LOADS ON NEGATIVE-PROJECTING CONDUITS

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● Neither the concept of the negative-projection loading condition nor its utilization to insure lighter loads on culverts is new. Spangler[1] presented the load theory for this case in 1950, but the work reported here is the first experimental study of this phase of conduit loading.

The term "negative projecting conduit" as now used refers to the method of "culvert" construction in which the conduit is laid in a shallow trench dug in the natural soil of the embankment subgrade. The resulting negative-projection loading conditions fall into one of two general classes, in both of which the settlements of the interior prism of fill over the conduit, or over the trench in which it is laid, are greater than those in the adjoining exterior prisms which rest on compacted or natural subgrade. The resulting shearing forces act upward on the interior prism, transferring a part of its weight to the adjacent exterior prisms.

The other general class of negative-projection loading condition is termed the "imperfect-ditch condition." This designation is a carry-over from previous work, but it is descriptively correct, because the loading conditions are an imperfect, or incomplete, approach toward true ditch-conduit loading conditions. The imperfect-ditch condition normally is produced by compacting fill around the pipe up to some selected height over it, excavating a trench down to the pipe and refilling the trench with loose, uncompacted material. The resulting loading conditions are similar to those for negative-projecting conduits, except in two particulars: (1) the material at the sides of the trench will be less compressible than that in the trench, but may not be as firm as the soil of the natural subgrade; and (2) the width of the trench normally is no greater than the outside diameter, or breadth, of the conduit.

The Iowa Engineering Experiment Station made studies of the loads on positive projecting conduits from 1915 to 1920. Dean Marston was so impressed by the magnitudes of the loads in those studies that he attempted to find a method of construction which would produce lower loads for given heights of fill. In 1920–21 a forerunner of the present imperfect-ditch condition did reverse or decrease the frictional transfers to such an extent that the loads for heights of fill up to 12 ft. were close to those by the previously developed ditch conduit load theory, and those for heights of fill up to 20 ft. were much lower than those in the 1919–20 study with positive projections.

The completion of the projecting-conduit load theory (for positive projection)[2] in 1926 made possible a general qualitative explanation of the results of the 1920–21 study. The imperfect-ditch condition then was given sufficient publicity that the method was reported to be used in Pennsylvania in the early 1930's. It was recognized in 1934 by the Bureau of Public Roads in a memorandum to its district engineers. In more recent years, reports from several western states, notably California, indicate that the negative-projecting-conduit method has made it possible to use concrete pipe satisfactorily under some unusually high fills.

Despite the lapse of time and the accumulation of field experience, the safe structural design (Fig. 1) of a negative-projecting-conduit installation still involves considerable judgment. Spangler's load theory appears to be a logical development based upon correct theoretical concepts, but his paper presents no supporting data. This report presents the first measured values of settlements for use in that theory.

Cooperative Agreement—This study of the loads on negative projecting conduits is being carried out under a coöperative agreement between the station and the Iowa State Highway Commission. The Bureau of Public Roads is also a coöperator in that a part of the funds provided by the highway commission are from federal-aid allotments; in addition, the cur-

[1] Spangler, M. G. A Theory on Loads on Negative Projecting Conduits. Proceedings, Highway Research Board, Vol 30, p. 153. (1950).

[2] Marston, Anson. The Theory of External Loads on Closed Conduits in the Light of the Latest Experiments. Proceedings, Highway Research Board, Vol. 9, p. 138 (1929) Iowa Engineering Experiment Station, Bul 96 (1930).

rent study utilizes parts of the set-up for a 1927 study in which the bureau cooperated.

Objectives—The primary objectives of the current study are: (1) to determine the loads on three negative projecting conduits, and to observe the actions and factors which affect those loads, and (2) to utilize the data from (1) in the determination of both a reliable method and of safe values of certain constants for calculating the probable maximum loads on negative-projecting conduits.

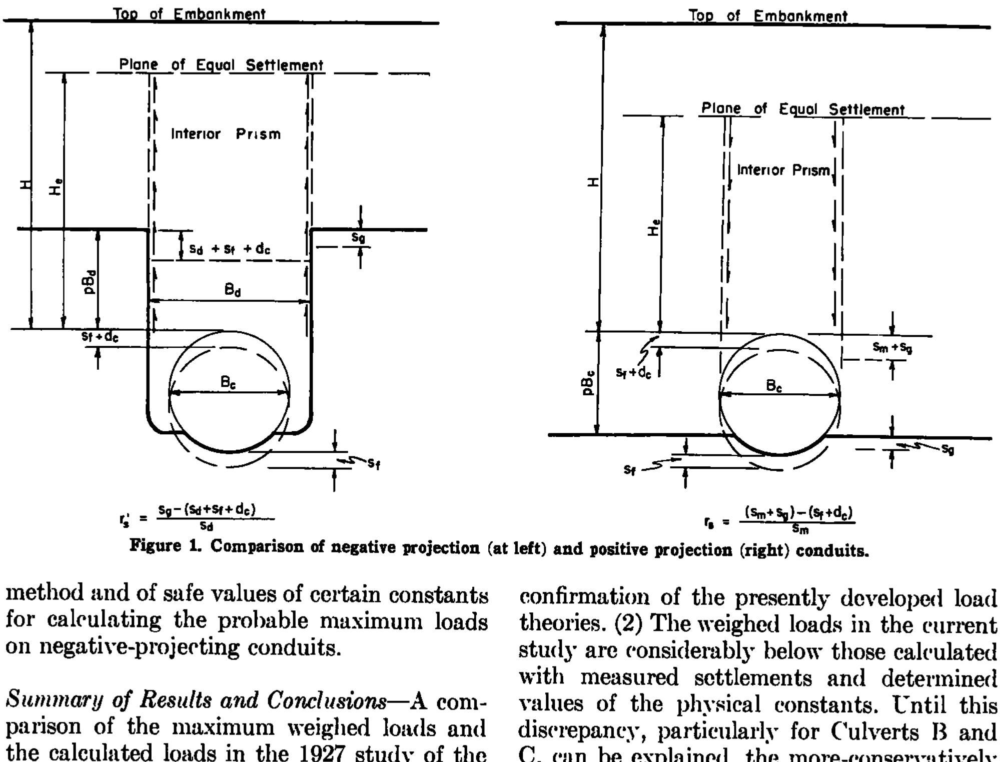

Figure 1. Comparison of negative projection (at left) and positive projection (right) conduits.

