*Discussion on Paper No. 6688**

The wide trench condition and its effect on the loads imposed on rigid underground conduits

by

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Mr A. G. I. Shayo (Messrs J. D. and D. M. Watson) submitted the following comments.

Transition depth in a parallel-sided trench

43. In a shallow trench the slice of fill on top of the pipe behaved like a flexible beam, propped in the middle by the pipe and supported at the edges by the frictional forces on the trench sides. This slice of fill deflected as shown by the dotted lines in Fig. 11. When the slice was thin, the deflexion would be sufficient to cause rupture along the vertical planes a–a. The external prisms then tended to drag down the internal prism by frictional shear forces. This constituted wide trench conditions of loading.

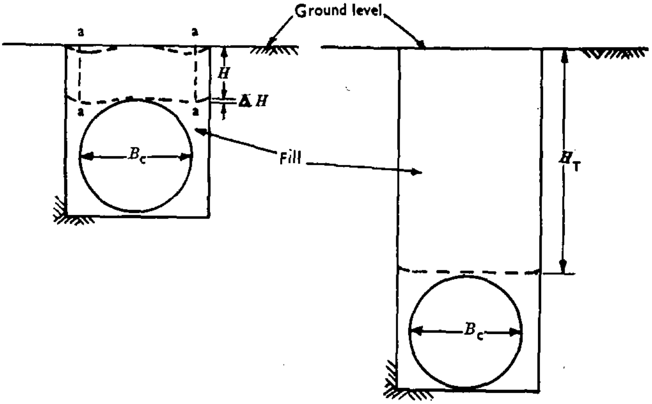

FIG. 11

44. As the depth, H, of the slice of fill increased, it became more rigid and the deflexion, ΔH, decreased until a depth, H_T, was reached at which the deflexion was no longer sufficient to cause rupture along the planes a–a. At this depth and beyond it the prism of fill over the whole width of trench acted as a unit. This constituted narrow trench loading conditions. H_T was the transition depth.

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* *Proc. Instn civ. Engrs*, vol. 26, September 1963, pp. 105–118.

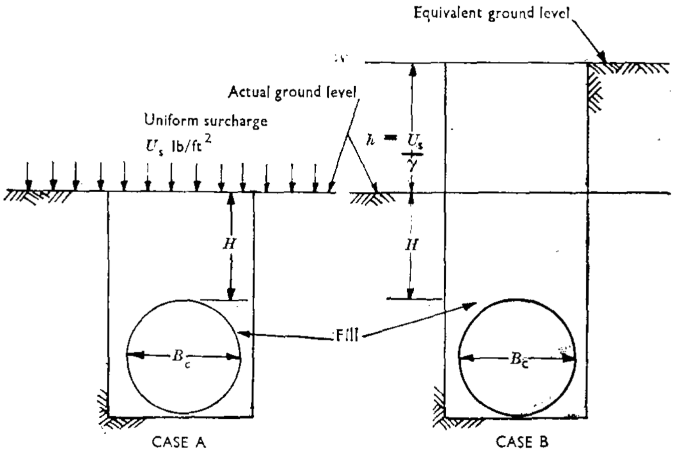
Equivalent ground level
Actual ground level
Uniform surcharge
U_s lb/ft^2
$h = \frac{U_s}{\gamma}$
H
H
Fill
B_c
B_c
CASE A
CASE B

Fig. 12

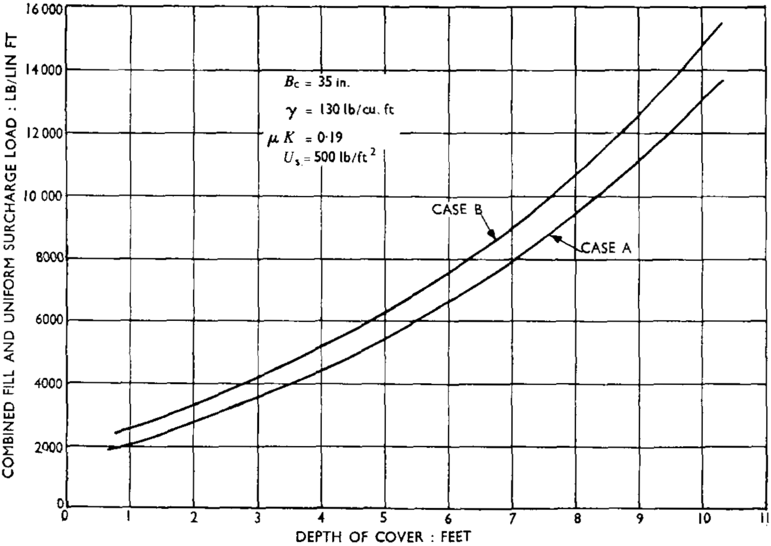
B_c = 35 in.
γ = 130 lb/cu. ft
μK = 0·19
U_s = 500 lb/ft^2
CASE B
CASE A
COMBINED FILL AND UNIFORM SURCHARGE LOAD : LB/LIN FT
DEPTH OF COVER : FEET
0
2000
4000
6000
8000
10 000
12 000
14 000
16 000
0
1
2
3
4
5
6
7
8
9
10
11

Fig. 13

45. The effect of introducing uniformly-distributed load on top of the fill would appear to be to increase the deflexion ΔH. Hence a greater depth than H_T would be required to give the slice of fill sufficient rigidity to prevent rupture along planes a–a.

46. From the preceeding argument, it would appear that for a particular width of trench, the transition depth, when uniformly-distributed surcharge was applied, was greater than that when no surcharge was applied.

