An Experimental Study of Lateral Pressures on Abutment Retaining Walls

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This paper presents the results of an experimental study of the lateral pressures transmitted through the soil to an abutment retaining wall. The lateral pressures were the result of concentrated surface wheel loads and were measured in the soil backfill and at the soil-structure interface.

The first portion of the study was an evaluation of the effect of variations in the type of soil used in the backfill on the pressure distribution. This was accomplished by using two different types of soil: well-graded granular soil with considerable fines, and a uniformly graded medium sand. The results show the variation in pressure attributed to the difference in soil characteristics.

The second portion of the study was an evaluation of the effect of the relative rigidity of an abutment retaining wall on the magnitude and distribution of soil pressure. For this study two types of abutment retaining walls were used and compared.

In each phase of the investigation, the resulting experimental pressures are compared with the theoretical Boussinesq solution of lateral pressures transmitted through an elastic, homogeneous, isotropic, semi-infinite media. The results indicate that the pressures at the soil-wall interface are larger than the pressures measured in the soil. This increase in pressure is due to the discontinuity in the soil mass resulting from presence of the abutment retaining wall. The results also indicate the effect of flexibility of the wall on the lateral pressure at the soil-wall interface.

•THE PROBLEM investigated concerns the transmittal of lateral pressure through a soil backfill to an abutment retaining wall structure. The lateral pressure was the result of a concentrated wheel load on the surface of the backfill material.

M. G. Spangler (8) in 1938 reported one of the first experimental results concerning this problem. The objective of his study was to determine the magnitude and distribution of lateral forces transmitted to a retaining wall through a gravel backfill by a concentrated wheel load applied on the backfill surface. He found the measured pressures were distributed in accordance with the Boussinesq theory of distribution of pressures through an elastic medium due to a concentrated load. The magnitudes of the pressures were two to three times as great as those calculated by the Boussinesq equations. In his investigations, one type of soil was used with one type of wall construction. Deflection of the wall was not investigated.

L. White and G. Paaswell (14) in 1939 discussed the application of the Boussinesq equation for soils from a theoretical viewpoint. It was generally agreed that the Boussinesq equation would be a closer approximation than the usual rule of thumb. This rule utilizes an additional depth of backfill in the calculations of lateral pressure due to surcharge loads. Their findings, as well as the experimental evidence of Spangler, showed that the intensity of pressure due to a surface load is maximum near the surface and diminishes rapidly in intensity with depth. This observation is quite in contradiction to the usual method of analyzing surcharge loads.

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W. Weiskopf (13) in 1945 proposed a theory concerning the pressure created against a rigid wall. His theory assumed that an imaginary load P′ would induce a lateral pressure against the vertical plane. This value would be equal to the lateral pressure exerted by the actual load P on that plane in the unrestrained soil mass, and would combine with this load. Therefore, the actual pressure, which would be measured at the wall, would be double the lateral pressure exerted by the actual load.

Relatively little work has been done with the problem of lateral pressure created by surcharge loads. There is little evidence, in the literature, of work presently being done on the subjects of comparison of pressures created with different soils, and the effect of the movement of the retaining wall under pressure.

The first objective of the investigation was to determine the variation of lateral pressure distribution resulting from different types of soil under wheel loads. The second objective was the comparison of pressure distribution due to the relative rigidity of the wall construction.

To accomplish these objectives, a special test abutment was constructed incorporating the essential study features which were the walls of the abutment. One wall of the abutment was relatively flexible, whereas the other was rigid. A number of pressure sensing devices were placed in the backfill and the backfaces of the walls. These pressure sensing elements provided measurement of lateral pressure in the soil mass and on the walls.

In the investigation of variation of pressures due to different soil types, the main problem was to study the pressure bulbs created. The objective was to determine if the soil characteristics would have any influence on the pressure bulbs developed. To obtain a complete picture of the pressures created, the pressures were measured both in the soil away from the wall and at the soil-wall interface. The two soils used were different in their gradation characteristics.

The pressure bulbs created for both soils were compared with the theoretical Boussinesq solution for pressure distribution. The comparisons were made both in the horizontal and vertical planes thus illustrating the complete pressure bulb as it was developed throughout the soil to the wall.

The second objective was to determine the effect of wall movement on pressure created. The slab of the abutment was on rollers at the flexible wall which allowed the wall to deflect when pressure was applied. The wall deflections were measured as well as the applied pressures both at the flexible wall and at the rigid wall. These pressures were also compared with the theoretical Boussinesq solution.

THEORY OF LATERAL PRESSURE

Application of Elastic Theory

In 1885, J. Boussinesq derived equations for the stresses on a boundary of a semi-infinite body using the theory of elasticity. Boussinesq's stress distribution theory was for the simplest case of loading of a solid which was considered to be a homogeneous, elastic, isotropic, semi-infinite medium. This would be the case of a single, vertical, concentrated load applied at a point on the horizontal surface.

The application of a concentrated load on the ground surface would result in a lateral stress distribution as shown in Figure 1. The equation for lateral stress derived by Boussinesq is as follows:

$$\sigma_X = \frac{P}{2\pi}\left[\frac{3X^2Z}{R^5} - (1 - 2\mu)\left(\frac{X^2 - Y^2}{R^2r^2(R + Z)} + \frac{Y^2Z}{R^3r^2}\right)\right] \tag{1}$$

in which μ = Poisson's ratio, and all other symbols have the meanings indicated in Figure 1. For the complete derivation of Eq. 1, see S. Timoshenko (11). Poisson's ratio for soil has always been very difficult to ascertain. The range of Poisson's ratio varies from $\mu = 0$ to $\mu = 0.5$. It can be said that the order of magnitude of Poisson's ratio for soil must be closer to the upper limit of 0.5 than to the lower limit of zero. Eq. 1 would then be simplified and results in:

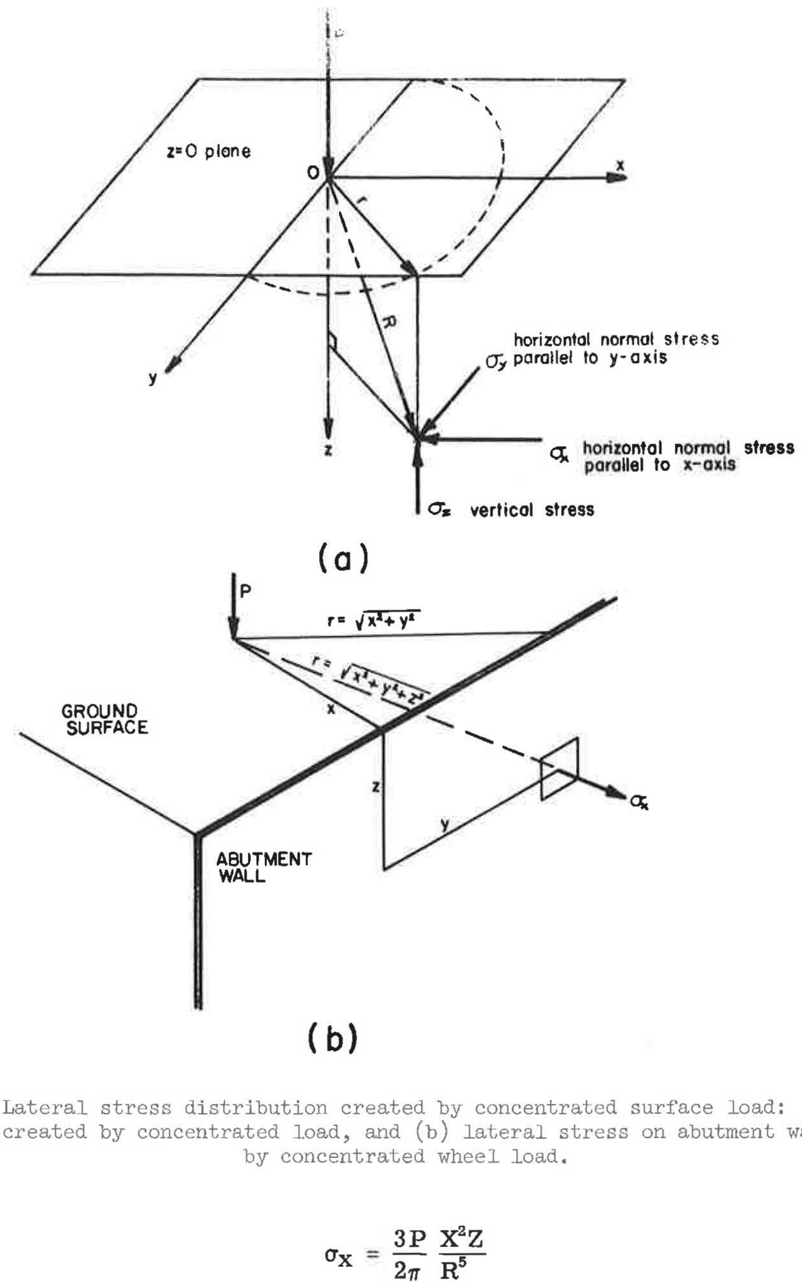

Figure 1. Lateral stress distribution created by concentrated surface load: (a) stress components created by concentrated load, and (b) lateral stress on abutment wall created by concentrated wheel load.