Summary of Results and Conclusions—A comparison of the maximum weighed loads and the calculated loads in the 1927 study of the loads on positive-projecting conduits and in the 1949 study of the loads on negative-projecting conduits, is given in the following tabulation.

The results in this tabulation are the basis for two conclusions: (1) The weighed and calculated loads for these negative-projecting conduits are materially lower than those in the 1927 study of the loads on positive-projecting conduits of the same types under a fill constructed to the same height and of the same fill material; this fact provides qualitative confirmation of the presently developed load theories. (2) The weighed loads in the current study are considerably below those calculated with measured settlements and determined values of the physical constants. Until this discrepancy, particularly for Culverts B and C, can be explained, the more-conservatively calculated loads should be accepted as giving the better indication of the reduction in load which can be obtained through the use of the negative-projection condition.

LOADS IN LB. PER LIN. FT. OF CONDUIT

	Culvert A		Culvert B		Culvert C	
	Weighed	Calc.[a]	Weighed	Calc.[a]	Weighed	Calc.[a]
1927 study Positive projection Load	p = 0.90 9,990	p = 0.90 11,600	p = 0.90 10,120	p = 0.90 11,400	p = 0.90 9,990[b]	p = 0.90 11,600[b]
1949 study Negative projection Load	p′ = 0.25 4,710	p′ = 0.25 5,290	p′ = 0.50 3,200	p′ = 0.50 4,550	p′ = 0.75 2,660	p′ = 0.75 3,900

[a] Calculated in accordance with the applicable load theory.
[b] Loads for Culvert A used as basis for comparison.

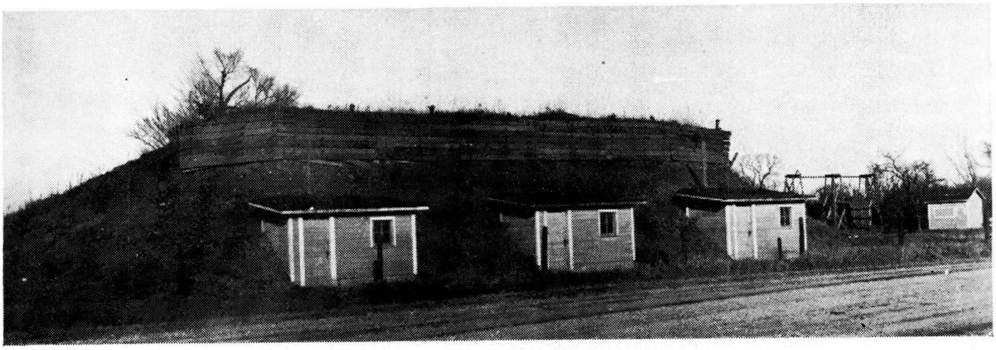

Figure 2(a). Completed fill with scale houses at bottom. Note 5-ft. cribbing at top of fill (1927 studies).

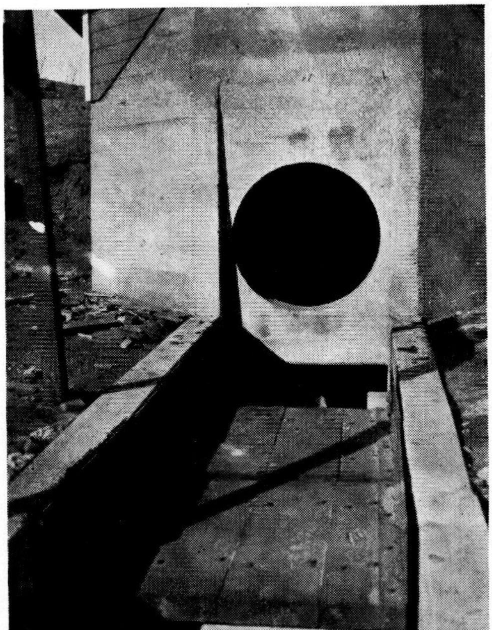

Figure 2(b). Two weighing platforms installed in line, each with its own lever-support system.

GENERAL PLAN OF CURRENT STUDY

The study of the loads on negative-projecting conduits utilizes parts of the set-up for the 1927 study. The general plan for the earlier study will be explained, and then the procedures in the current study will be presented.

The 1927 Study—This study has been reported in detail only in a progress report submitted by Spangler under date of January 1, 1929. The following descriptions and procedures are summarized from that report:

The layout of culverts, the weighing systems and scale houses, and the dimensions of the fill in the 1927 study were the same as those shown in Fig. 3. The original project outline called for a fill 10 ft. high over the conduits. When the fill was nearly up to the 10-ft. level, it was decided that a fill 15 ft. high was desirable. Consequently, the additional 5 ft. of fill was placed as a cribbed fill 16 ft. wide and 70 ft. long.

Each culvert consisted of four center sections 47½ in. long and two end sections (not weighed) 5 ft. 11 in. long; all pipe sections had plane ends. The pipe for Culvert A was 36-in. reinforced-concrete pipe with 4-in. walls; for Culvert B, 42-in. cast-iron pipe with 1.10-in. walls; for Culvert C, corrugated-metal pipe of 43 in. outside diameter, rolled from 8-gage metal.