47. The Author had taken the transition depth to be the same when there was, and when there was not, surcharge. That assumption might be one of the reasons why a discontinuity appears in his curve for combined fill and uniform surcharge loads (Fig. 8 of the Paper). It was very difficult to visualize the jump of about 1000 lb/lin. ft occurring in actual loading; this suggested that there was an over-estimation (or under-estimation) of one of the loads at this point.

48. Was it not true that the transition depth was dependent on the conditions existing above the pipe and that as such it should not be determined independent of these conditions?

Uniform surcharge loads

49. The Author considered the two cases shown in Fig. 12 as being identical for the purpose of working out the combined fill/uniform surcharge load coming on the pipe. Assuming 'complete trench conditions', however, which would hold for shallow trenches, and working out the equations for the combined loads from fundamental principles, the following equations were derived:*

For Case A

$$\text{Combined load } (W_f + W_{us}) = e\,\frac{2\mu KH}{B_c}\left(U_s B_c + \frac{\gamma B_c^2}{2\mu K}\right) - \frac{\gamma B_c^2}{2\mu K}$$

$$= \frac{\gamma B_c^2}{2\mu K}\left(e\,\frac{2\mu KH}{B_c} - 1\right) + U_s B_c . e\,\frac{2\mu KH}{B_c}$$

For Case B

$$\text{Combined load } (W_f + W_{us}) = \frac{\gamma B_c^2}{2\mu K}\left(e\,\frac{2\mu K}{B_c}\cdot(H+h) - 1\right)$$

Fig. 13 showed a comparison of the loads calculated from the two equations.

50. The method of substituting a column of fill of height $h = U_s/\gamma$ for the uniform surcharge over-estimated the combined load. By that method, friction, which in that case increased the load on the pipe, was assumed to act in the equivalent column; i.e. frictional shear forces were assumed to act over an area of a height $(H+h)$. In actual practice those forces acted over an area of a height H only. Case A restricted the frictional forces to the actual height H and also took into account the fact that at ground level the vertical pressure was U_s/sq. ft and adjusted the lateral pressures and frictional shear forces accordingly.

51. The over-estimation of the frictional shear forces might be another reason for the discontinuity in the combined load curve (Fig. 8).

52. The equivalent column method simplified calculations since the tables and graphs for ordinary fill load could be used for the combined load. But as it over-estimated the load it might result in uneconomical designs.

The Author, in reply to Mr Shayo, stated that the argument in §§ 43–48 raised an interesting matter with reference to §§ 13–15 of the Paper, which admittedly required further investigation, as had been implied in § 15. Thus, if Example 1 in the Paper

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* e is the base to natural logarithm and in these equations it is raised to the power of $(2\mu KH)/B_c$ and of $[2\mu K(H+h)]/B_c$ respectively.

were extended to 2-ft cover, the combined fill and uniform surcharge loads would be as follows:—

		2	3	4	5	5·65	7	8	10	
Wide trench	H =	2	3	4	5	5·65	7	8	10	ft
Condition	W'_{c130} =	780	1430	1820	2600	3100	4350	4940	6250	lb/ft
	W_w =	230	230	230	230	230	230	230	230	,,
	W'_{us500} =	2470	2730	3120	2860	2700	2340	2340	2340	,,
Total load	=	3480	4390	5170	5690	6030	7120	7510	8820	,,
Narrow trench										
Condition	W_{c130} =	1200	1750	2320	2780	3100	3720	4160	4930	,,
	W_w =	230	230	230	230	230	230	230	230	,,
	W_{us500} =	2150	2075	2000	1900	1810	1710	1640	1470	,,
Total load	=	3580	4055	4550	4910	5140	5660	6030	6630	,,
Possibly effective total load	=	3480	4055	4550	4910	5140	5660	6030	6630	,,
Compared with § 39(c)	=			5170	5690	6030	6030	6030	6630	,,

54. The curves of these combined loads would obviously intersect at some depth between 2 and 3 ft. There was therefore a theoretical probability of the occurrence of a transition depth for combined fill and uniform surcharge loading at which the frictional forces would be reversed. Such a transition depth would eliminate the discontinuity referred to in §§ 14 and 15 and result in lower effective loads at depths of cover exceeding it and up to and somewhat beyond the fill load transition depth. Theoretically, this combined load transition depth would increase as the trench width increased for the same value of B_c.

55. In the Example given above, the reduction in loading would be effective over cover depths of 4 to 8 ft, but only in 'field and garden' loading. In 'road' loading, the loads imposed by vehicle wheels were assumed to be independent of frictional effects and it would therefore be necessary to consider only the fill load transition depth in computing the total load, as in Example 30 of the paper.

56. Contrary to Mr Shayo's expectation in § 45, the apparent effect of the added uniform surcharge was to *reduce* the transition depth.

57. However, unlike the fill load transition depth, there was as yet no experimental confirmation of the existence and effects of a combined load transition depth. The Author therefore considered that, pending experimental investigation of this aspect of loading, the method given in the Paper was safe and should continue to be used, despite the fact that it was possibly conservative over a limited range of cover in 'field' loading.

58. With reference to §§ 49–52, in general design, where the nature and position of uniformly distributed surcharges are not predetermined, it was considered advisable to assume the 'worst' conditions, i.e. for 'wide' trench conditions, that the surcharge itself developed unfavourable friction (with $K\mu = 0{\cdot}19$); and for 'narrow' trench conditions, that the surcharge itself was frictionless. In § 49, Mr Shayo's Case A for the wide trench condition assumed that the surcharge was frictionless. This explained the difference in the curves A and B in Fig. 13, since Case B assumed a frictional surcharge in the 'complete' condition.

59. The difference in the loads at the discontinuity was caused partly by frictional differences and partly by the difference in the actual surcharge load, i.e. between $B_c U_s$ in the wide condition and $B_d U_s$ in the narrow condition.