$$\sigma_X = \frac{3P}{2\pi}\frac{X^2Z}{R^5} \tag{2}$$

Calculations for Theoretical Pressures

Calculations were made, according to Boussinesq's theory, to determine the location of the load for the maximum lateral pressure in a horizontal plane. This was accomplished by two methods. First, calculations were made for horizontal planes passing through the depths of 1, 2 and 3 ft with a unit load placed every one-half foot from the wall, on the centerline, until the maximum values of lateral pressures were obtained. The resulting curves are shown in Figure 2. Second, the Boussinesq equation was differentiated with respect to X (the distance from the wall) to determine the location of the load for maximum lateral pressure. Solving for x gave the relationship $X = Z\sqrt{2/3}$.

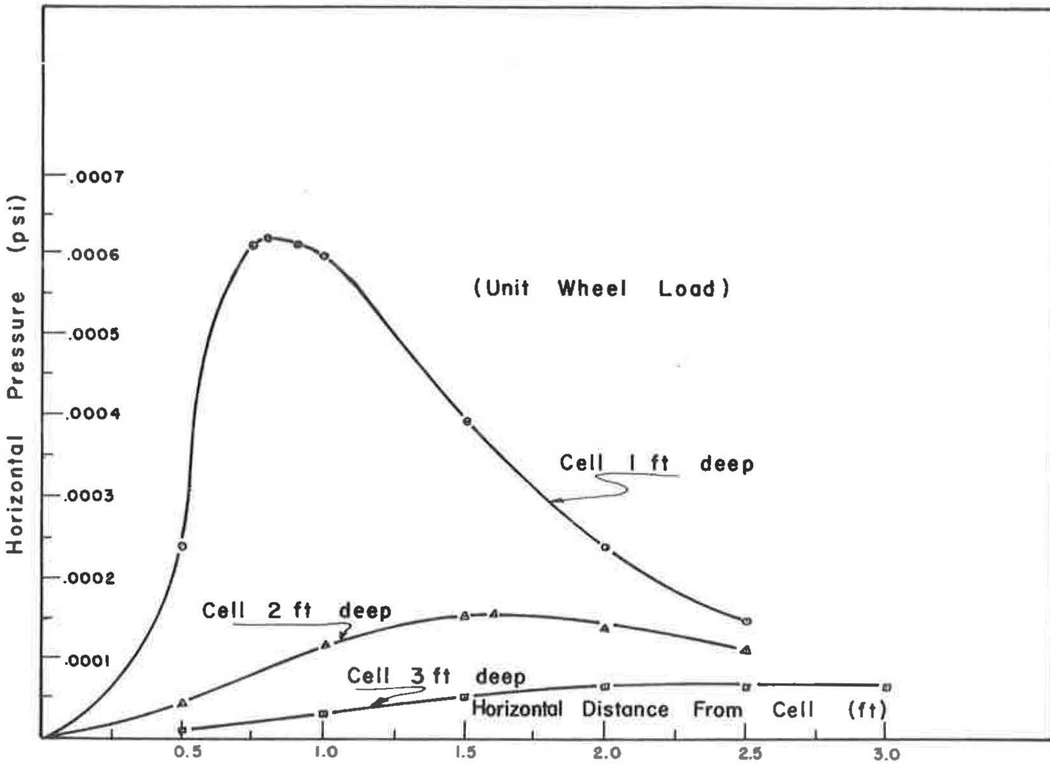

Figure 2. Theoretical variation in horizontal pressure as a wheel load approaches pressure cell.

The relationship is shown in Figure 2, in which the theoretical pressure distribution is plotted in a manner similar to that of an influence line. These calculations determined where the load should be placed to obtain the maximum lateral pressure in the horizontal planes at depths of one, two and three feet. To determine the maximum lateral pressure in this vertical plane, the Boussinesq equation was differentiated with respect to Z (the distance below the surface). The maximum lateral pressure in the vertical plane will theoretically occur at a depth $Z = X/2$.

EXPERIMENTAL SETUP

The Test Abutment

The test abutment was designed as a part of a larger research project for the New Mexico State Highway Department. An isometric view with dimensions is shown in Figure 3. It is apparent that there is a definite difference in the construction of the two walls. The flexible wall is basically a simple cantilever type. The rigid wall is a step type cantilever and is constructed rigidly. This was done to determine the variations in soil pressure with respect to the relative rigidity of wall construction.

Figure 4 shows an end view of the test abutment before the backfill material was placed. Figure 5 shows the approach from the roadway after backfilling.

The Test Vehicle

The test vehicle is shown diagrammatically in Figure 6. The truck was loaned to the project by the New Mexico State Highway Department. The truck was loaded evenly with iron rails and the resulting wheel loads were as follows: front wheels, 2,350 lb each wheel; and rear wheels, 10,400 lb each dual.

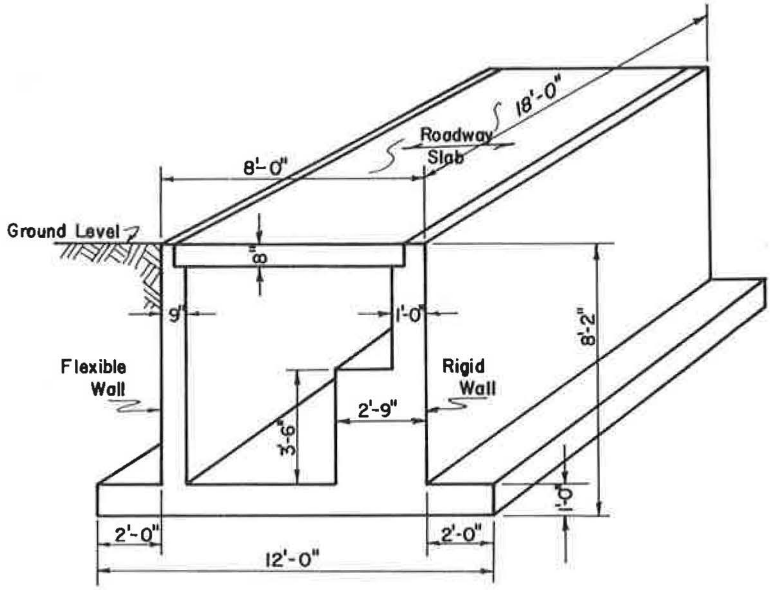

Figure 3. Test abutment.