The pipe of each culvert was laid, with a projection ratio of 0.90, in a sand bedding. The bedding for each of the four center sections of each culvert was prepared in a bedding or weighing platform (Fig. 2). Each bedding platform was supported at three points by an I-beam lever system fitted with hardened-steel knife-edge bearings. Each lever system transferred a definite proportion of the platform load to a platform scale in one of the scale houses built between the head and wing walls at the ends of culverts. The beddings for the 6-ft. end sections were prepared in similar platforms which were rigidly supported.

The spaces between adjacent platforms, and

between the platforms and the concrete sides of the weighing-lever trenches, were covered with strips of galvanized iron before the sand beddings were placed. The spaces between adjacent pipe sections were covered similarly.

The weighing system for each weighing platform was calibrated before the sand bedding was formed. These calibrations showed an average ratio of 30:1; that is, 30 lb. of load on a platform gave a reading of 1 lb. on the corresponding platform scale.

The fill was placed with horse-drawn slip scrapers; there was no artificial compaction except that due to team traffic.

The unit weight and the coefficient of internal friction of the fill material were determined by sinking two shafts from the surface of the fill to the level of the top of the pipe. The first shaft was sunk in December 1927, just as the fill was completed, and the other in August 1928.

The average unit weights, determined by weighing all of the material from each foot of depth were 119.8 and 121.8 lb. per cu. ft. in the two determinations; a value of 120 is used in calculating loads.

The values of coefficient of internal friction, determined with the excavated material, ranged from 0.53 to 0.81; these give values of $K\mu$ of 0.191 to 0.184. The theoretical maximum value of 0.1924 is used in load calculations.

The 1949 Study—The current study utilizes the bedding and weighing systems of all three culverts as installed for the 1927 studies, and the pipe of Culverts A and B. The corrugated metal pipe of Culvert C was replaced with 36-in. reinforced-concrete pipe.

Removal and Replacement of Fill—The fill over the three culverts of the 1927 study was removed down to the new subgrade levels (Fig. 3), in the fall of 1948 by the use of a small "cat" and "tumble-bug" scraper. Natural consolidation, and the effects of dry weather, had produced a subgrade so hard that fine grading was difficult; fine grading of Culverts B and C was postponed till the spring of 1949.

A trench 4 ft. wide was dug down to the top of the pipe of Culvert A for the full distance between headwalls. The fill over the upper portion of the pipe was removed with shovels. A narrow hoe then was used to loosen the balance of the fill at the sides down to the top of the sand bedding and to pull it to the sides of the 6-ft. dummy section at each end. This procedure required that the side of the trench be curved outward slightly at the midheight of the pipe, making it possible to remove most of the side fill and loosen the balance. A temporary cover then was placed over the trench and work was suspended.

When work was resumed in the early summer of 1949, the subgrades for Culverts B and C were completed and the trench for Culvert B excavated and cleaned. Since the corrugated-metal pipe of Culvert C was to be replaced, the trench was dug and the pipe sections lifted out with a mobile crane. Then the trench was cleaned, and the new concrete pipes were placed and lined up; all this was done with special care to disturb the sand bedding as little as possible.

As soon as the recalibrations of the weighing systems (described in the next section) were completed, each trench was filled with loose material, shovel-placed. The balance of the fill up to the 10-ft. level was placed with the tumble-bug scraper in 6-in. layers to build up 2-ft. lifts. The tractor was not permitted to cross the trench over the four center sections of each culvert till the fill was at least 1 ft. above the subgrade, though an effort was made to have all other portions of the fill receive equal compaction. The upper 5 ft. of cribbed fill was placed with a dragline working at each end and at the middle on one side; this fill was placed in layers as cribbing planks were added.

Since the cribbed fill received no compaction, it was rounded up slightly and later leveled off to a height of 15 ft. ± 0.1 ft.

The cribbing was made of 2- by 10-in. planks. The longitudinal planks were restrained with rods. The end planks were restrained by cleats on the ends of the side planks. Two-in. blocks were placed temporarily under each cribbing plank as it was set, so that the plank and its restraining rods might settle with the fill. Also, a strip of lightweight roofing was tacked to the lower-inside edge of each plank to cover the space between it and the next lower plank.

Rehabilitation and Recalibration of Weighing Systems—Before any fill was removed, the weighing systems for all three culverts were cleaned and reconditioned in the fall of 1948. The knife-edge bearings were examined and cleaned with a wire brush. Each main-load

