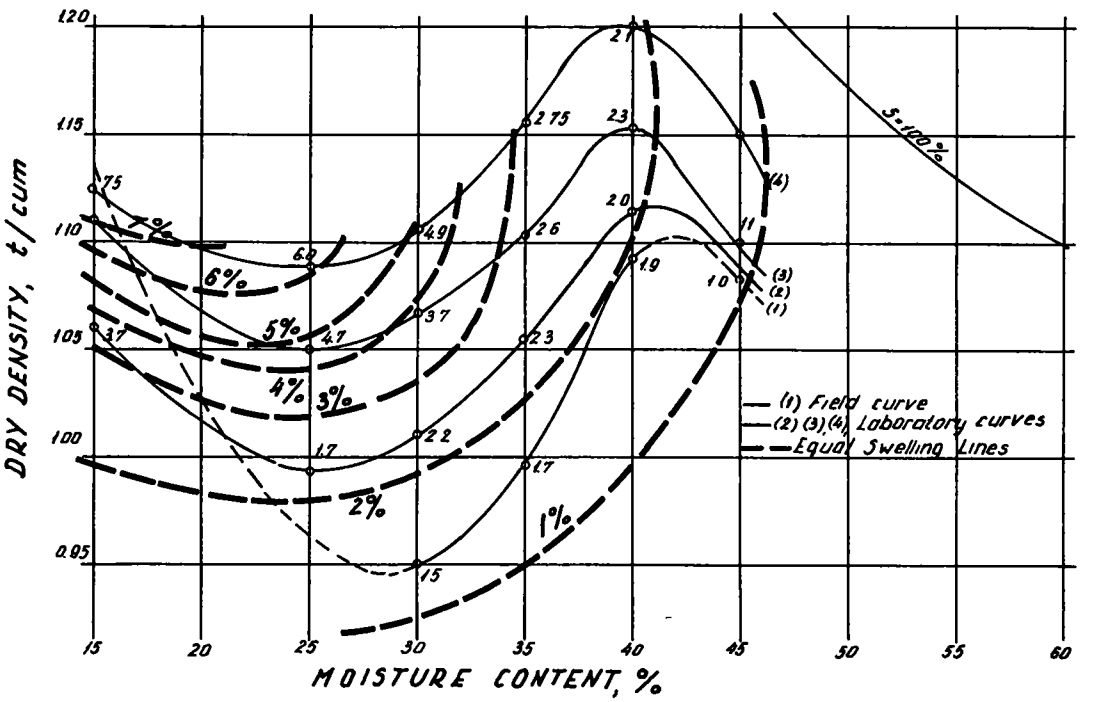

Figure 3. Equal swelling lines for compacted clay.