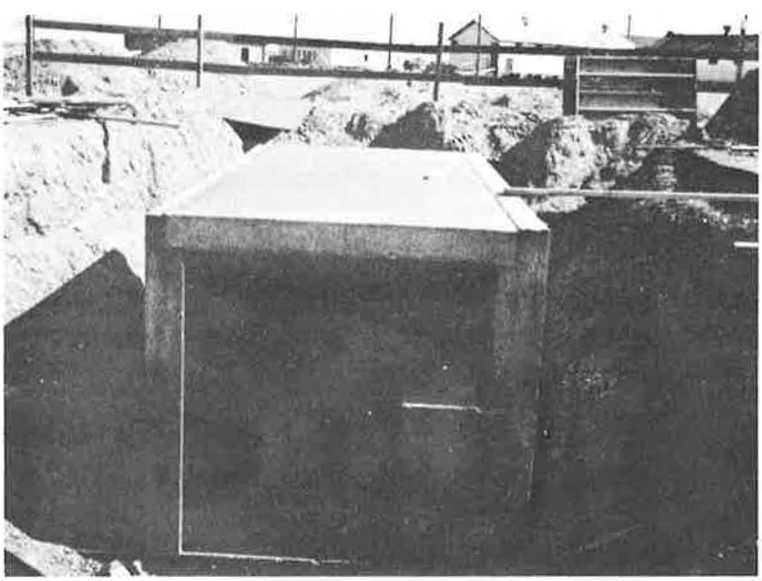

Figure 4. End view of test abutment.

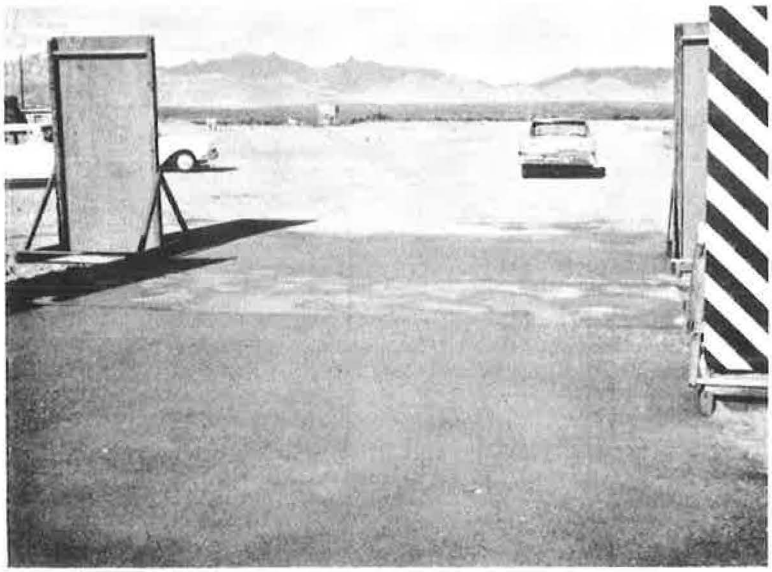

Figure 5. View of abutment from roadway showing approach.

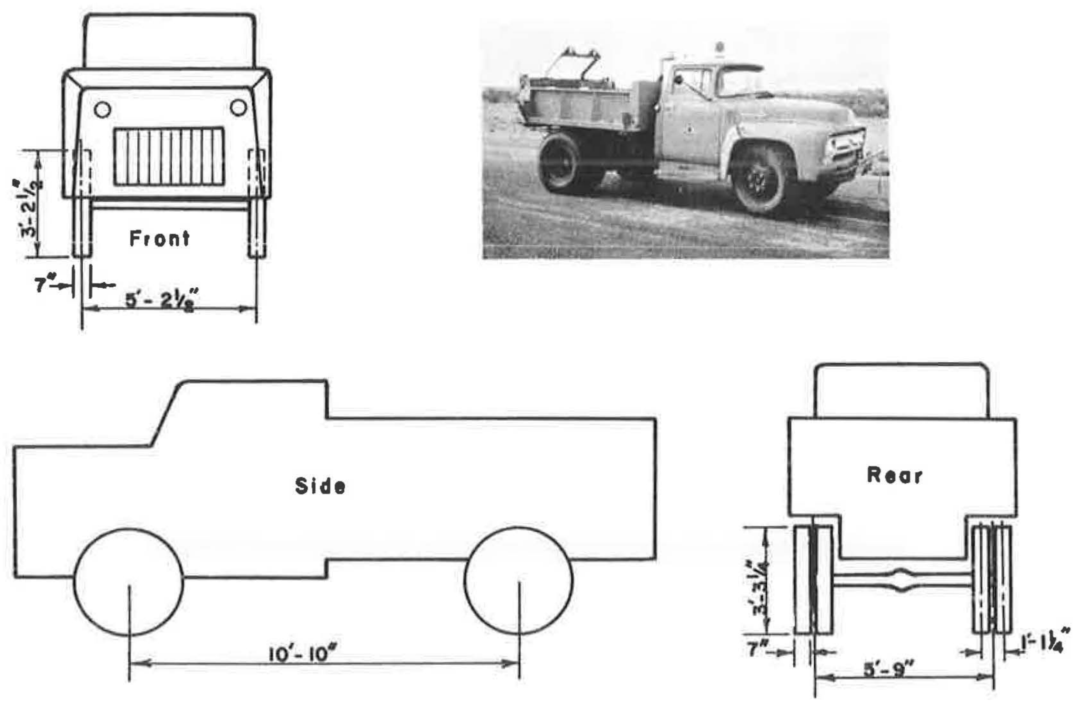

Figure 6. Single-axle truck.

Backfill Materials

Two different backfill materials were used in this study. The first material was a native soil found at the test site; its gradation is shown in Figure 7. The uniformity coefficient of the native soil was 13.9, which should normally designate a well-graded soil. It was apparent from the gradation curve that the material was gap-graded. This was to be expected because the material was used as it was uncovered and the gap-grading may be traced directly to the action of weathering of the soil. The characteristics

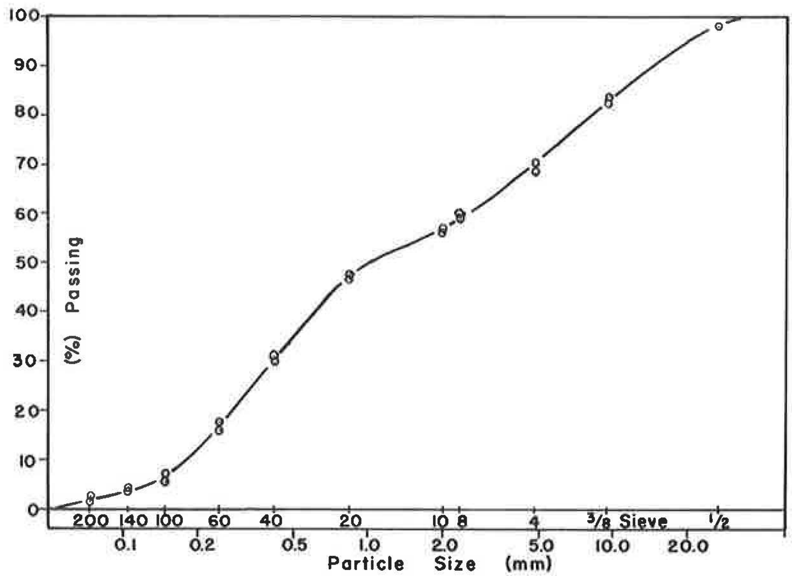

Figure 7. Gradation of selected backfill material (native).

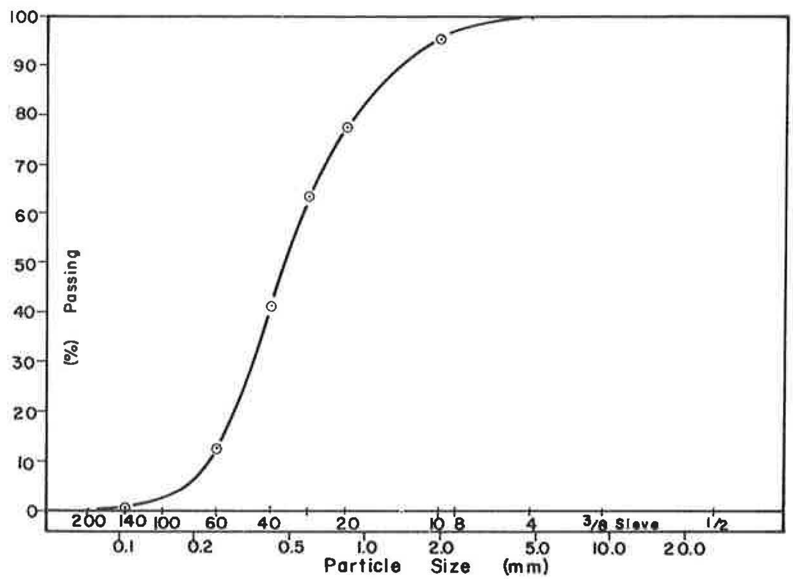

Figure 8. Gradation of sand backfill material.