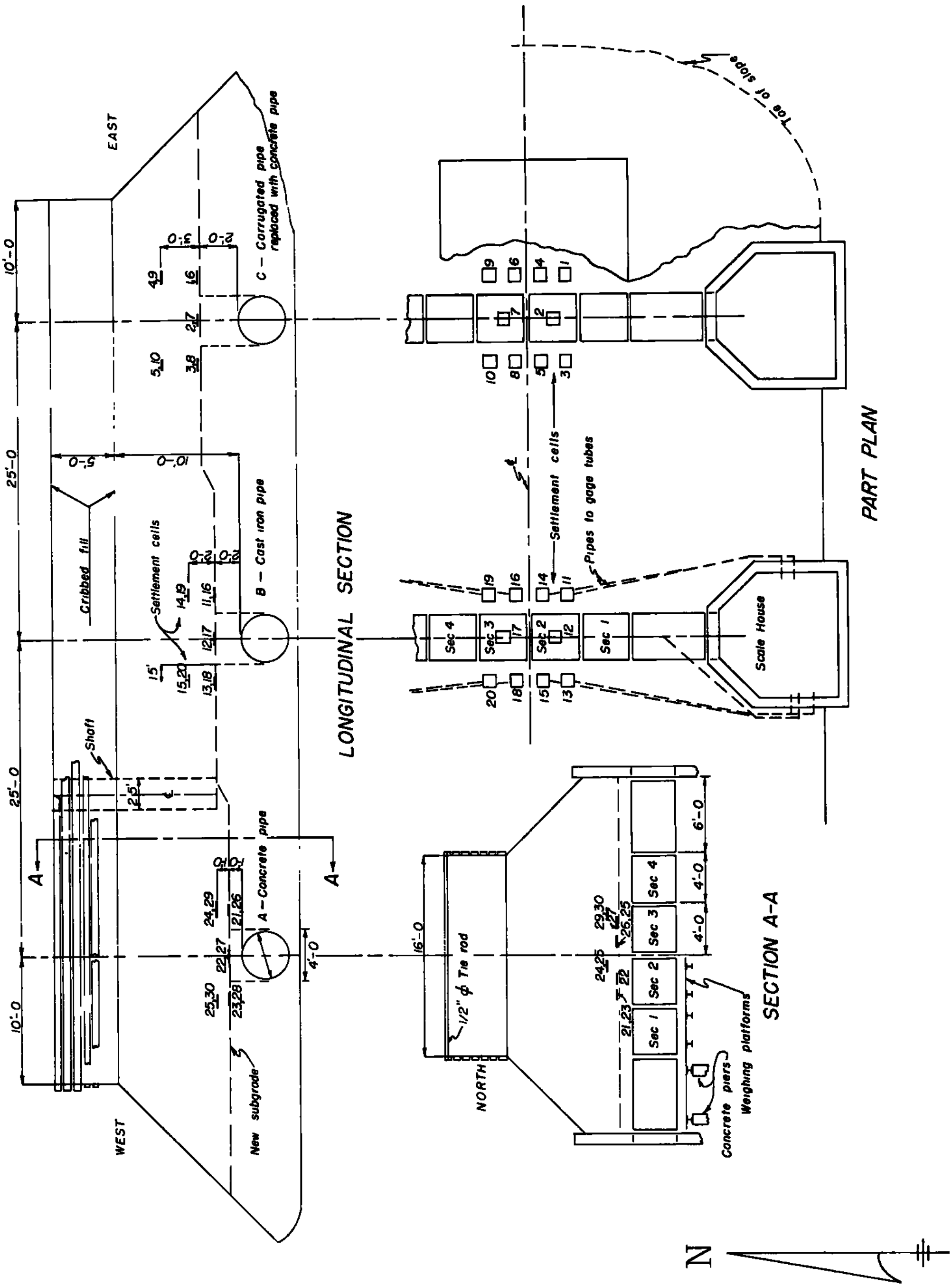

Figure 3. General layout of negative-projecting conduits of the Iowa Engineering Experiment Station studies.

beam was jacked up just enough to permit removal of the support on the scale platform. The scale was then cleaned and checked and the scale support repaired if necessary.

It should be noted that the weighing systems were reconditioned before any of the original fill was removed and that the eight scales for Culverts A and B had been carrying loads almost double their rated capacities for 21 years. It should be noted also that after the reconditioning each scale gave the same reading when balanced by moving the poise in or out.

Before any fill was replaced, the weighing systems of two or more of the four center sections of each culvert were recalibrated by placing concrete-slab weights on a wooden-saddle platform resting on one pipe section. This calibration was made with the pipe in place in the continuous sand bedding and gave an average ratio of 31:1. The recalibration showed that slight inequalities in settlement had caused some binding between adjacent pipe sections. Such cases were corrected by using a pinch bar to adjust the sections longitudinally.

Measurements of Settlement—The settlements of the subgrade, the fill over the pipe at subgrade level, and the fill over the subgrade at heights equal to the negative projection distances (Fig. 3), were measured with settlement cells of an improved design (Fig. 4). Every fall since their installation all the cells have been drained and refilled with a 50:50 solution of radiator alcohol and water; each spring the cells were drained, flushed, and filled with water.

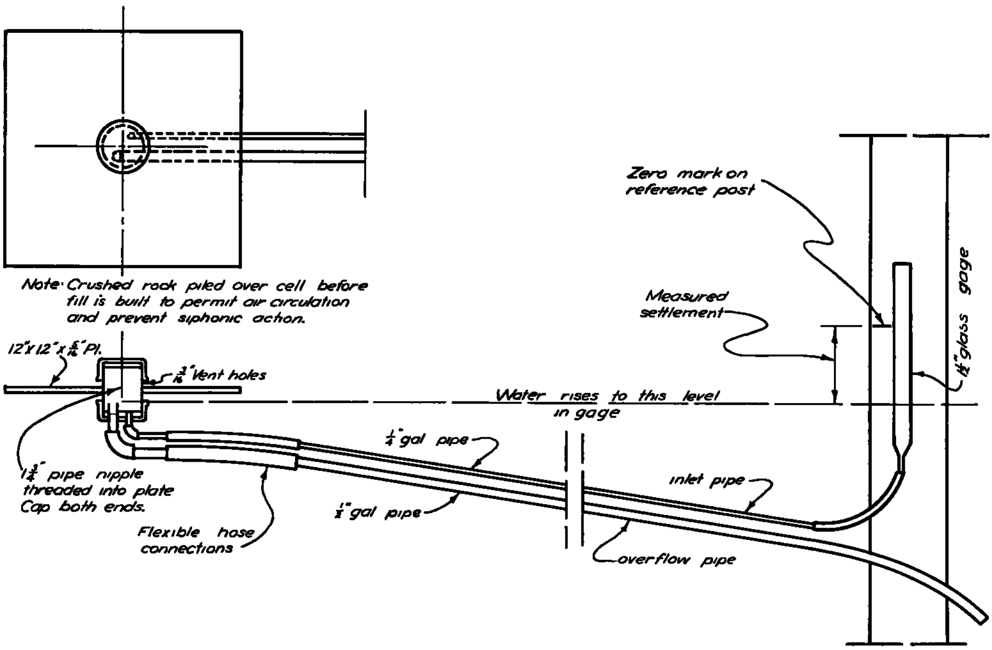

Figure 4.