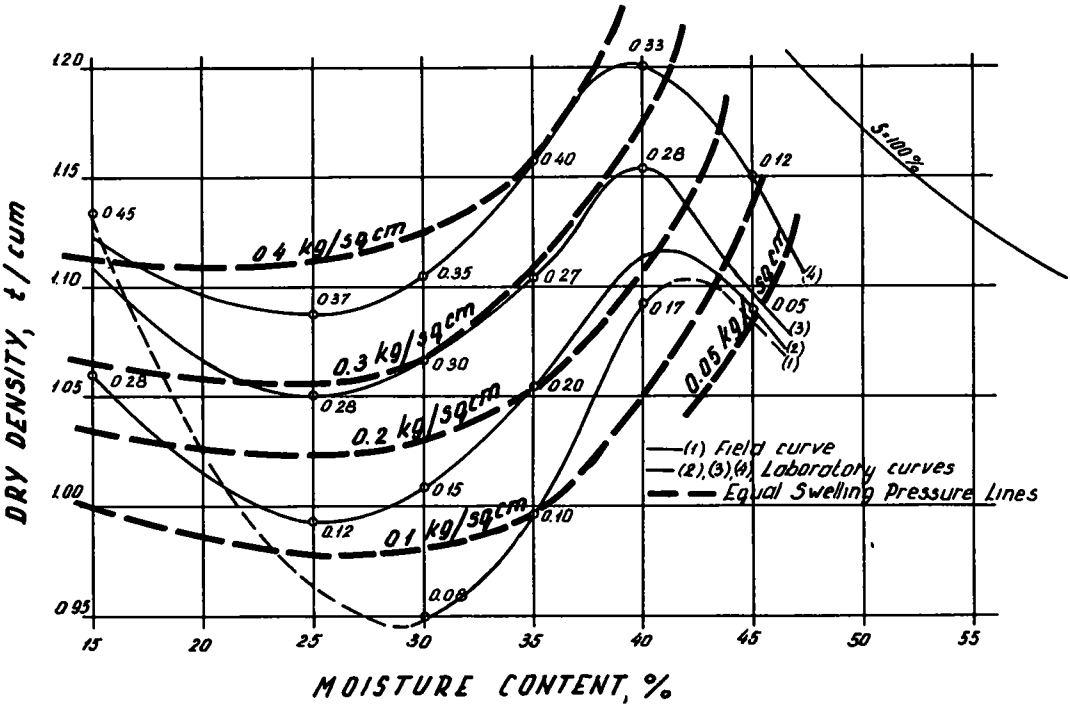

Figure 4. Equal pressure lines for compacted clay.

experimental asbestos-cement pipelines subjected to moisture variations in the clay backfill. The pipe diameter was 4 in., the length of each line 20 m and they were buried at a depth of 0.9 m. In the center of each pipeline a standpipe of the type used for irrigation was installed. The individual pipes (4.0 m long each) on both sides of the standpipe were mounted with vibrating wire strain gages (9) in the longitudinal direction of the pipelines and horizontal with both sides of the pipe section. Metal plates were attached to the top of these pipes for measurement of horizontal movements. The plates were made accessible and at the same time protected by a 6-in. aluminium sleeve resting on the pipeline.

The backfill placement conditions varied as follows: Pipeline I was buried under compacted wet soil, simulating an installation of pipeline under wet conditions. Compaction was accomplished by hand tamping. Pipeline II, on the other hand, was placed under dry backfill, simulating a practice often encountered in Israel, in which the trench and backfill are left exposed to drying before backfilling. Backfilling was accomplished by hand tamping of dry clay in lumps.

The behavior of the pipelines was observed under gradual moisture changes caused by the winter rains of 1958/59 and later under concentrated irrigation.

Distribution of Horizontal Moments.— The zero readings on the vibrating wire strain gages were taken before backfilling at the end of the summer of 1958. Later readings were taken periodically in conjunction with determinations of moisture changes in the backfill. Upon the swelling of the clay backfill, considerable horizontal transverse loads were