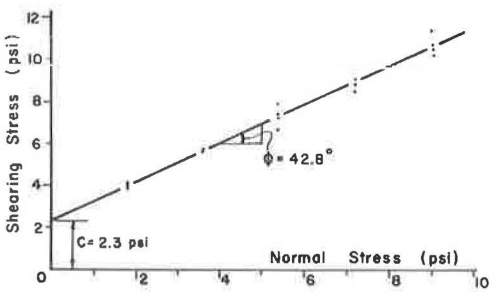

Figure 9. Direct shear envelope for native backfill material.

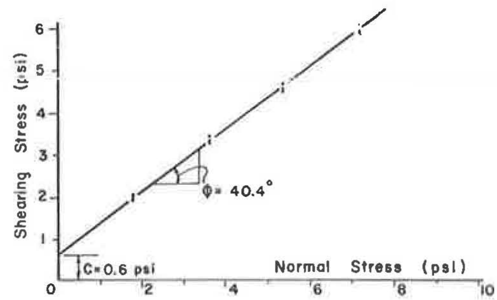

Figure 10. Direct shear envelope for sand backfill material.

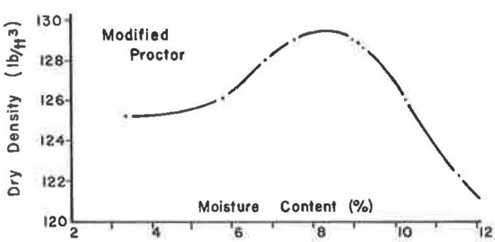

Figure 11. Moisture-density relationship for native backfill material.

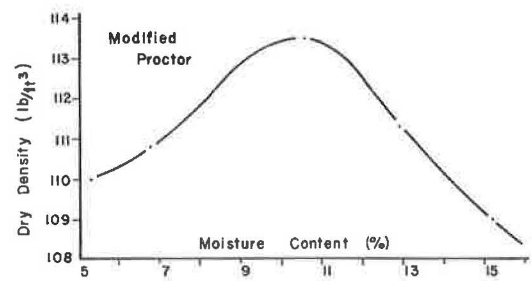

Figure 12. Moisture-density relationship for sand backfill material.

of gradation of this soil, and the adequate but not excess of fine material, allowed this soil to be compacted to a very dense condition.

The second soil used for backfill was a clean washed plaster sand; its gradation is shown in Figure 8. The uniformity coefficient for the sand was 2.39, which was considered a uniform material.

The standard direct shear test was run to determine the angle of internal friction and the cohesive properties of both soils.

The direct shear envelope for the native soil backfill is shown in Figure 9. The angle of internal friction of the native soil was found to be 42.8°, and the effective cohesion was 2.3 psi. The direct shear envelope for the plaster sand backfill is shown in Figure 10. The angle of internal friction for the sand was found to be 40.4°, and the effective cohesion was 0.6 psi.

Compaction tests were made on both soils to enable the achievement of the greatest amount of compaction when backfilling. The moisture-density relationships for the native soil backfill and the plaster sand are shown in Figures 11 and 12, respectively. The maximum dry density was found to be 129.5 pcf at a water content of 8.5 percent for the native soil. The plaster sand had a maximum dry density of 113.5 pcf at a water content of 10.5 percent. The Modified Proctor test was used to determine these relations.

Placing of Backfills

The native soil was placed into the excavated hole by hand and was compacted in 4- to 6-in. layers by using a pneumatic tamper. The pneumatic tamper was necessary in compacting the native soil due to the larger particle sizes of the material. Random in-place density tests were made to check the degree of compaction achieved. The water-balloon method was used in determining the volume of the test hole. This method was used on both backfill materials. In-place densities for the native soil are given in Table 1.

TABLE 1

IN-PLACE DENSITY RESULTS FOR NATIVE SOIL

Dist. from Wall (ft)	Depth from Surface (ft)	Dist. from Centerline	Water Content (%)	Dry Density	Percent of Modified
		(a) Flexible Wall			
2.0	4.0	Centerline	8.8	121.0	93.5
2.0	4.0	6 ft South	6.3	109.0	84.2
2.0	4.0	6 ft North	7.3	113.3	87.5
2.0	2.5	Centerline	5.3	108.5	83.7
2.0	1.5	Centerline	9.4	122.2	94.6
2.0	1.5	6 ft North	8.7	127.0	98.4
2.0	1.5	6 ft South	7.5	135.5	105.0
		(b) Rigid Wall			
2.0	4.0	Centerline	8.5	121.2	93.8
2.0	3.0	6 ft North	7.5	115.7	89.6
2.0	3.0	Centerline	8.9	128.5	99.5
2.0	3.0	6 ft South	8.8	118.8	91.7
2.0	2.0	Centerline	6.6	123.0	93.3
2.0	2.0	6 ft South	10.2	122.2	94.6
2.0	2.0	6 ft North	6.9	121.5	94.0
		(c) Rigid Wall After Rolling			
5.0	Surface	Centerline	6.8	123.0	95.3
		(d) Flexible Wall After Rolling			
2.0	Surface	Centerline	4.1	137.5	106.7

TABLE 2

IN-PLACE DENSITY RESULTS FOR PLASTER SAND

Dist. from Wall (ft)	Depth from Surface (ft)	Dist. from Centerline	Water Content (%)	Dry Density	Percent of Modified
		(a) Flexible Wall			
3.0	3.0	Centerline	11.7	112.2	99.0
3.0	2.0	Centerline	15.5	108.6	95.7
3.0	1.0	Centerline	15.1	107.5	94.7
		(b) Rigid Wall			
4.0	3.0	Centerline	10.0	112.1	99.0
2.5	3.0	Centerline	9.7	105.0	92.5
2.0	2.0	Centerline	12.6	112.5	99.2
1.0	2.5	Centerline	11.2	111.9	98.5

The washed plaster sand used was also placed by hand. The method of compaction used was vibration, which employed a hand vibratory compactor in a single unit. Random in-place density tests were also made. In-place densities for the washed plaster sand backfill are given in Table 2.

After the backfill materials had been placed and compacted, the last operation was the use of a steel-wheel roller to compact the top two to three inches. The roller created a smooth approach to the test area.

Pressure Cells

Two types of pressure cells were used. The first was a can-type pressure cell. Each cell was instrumented with four bonded resistance-type strain gages, which made up the four legs of one Wheatstone Bridge. This provided an extremely sensitive pressure cell. The sensitivity of pressure reading was needed to measure some of the smaller pressures recorded.

The second type of pressure cell was a Carlson stress meter for soils manufactured by Roy Carlson of Berkeley, California. The Carlson cell is basically a half-bridge circuit. When a pressure is applied to the face of the cell, one resistance decreases while the other increases. These cells were used to determine the lateral pressures at the wall; while the can-type pressure cells measured the lateral pressures in the soil.

Figure 13 shows the apparatus used in the calibration of the pressure cells. The can-type cells were embedded in the soil at the center of the elastic membrane. A static load was applied at the end of the lever arm and the pressure was recorded. The soil used in the elastic membrane was compacted until a compaction near field conditions was achieved. Each cell was calibrated a minimum of three times by loading and unloading until the calibration curve was reproduced. The Carlson cells were calibrated by application of a direct uniform load. These cells were also calibrated a minimum of three times. The calibration curves for three of the can-type pressure cells, which are representative of the sensitivity and linearity of all the can-type cells, are shown in Figure 14. Figure 15 shows the calibration curves for the Carlson cells.