When the 1927 study was started, a brass plug was leaded into the north headwall of each culvert, and similar points were set or drilled at the midlength of the invert of each of the four center sections of each culvert. Similar points were drilled in the new concrete-pipe sections of Culvert C. Using the headwall plugs as reference points, the settlements of the inverts were obtained from elevations determined with an engineer's level and a short section of level rod fitted with a steel point. It is possible to estimate rod readings to 0.001 ft. when the rod is lighted with a flash light.

The program for the 1927 study provided

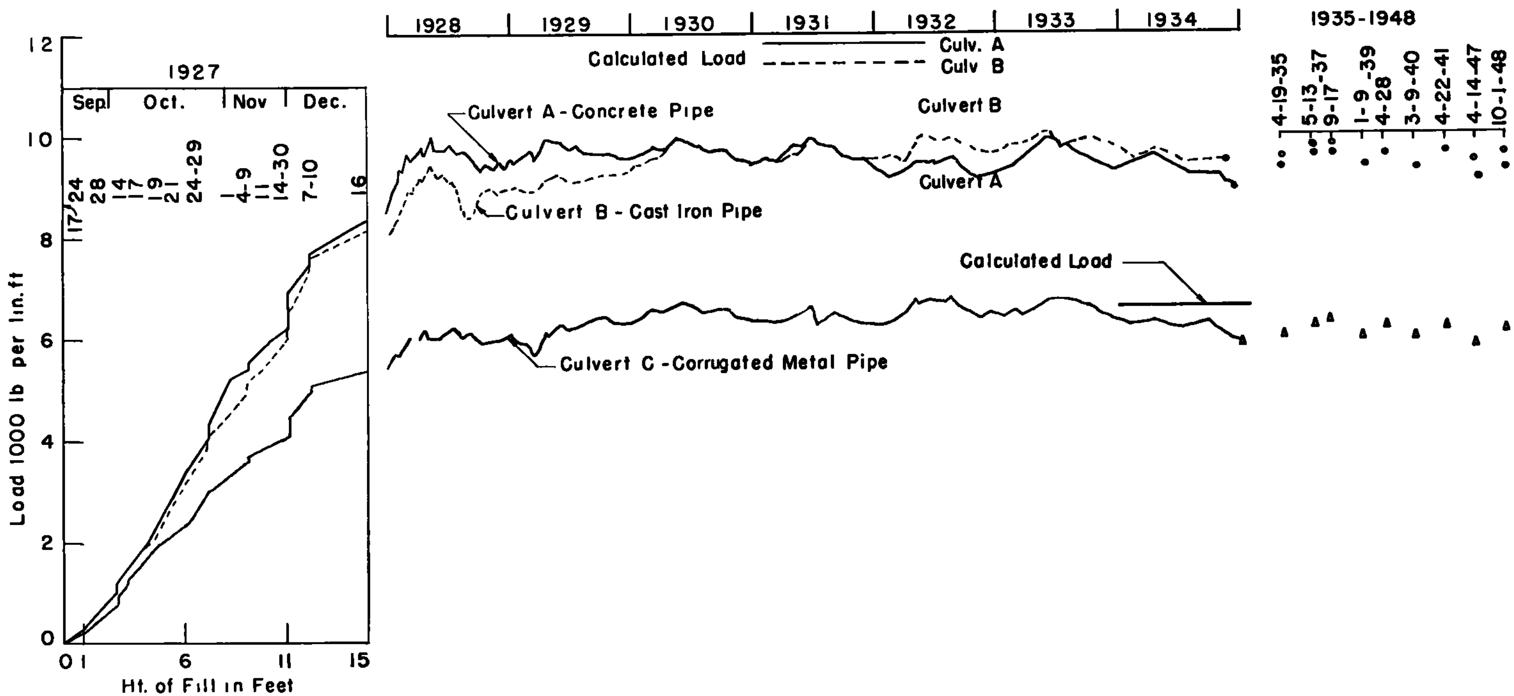

Figure 5. Load-time graphs, positive projection (1927 tests).

for measurements of diameter changes with micrometer heads mounted on Stoic-metal[3] rods. A review of those records showed that the settlements due to diameter changes were so small that they could be neglected. Accordingly, this settlement is assumed to be zero in the current study.

The settlement-plate readings, to $\frac{1}{16}$ in., were taken as the fill was built and periodically thereafter. The settlements of the pipe inverts developed more slowly, so they were determined less frequently.

Determination of Unit Weight and Coefficient of Internal Friction of Fill Material—The unit weight of the fill material was determined by sinking a shaft 2.5 by 3.5 ft. in cross-section, and weighing all of the material from each 1.0-ft. depth. The data, obtained in 1950 about 15 months after the fill was completed, show an average unit weight of 116.0 lb. per cu. ft.

The values of μ (coefficient of internal friction) were determined from several trials with the material from each 1.0-ft. depth as the shaft was dug. These data show μ to have an average value of 0.71, with maximum and minimum values of 0.88 and 0.62. Since the corresponding values of $K\mu$ are between 0.180 and 0.192, the maximum value of $K\mu$ = 0.1924 will be used in load calculations.

Much of the fill was dry, some of it almost powdery dry, when placed. When the shaft was sunk in 1950, much of the fill was rather loose and did not appear to have been moistened. However, the unit weight indicates a fairly high density for this material.

LOAD AND SETTLEMENT DATA

The loads for Culverts A and B in the 1927 study provide the basis for a comparison which illustrates the load advantage which may be gained through the production of negative-projection loading conditions. The complete load records of the 1927 study, which have not been previously reported, are presented first. Although the loads on the flexible-type pipe of Culvert C cannot be used for direct comparisons, they provide additional data on the general load problem and so are included.