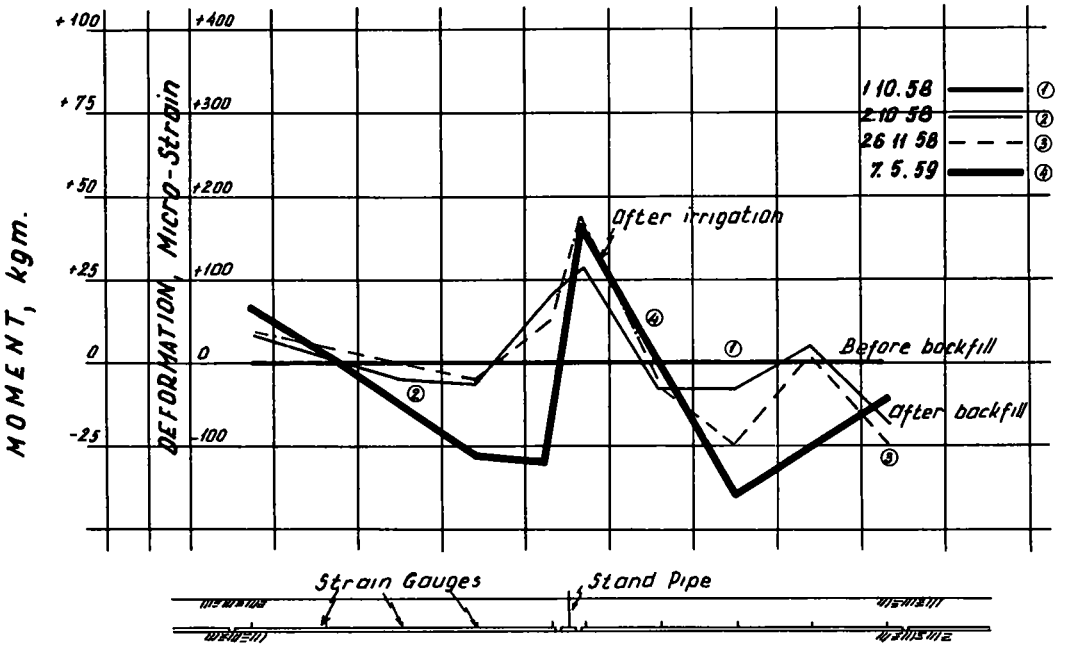

Figure 5. Distribution of longitudinal moments in the horizontal direction, pipeline I.

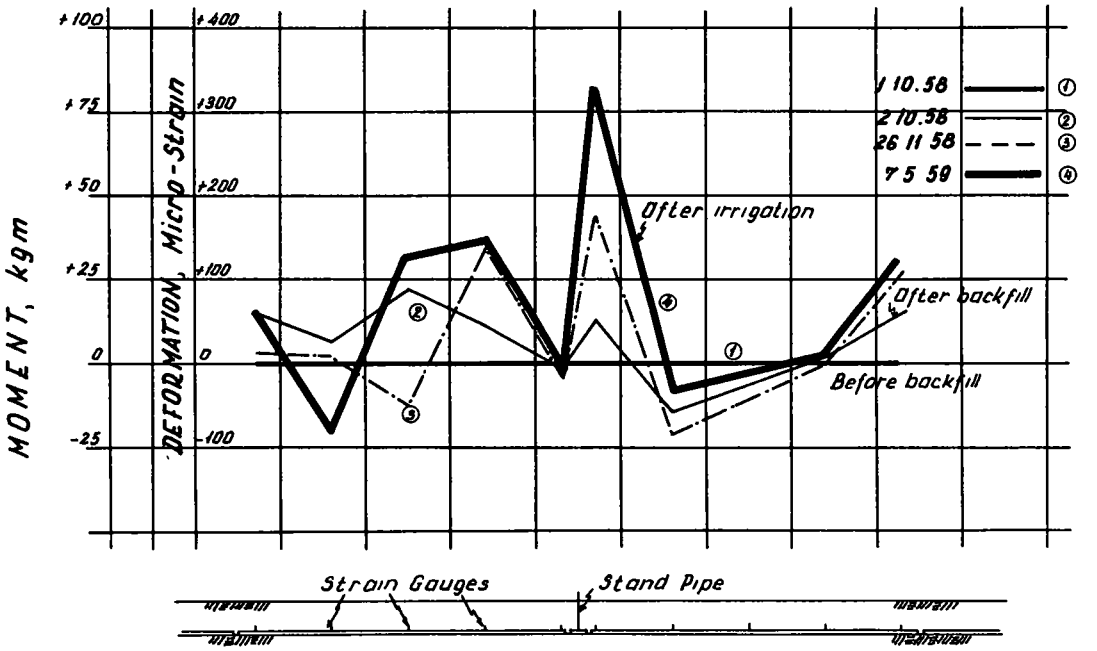

Figure 6. Distribution of longitudinal moments in the horizontal direction, pipeline II.

developed along both pipelines. The horizontal moment distributions due to these loads and their variation with time are presented in Figure 5 for pipeline I and in Figure 6 for pipeline II.

Distribution of Horizontal Loads. — From the moment diagrams the lateral load distributions along the pipelines were established. These are presented in Figures 7(a) and 8(a) for pipeline I and II respectively.