Each cell was hand placed in the backfill material. The soil was compacted about six to eight inches above the desired location. A small amount of soil was then removed

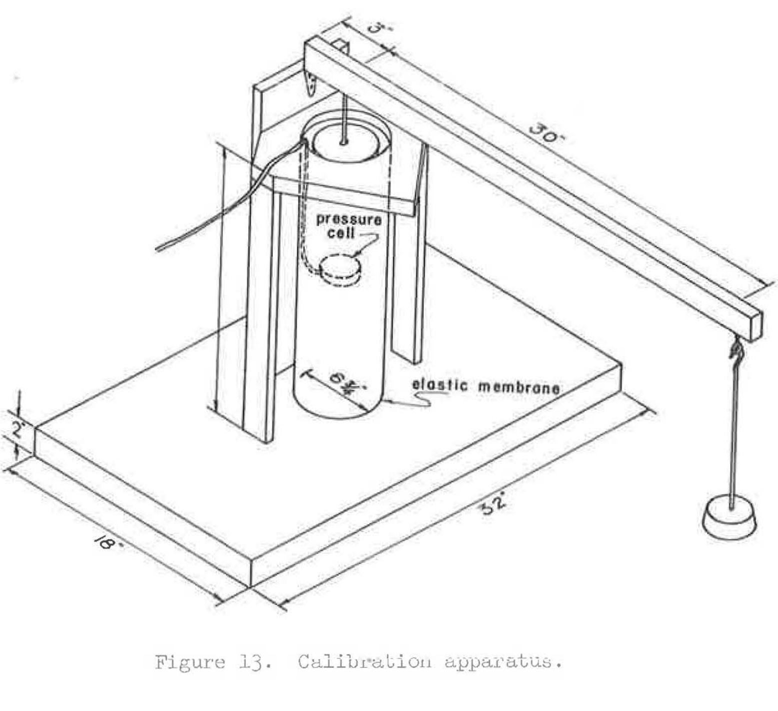

Figure 13. Calibration apparatus.

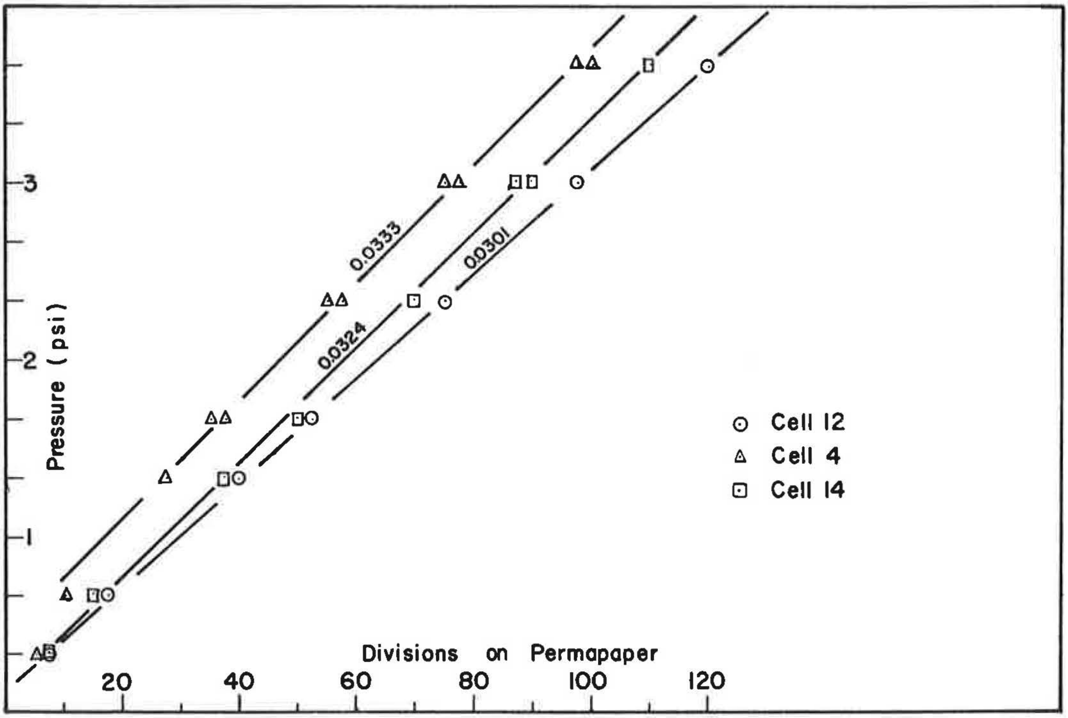

Figure 14. Calibration of can type pressure cells.

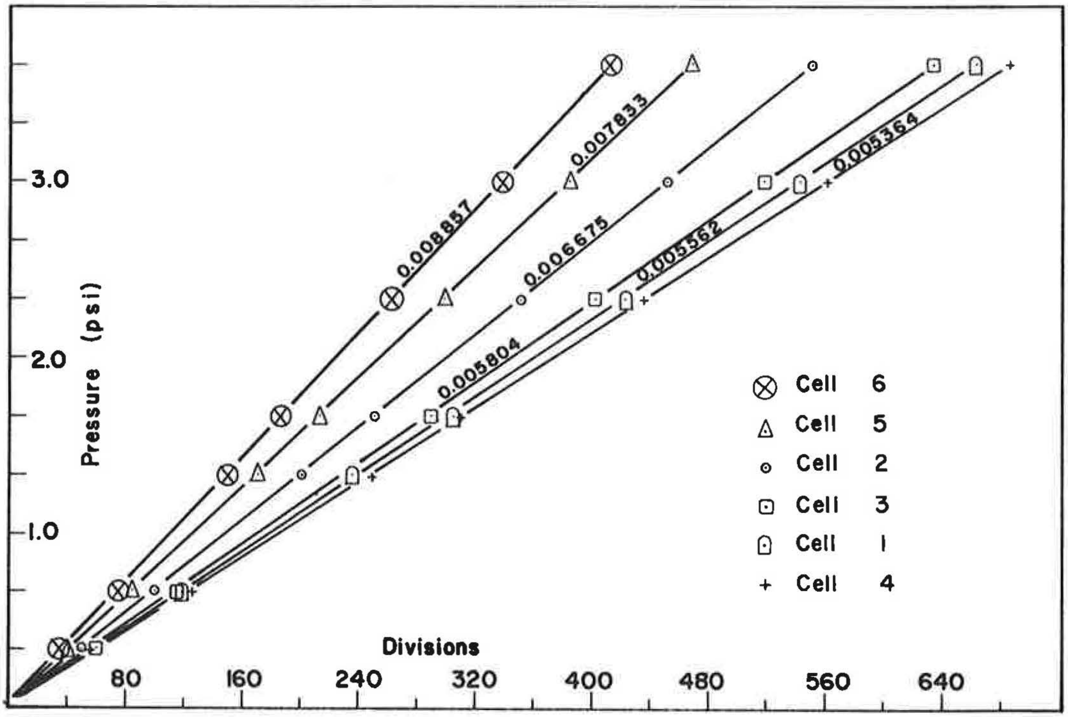

Figure 15. Calibration of Carlson pressure cells.