[3] Trade name for a low-expansion nickel-steel.

Loads in the 1927 Study—The weighed loads on the three culverts in the 1927 study are shown by Fig. 5.

It will be noted that the load for Culvert B decreased sharply after the fill was completed and did not again equal that for Culvert A till the summer of 1930. Because of a misunderstanding, the first shaft for the determination of the physical constants of the fill material was located so that one side of the shaft was only 1 ft. from the side of Culvert B. The effect of the shaft was not reflected in the weighed loads till the shaft was about 8.0 ft. deep; the effect appeared to be greatest about the time the shaft was completed and refilled and was limited primarily to the two center sections of Culvert B. Since the average load

TABLE 1
ANNUAL MAXIMUM WEIGHED LOADS 1927 STUDY—PROJECTING CONDUITS

Year	Loads in lb. per lin. ft. of conduit					
	Culvert A		Culvert B		Culvert C	
	Mo.	Load	Mo.	Load	Mo.	Load
1928	May	9,880	May	9,340[a]	May	6,220
1929	Apr.	9,950	Dec.	9,360[a]	Sept.	6,400
1930	May	9,960	May–June	9,860[a]	May	6,640
1931	June	9,990	June	9,950	June	6,610
1932	Aug.	9,590	May–July	10,010	Aug.	6,840
1933[b]	May	9,950	May	10,120	July	6,760

[a] Not true maximums because of effect of the shaft.
[b] Records for 1934–48 not complete enough to show annual maximums.

for the four sections of this culvert increased gradually till it equalled and then exceeded that for Culvert A, no attempt is made to correct the load data for Culvert B during this period.

The records for these three culverts illustrate two phenomena observed in each of the Iowa Engineering Experiment Station's long-time, weighed-load studies of the loads on conduits under earth fills. The load record for each culvert shows the usual seasonal fluctuations, with the maximum for each year in the summer and the minimum in the winter; the winter minimums normally were at least 90 percent of the summer maximums. That the loads for each culvert tended to increase for a period of years, with minor fluctuations from year to year, is illustrated by the records for Culverts A and C.