From the load-distribution variation with time it may be seen that the loads developed by the backfill lateral pressure on both pipelines (namely, after completion of the backfilling operation) are low in comparison to those caused by the nonuniform swelling pressures exerted by moisture variations in the clay. The difference between the load distributions (due to backfilling and swelling) increased with the increase of moisture content in the backfill and reached a maximum value after irrigation. In pipeline II this difference was much more critical than in the other pipeline, probably due to the initial dry soil conditions in pipeline II.

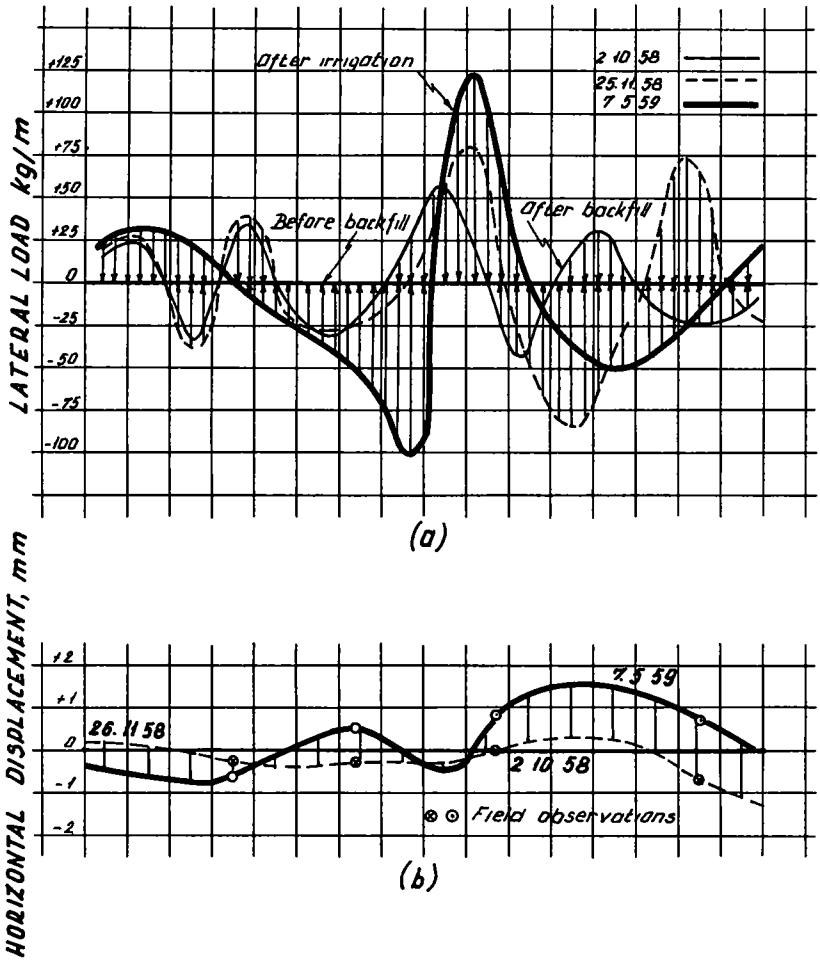

Figure 7. Lateral load diagram and horizontal displacement of pipeline I.

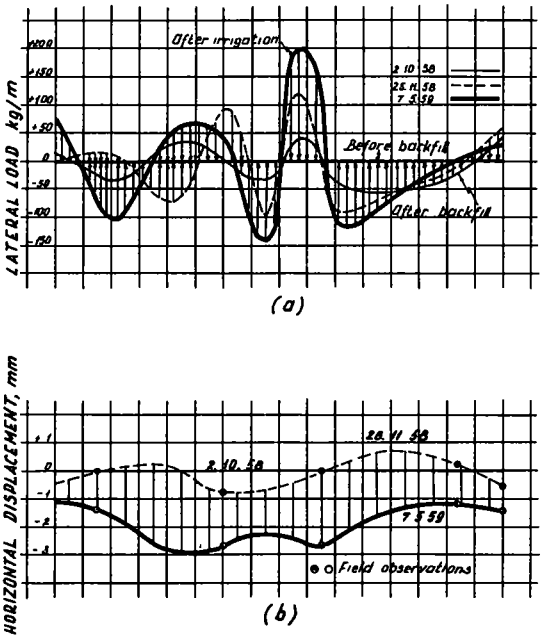

Figure 8. Lateral load diagram and horizontal displacement of pipeline II.