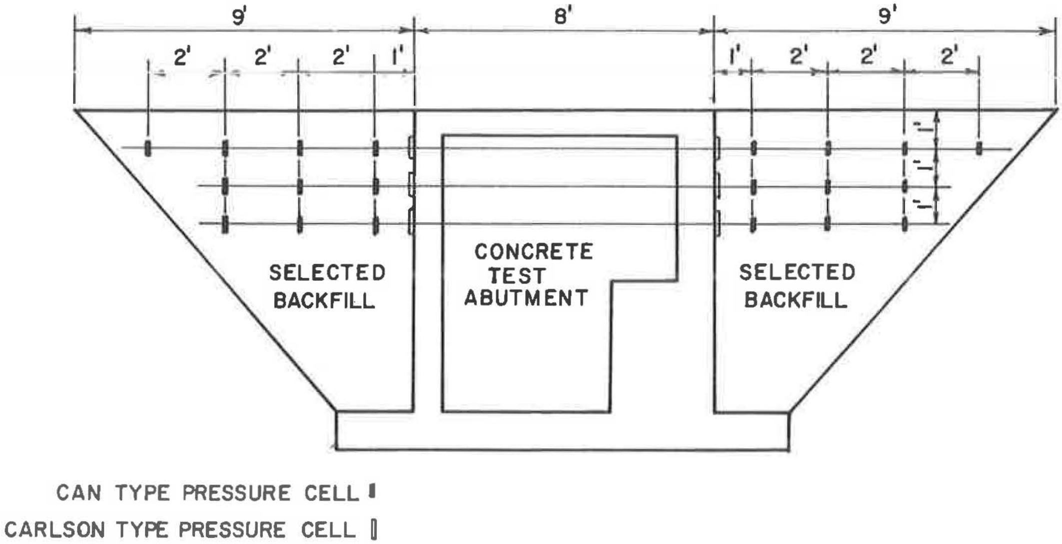

Figure 16. Location of pressure cells in backfill (native).

by using a post-hole digger and the cell was properly positioned. The soil was replaced and compacted around the cell. This procedure was used to achieve a uniform compaction of the soil around the cell. Figure 16 shows the location of the pressure cells in the native soil backfill. All cells were placed on centerline. The location of the pressure cells in the sand backfill was similar to the native soil, except the outer two rows of cells were omitted. After running the tests on the native soil, it was determined that less cells could be used because the pressures in the backfill away from the wall did not change.

EXPERIMENTAL PROCEDURE

To determine the distribution of lateral pressure both vertically and horizontally at the face of the abutment and also in the backfill, a method of locating the load at different points on the backfill was set up. A grid was laid out on the surface of the backfill as shown in Figure 17.

It should be restated here that all pressure cells were located on centerline. By locating the load on grid line 3N, 3 ft north of the centerline, the pressure would be measured at the centerline. This pressure would be the same as the pressure at 3N if the wheel was located at the centerline by reciprocal pressures. The above approach was used over the entire grid to give the complete picture of the pressure distribution.

Tests were conducted with the front and rear wheels to study the effect of different wheel loads. The front wheel was used first. The truck was driven as slowly as possible without stalling from a point approximately ten feet from the wall over one of the grid lines perpendicular to the wall. A continuous pressure reading was taken as the truck approached the abutment. Sanborn Recorders were used for recording the pressures measured by the pressure cells. A continuous record of the pressures was made as the truck approached and passed over the cells. Figure 18 shows a representative recording for a pressure cell at the wall and in the soil mass respectively. When the front wheels were on the abutment, the truck was stopped, thus assuring that the load carried by the rear wheels did not affect the soil pressures created by the front wheels. Each test was conducted a minimum of three times whenever possible.

The procedure used in conjuction with the rear wheels was exactly the same as that used for the front wheel except the truck was backed onto the backfill surface. The truck was placed so that the grid line was exactly in the center of the dual tires. When the test wheels were on the abutment, the truck was stopped to insure that the load

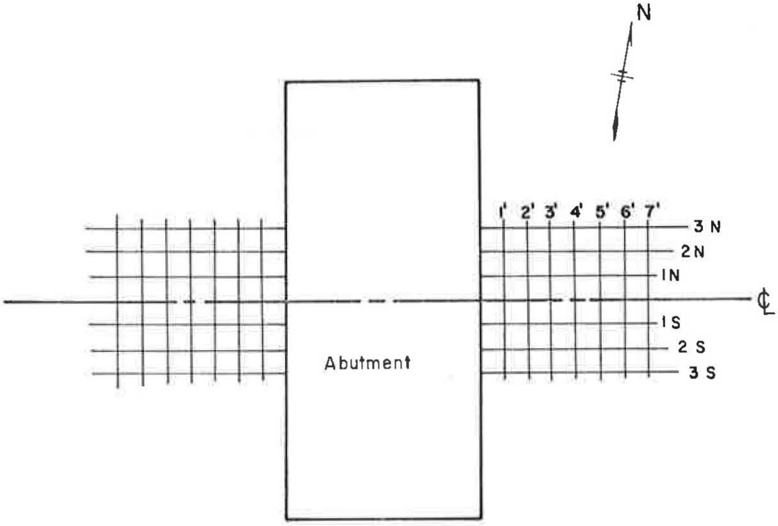

Figure 17. Grid pattern for location of surface wheel loads.

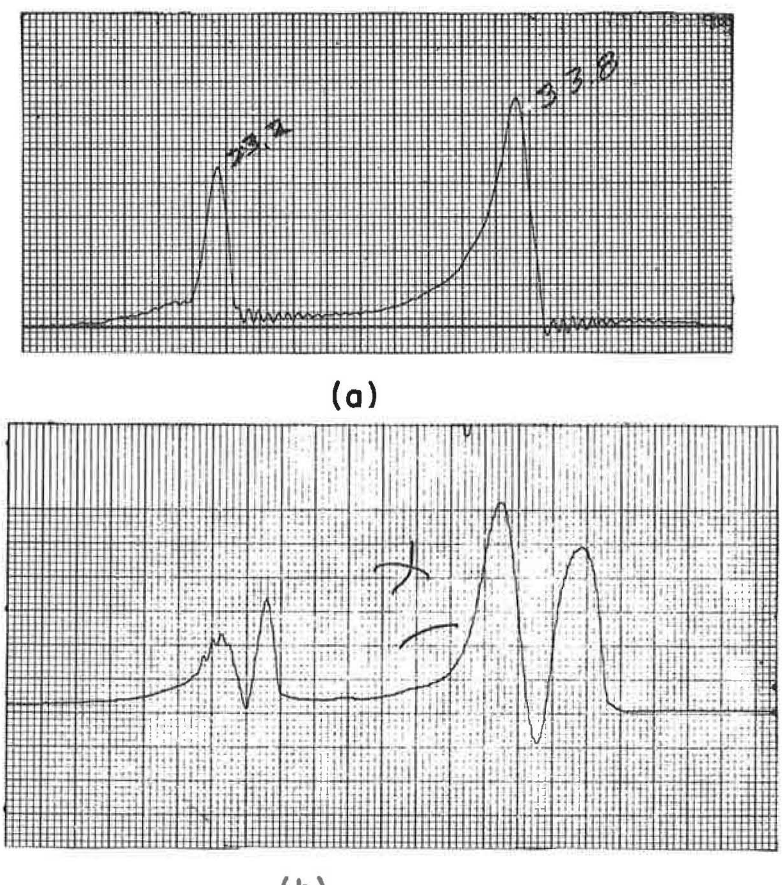

Figure 18. Data record for horizontal pressure due to truck: (a) Carlson pressure cell data at wall, and (b) can type pressure cell data in soil.

carried by the front wheel did not affect the soil pressures. These tests were also conducted a minimum of three times whenever possible.

To measure the relative magnitude of the deflection of the flexible wall under load, an Ames dial was mounted at the top of the wall on the inside, directly on centerline.

TEST RESULTS

This research resulted in six series of tests designated series A through F. In general, each series letter defines a particular physical setup in the testing program. The results of tests in each series are presented in the form of pressure bulbs. These resulting pressure bulb curves are compared with theoretical curves of the Boussinesq solution.

Series A—Comparison of the pressure created in the native soil by the front wheel of the truck to the pressure created in the sand backfill by the front wheel.

Series B—Comparison of the pressure created in the native soil by the rear wheel of the truck to the pressure created in the sand backfill by the rear wheel.

Series C—Comparison of the pressure created against the rigid wall for the front wheel of the truck and the native soil to the pressure created against the rigid wall for the front wheel and the sand backfill.

Series D—Comparison of the pressure created against the rigid wall for the rear wheel of the truck and the native soil to the pressure created against the rigid wall for the rear wheel and the sand backfill.

Series E—Comparison of the pressure created against the rigid wall for the front wheel of the truck and the sand backfill to the pressure against the flexible wall for the front wheel and the sand backfill.

Series F—Comparison of the pressure created against the rigid wall for the rear wheel of the truck and the sand backfill to the pressure created against the flexible wall for the rear wheel and the sand backfill.

The graphs are smooth curves through the approximate averages of the test points; however, all test points are shown for realistic comparison. The theoretical curves were calculated using the Boussinesq equation for lateral pressures under the test vehicle wheel loads.