The maximum weighed loads for each year,

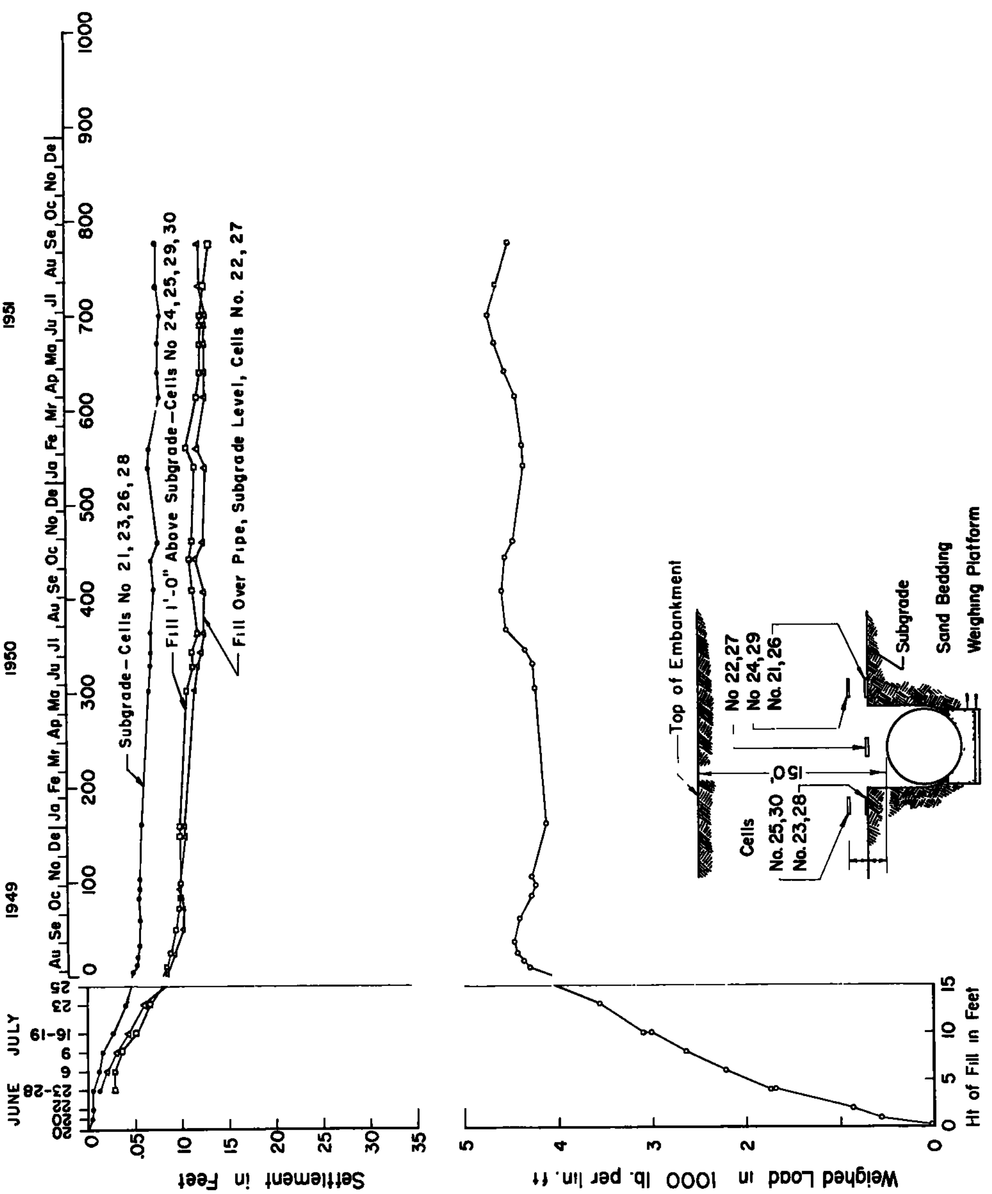

Figure 6. Load and settlement, Culvert A (subgrade 1 ft. above top o pipe

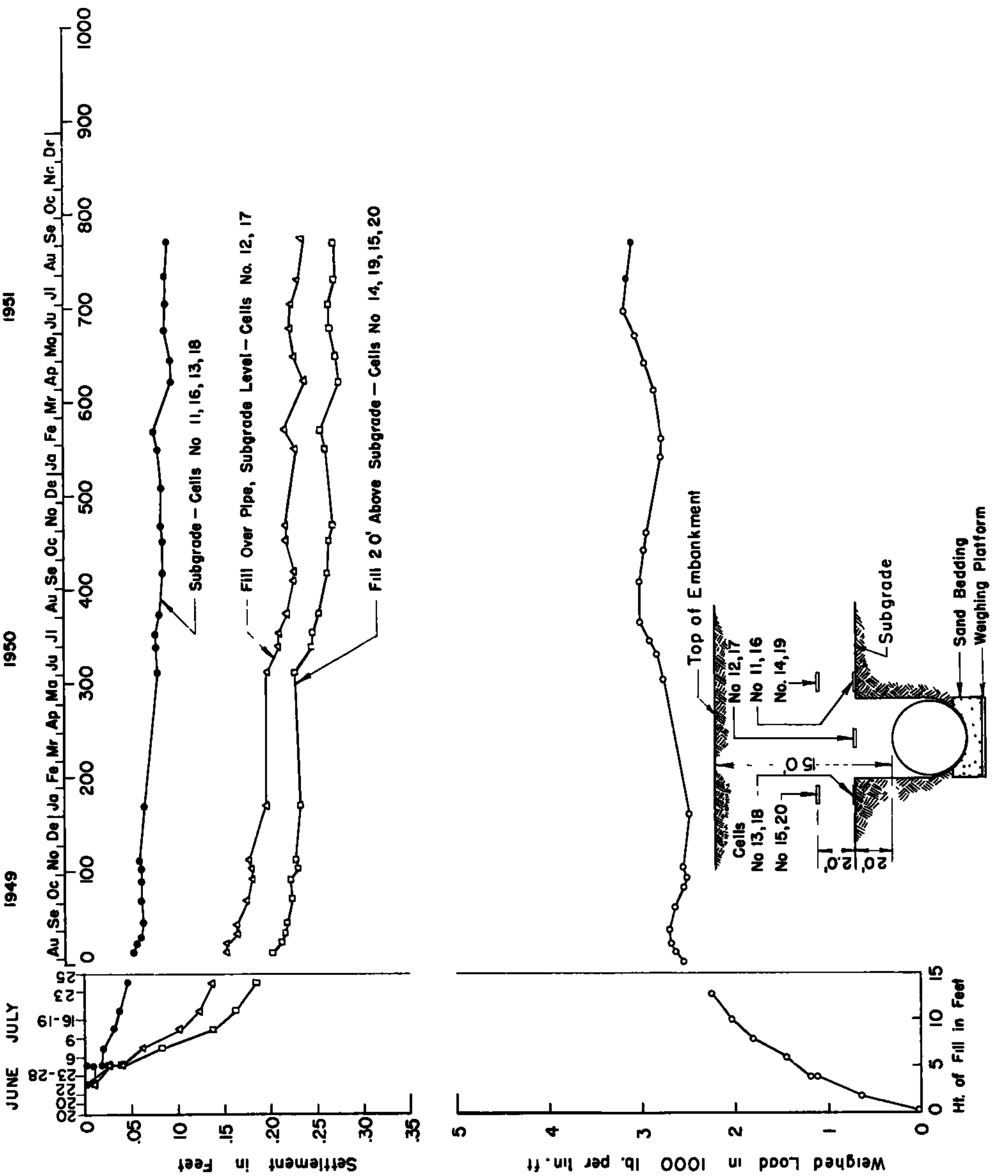

Figure 7. Load and settlement, Culvert B (subgrade 2 ft. above top of pipe).