Horizontal Movements. — The techniques developed for the measurement of the horizontal movement of the pipelines consisted essentially of precise measurements at various time intervals of angles between points along the pipelines and a fixed base line. The measurements were made possible by placing optical targets on top of the metal plates attached to each pipeline. The results obtained by measurements were correlated with the elastic lines established by calculations from the moment distributions. A reasonable agreement was found between the two methods, as may be seen from Figures 7(b) and 8(b). It may be noted that the greatest loads evolved at zones where the lateral movement was restrained.

CORRELATION BETWEEN CALCULATIONS AND EXPERIMENTAL RESULTS

Pipeline I. — From the laboratory study (Fig. 4) it may be seen that the maximum lateral swelling pressure that may be exerted under the soil placement conditions of pipeline I is about 0.15 kg per sq cm. Allowing for some release of pressure from the horizontal movements, it is justified to assume, for comparison, that the swelling pressure was reduced to 0.1 kg per sq cm. The resulting lateral load, then, is 120 kg per m, assuming that the pressure acts normal to the whole outside diameter of the pipe; i.e., 12 cm.

When this load was applied to the statical conditions described in Case (a) the resulting moments at the hinged ends and the middle of the conduit were found to be 0 kgm and 80 kgm, respectively. However, when it was assumed that the ends were fixed, the moments at the middle and the ends were computed to be 40 kgm. The application of the same load coupled with the conditions described in Case (b) yields moments of

TABLE 2

COMPARISON OF MEASURED AND COMPUTED VALUES, PIPELINE I

Values	Maximum Load on Pipe (kg/m)	End Moment (kgm)	Middle Moments (kgm)	Maximum Horizontal Movement (mm)
Measured values	125	38	38	1.5
Computed values				
Case (a) hinged	120	0	80	2.5
Case (a) fixed	120	40	40	0.5
Case (b)	120	41.5	10	1.0

41.5 kgm at the ends and 10 kgm at the middle, assuming K_o = 1.0 kg per cu cm for the tamped clay (10). The maximum computed horizontal movement resulting from the assumptions of Case (b) was found to occur in the center and equal to 1 mm. the values obtained by the calculations may be compared to the measured values in Table 2. In this case a reasonable correlation was obtained between the measured values and values arrived at by assuming the statical conditions of Case (a) with fixed ends.

Pipeline II. — The swelling pressure obtained in the laboratory study (Fig. 4) under the soil conditions of pipeline II was 0.4 kg per sq cm. However, allowing for the relatively large horizontal movement of this pipeline, a lateral swelling pressure of 0.2 kg per sq cm is assumed for the theoretical calculations. The resulting load, hence, is 240 kg per m.

The results of measurements and theoretical computations for this pipeline are compared in Table 3. In this case it may be noted that the approach based on subgrade reaction produced the best correlation with field values.

TABLE 3

COMPARISON OF MEASURED AND COMPUTED VALUES, PIPELINE II

Values	Maximum Load on Pipe (kg/m)	End Moment (kgm)	Middle Moments (kgm)	Maximum Horizontal Movement (mm)
Measured values	200	80	40	2.7
Computed values				
Case (a) hinged	240	0	160	5
Case (a) fixed	240	80	80	1
Case (b)	240	83	20	2.5

CONCLUSIONS

The theoretical approach suggested in this paper for determining the lateral longitudinal moments and displacements of pipes buried in expansive soils has shown that it is possible to estimate the swelling pressures that may occur in the field. It is obvious, however, that there are limitations to the use of the approach for further prediction of lateral pressures on conduits or other structures until much more research is conducted on the subject.

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