Pressures in Soil Mass

Test Series A. —Figure 19 shows the theoretical and experimental curves for the distribution of lateral pressure created in the native soil backfill by the front wheel of the truck. The experimental pressure measured on centerline at a 1-ft depth was approximately 76 percent of the theoretically calculated value; at a 2-ft depth, 67 percent; and at a 3-ft depth, 81 percent.

Figure 20 shows the distribution of lateral pressure created in the sand backfill by the front wheel of the truck. At a 1-ft depth on centerline, the measured pressure was 99 percent of the calculated theoretical value and was well approximated by the theoretical curve so that an experimental curve was not necessary. At a 2-ft depth the pressure was 67 percent of the theoretical value, and at a 3-ft depth, about 81 percent.

Comparing the results obtained for the native soil with those of the sand backfill shows the sand to have slightly higher pressure in the top foot of the soil created under identical load. The pressures at 2- and 3-ft depths were nearly equal.

Test Series B. —Figure 21 shows the distribution of lateral pressure created in the native soil backfill by the rear dual tires. At a 1-ft depth on centerline the measured pressure was 62 percent of the theoretical; at a 2-ft depth, 60 percent; and at a 3-ft depth, the measured pressure compared closely with the theoretically computed values.

Figure 22 shows the distribution of lateral pressure created in the sand backfill by the rear dual tires. At a 1-ft depth on centerline the measured pressure was 86 percent of the theoretical value; at a 2-ft depth, 64 percent; and at a 3-ft depth, the resulting pressure was approximately the same as the theoretical value and the experimental curve was not shown.

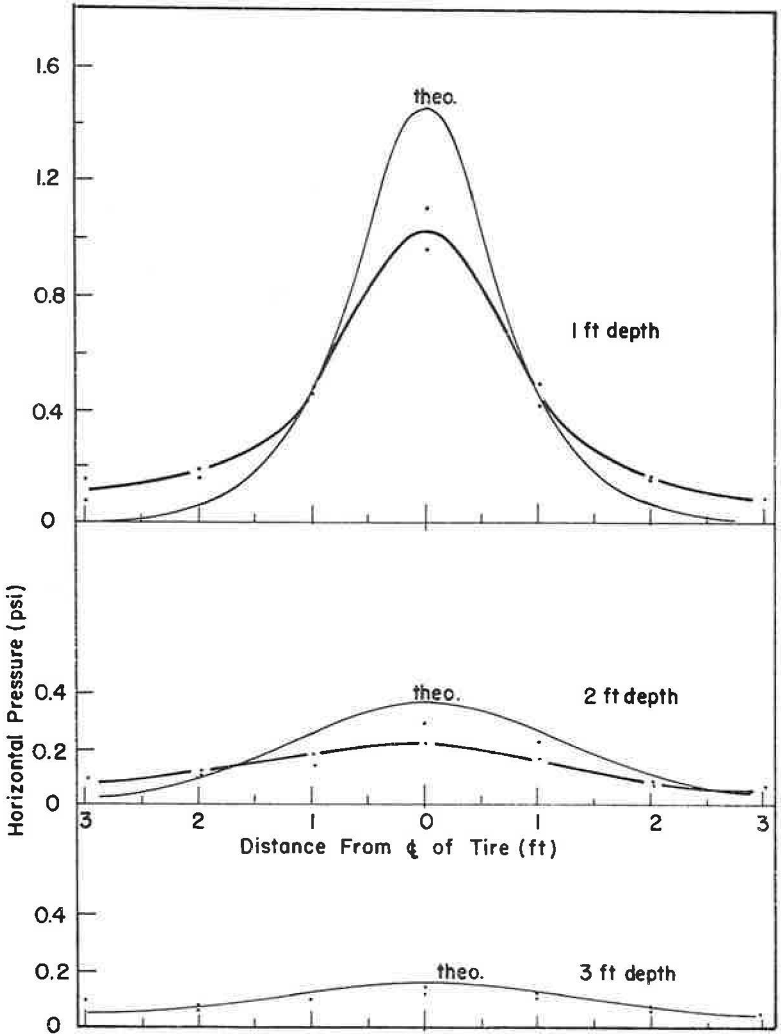

Figure 19. Distribution of lateral pressure in soil for truck front tire (native).

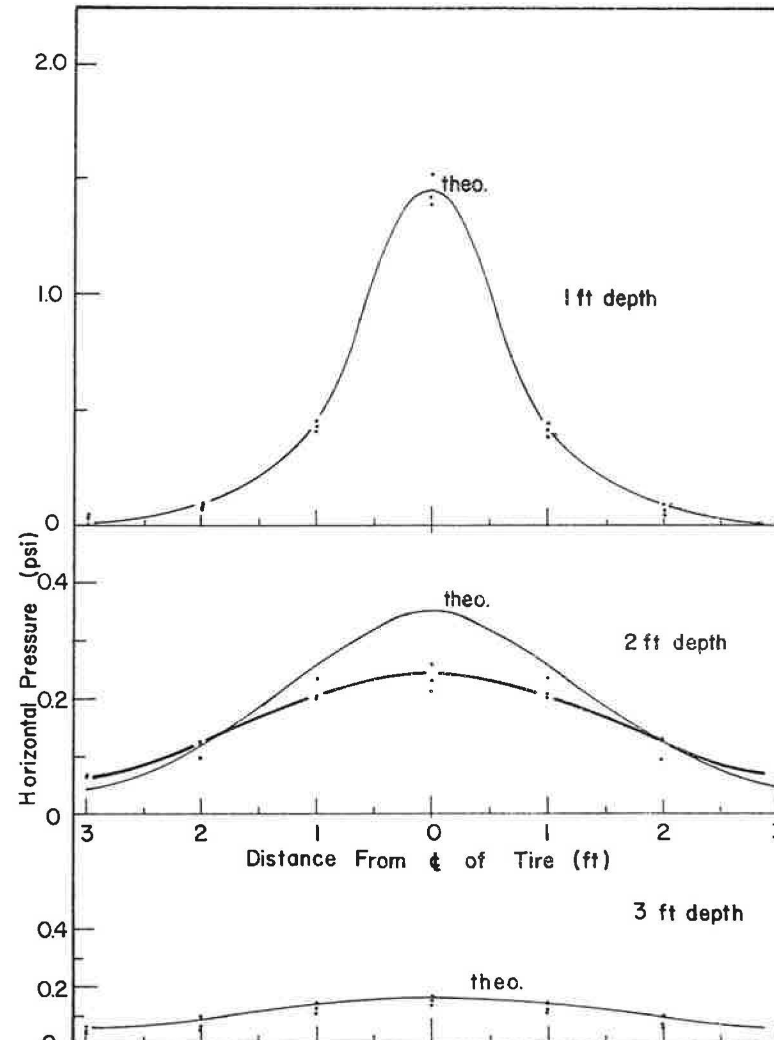

Figure 20. Distribution of lateral pressure in soil for truck front tire (sand).