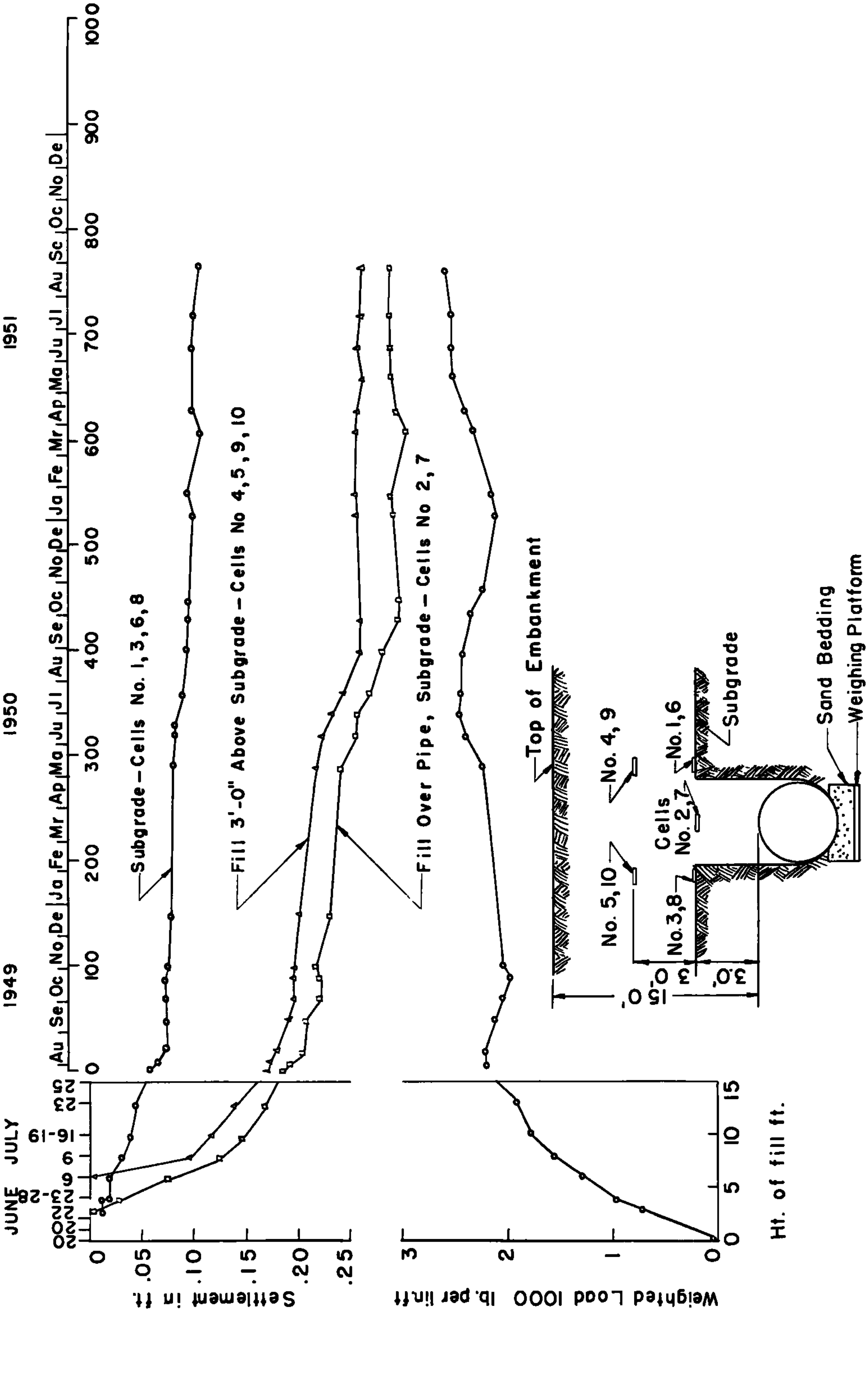

Figure 8. Load and settlement, Culvert C (subgrade 3 ft. above top of pipe).

1928–33, are shown in Table 1. The records for 1934–48 are not complete enough to show annual maximums, but they do indicate that the load on each culvert probably had reached its maximum by 1933 and that the fluctuations thereafter probably were much the same as those during the 1928–33 period.

The loads calculated with the measured settlements and the determined values of the physical constants of the fill material are: for Culvert A, 11,600; for Culvert B, 11,400; and for Culvert C, 6,450. The settlement data for Culvert C gave values of the settlement-projection product near zero, and ranging from −0.09 to small positive values. The load reported for Culvert C is that for $r_s p = 0.0$, or is equal to the weight of the prism of fill over the conduit. The calculated loads for Culverts A, B, and C are 116, 113, and 94 percent, respectively, of the maximum weighed loads. The close correlation between calculated and weighed loads provides additional confirmation of the Marston fill-load theory.

TABLE 2

SUMMARY OF WEIGHED AND CALCULATED LOADS, NEGATIVE-PROJECTION LOADING CONDITIONS

	Culvert A $p' = 0.25$	Culvert B $p' = 0.50$	Culvert C $p' = 0.75$
	lb. per lin. ft. of conduit		
Weighed Loads			
Fill completed, July, 1949	4300	2570	2250
Maximum, summer, 1949	4500	2670	2280
Minimum, winter, 1949–50	4150	2490	2000
Maximum, summer, 1950	4590	3070	2440
Minimum, winter, 1950–51	4330	2760	2170
Maximum, summer, 1951	4710	3200	2660
Calculated Loads			
Calculated load	5290	4550	3900
Ratio to maximum weighed load	1.12	1.41	1 46

Loads and Settlements in the Current Study—The load and settlement data in the current study of the loads on negative projecting conduits are shown by Figures 6, 7 and 8. The load graphs, and the summarized data in Table 2, show the usual seasonal variations and that the weighed loads are still increasing. The maximum weighed loads in the summer of 1951 were 109, 124, and 118 percent of the loads when the fill was completed in the summer of 1949. It is interesting, though it may or may not be significant, to note that the percentage increase in load has been least for Culvert A, whose weighed load was nearest to the calculated load.

These load and settlement data illustrate the variations which should be expected for similar conduits with supposedly similar loading conditions under fills of supposedly similar materials. The construction procedures were planned to insure that the fill immediately over the pipe, *i.e.*, the fill in the trench up to the subgrade level, would be loose and uncompacted, and that the fill over the subgrade would receive compaction from the earth-moving equipment. The settlement data indicate that this objective was realized for Culverts A and C, but for Culvert B the fill immediately over the conduit was slightly less compressible than the lightly compacted material over the adjacent subgrade. This is another variation which may not prove to be significant.

Table 2 summarizes the load records for these three negative-projecting conduits, and shows the comparison between the maximum weighed loads and those calculated with the Spangler formula. The correlation between weighed and calculated load is good for Culvert A; the wider variations for Culverts B and C suggest that until the variations can be explained the safe procedure will be to judge the effectiveness of negative-projection loading on the basis of calculated load.

A comparison of the calculated loads in the two studies shows that the calculated loads for the negative projecting conduits, with three values of negative projection, are 45, 40, and 34 percent of those for 0.90 positive projection in the 1927 study. This comparison demonstrates the effectiveness of negative-projection loading as a means of decreasing the load on culverts to be installed under high fills.