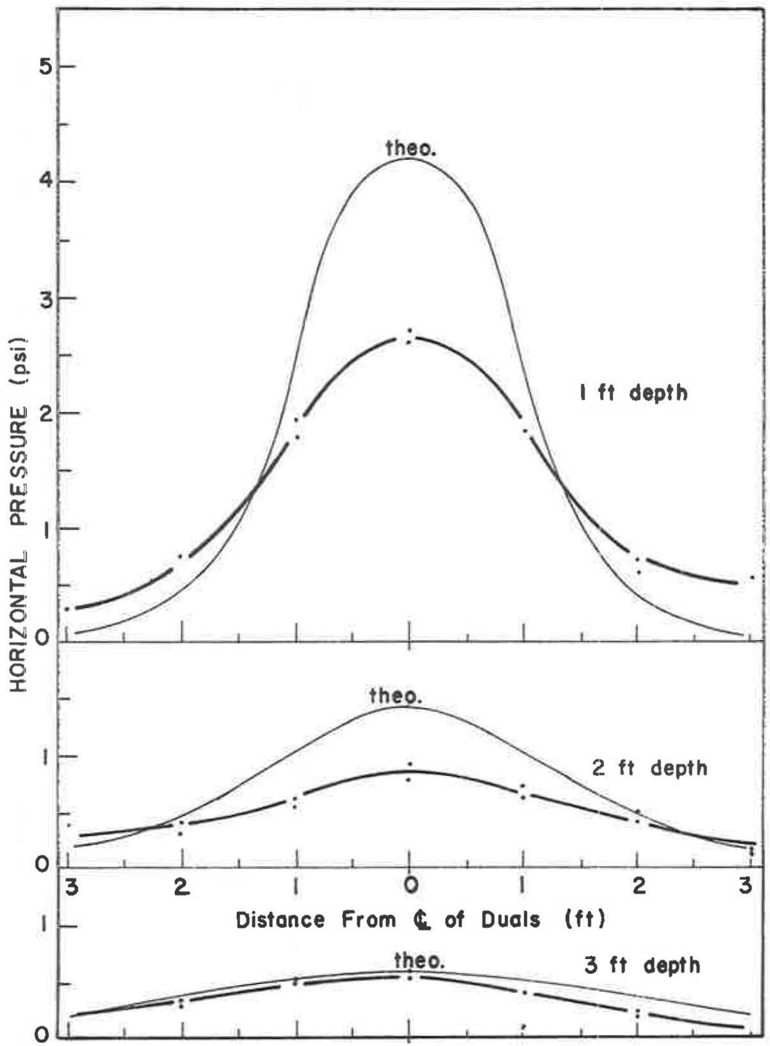

Figure 21. Distribution of lateral pressure in soil for truck rear dual tires (native).

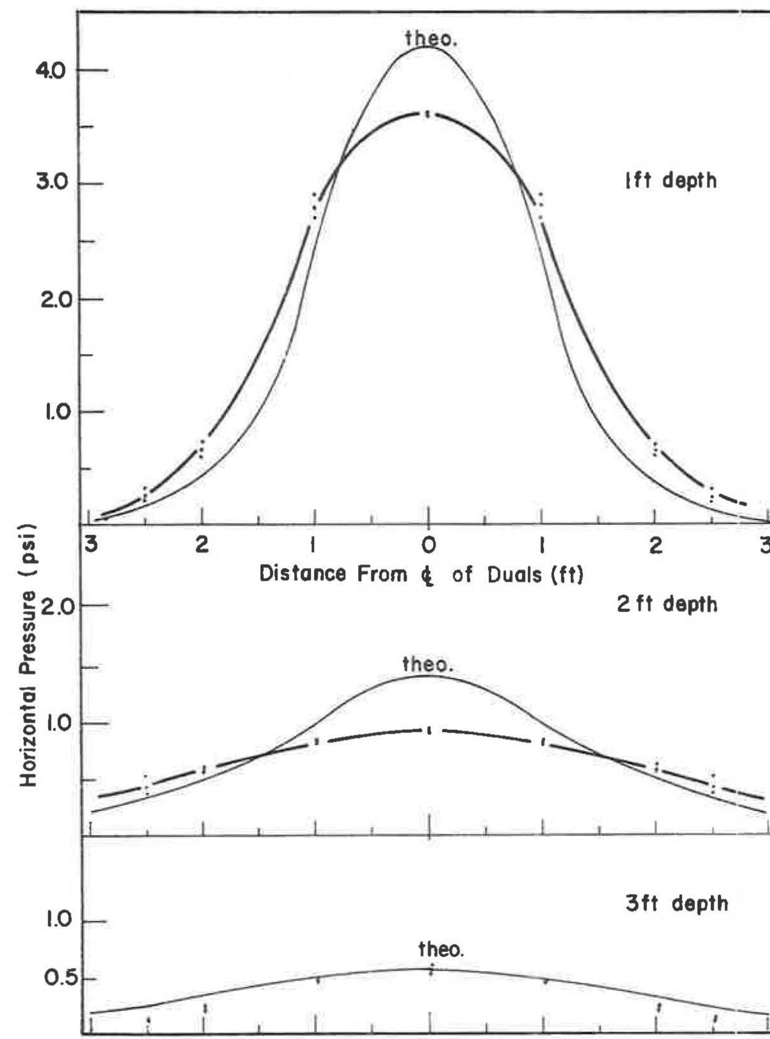

Figure 22. Distribution of lateral pressure in soil for truck rear tires (sand).

Comparing the results of the native soil with the sand backfill for the rear duals shows that the pressure created within the first foot was significantly higher in the sand backfill than in the native soil backfill. The experimental pressure measured in the sand backfill was approximately 135 percent of the pressure measured in the native soil at a 1-ft depth. The pressures at 2- and 3-ft depths were nearly equal. The experimentally measured pressures were roughly 60 percent of the theoretical value at the 2-ft depth and almost equal to the theoretical value at the 3-ft depth.

Pressures at Soil-Wall Interface

Test Series C. —Figure 23 shows the distribution of lateral pressure against the rigid wall for the front tire of the truck on the native soil backfill. At a 1-ft depth on centerline, the pressure measured was 190 percent of the calculated theoretical value; the pressure measured at the wall was 250 percent of the pressure measured in the soil. At a 2-ft depth the pressure measured against the wall was 158 percent of the theoretical value and was 275 percent of the pressure measured in the soil. At a 3-ft depth, the pressure measured against the wall was small in magnitude but was 126 percent of the theoretical value and 154 percent of the pressure measured in the soil.

Figure 24 shows the distribution of lateral pressure against the rigid wall for the front tire of the truck on the sand backfill. At a 1-ft depth on centerline, the pressure created was 379 percent of the theoretical value. The pressure measured against the wall was 385 percent of the pressure measured in the soil. At a 2-ft depth, the measured pressure was 222 percent of the theoretical value and 333 percent of the pressure measured in the soil. At a 3-ft depth, the measured pressure was 188 percent of the theoretical value and approximately 200 percent of the pressure measured in the soil.

Figure 25 shows the soil pressure at the rigid wall for different front wheel locations on the native soil backfill. The curves illustrate the variation in soil pressures created against the wall with respect to depth for a specific wheel location on centerline. At a 1-ft depth on centerline, the pressure was maximum when the load was located approximately 0.8 ft from the wall. At 2- and 3-ft depths on centerline, the pressures were maximum when the load was located approximately 1.6 and 2.4 ft, respectively, from the wall. These curves also show how the pressure against the wall changes as the wheel of the truck approaches the abutment.

Figure 26 shows the soil pressure against the rigid wall for different front wheel locations on the sand backfill. The curves show the variation of soil pressures with respect to depth for specific wheel locations on centerline.

Comparison of Figures 25 and 26 shows the pressure development against the wall was similar in characteristics, but of varying magnitude.

Test Series D. —Figure 27 shows the distribution of lateral pressure against the rigid wall for the rear dual tires of the truck on the native soil backfill. At a 1-ft depth on centerline, the pressure measured was 152 percent of the theoretical value. The measured pressure at the wall was 241 percent of the pressure measured in the soil. At a 2-ft depth, the pressure at the wall was 153 percent of the theoretical value and 275 percent of the pressure in the soil. At a 3-ft depth, the pressure against the wall was 138 percent of the theoretical value and 150 percent of the pressure in the soil.

Figure 28 shows the distribution of lateral pressure against the rigid wall for the rear dual tires of the truck on the sand backfill. At a 1-ft depth on centerline, the pressure was 195 percent of the theoretical value; pressure at the wall was 228 percent of the pressure in the soil. At a 2-ft depth, the pressure at the wall was 216 percent of the theoretical value and 337 percent of the pressure in the soil. At a 3-ft depth the pressure against the wall was 174 percent of the theoretical value and of the pressure in the soil.

Figure 29 shows the pressures created against the rigid wall for different rear wheel locations on the native soil backfill. Figure 30 shows the pressures against the rigid wall for different rear wheel locations on the sand backfill. The experimental pressures measured in the sand backfill at the soil-wall interface were approximately 200 percent of the theoretical value for both back and front wheel loadings, except for the 1-ft depth under the front wheel where the experimental pressure was 379 percent of the theoretical.

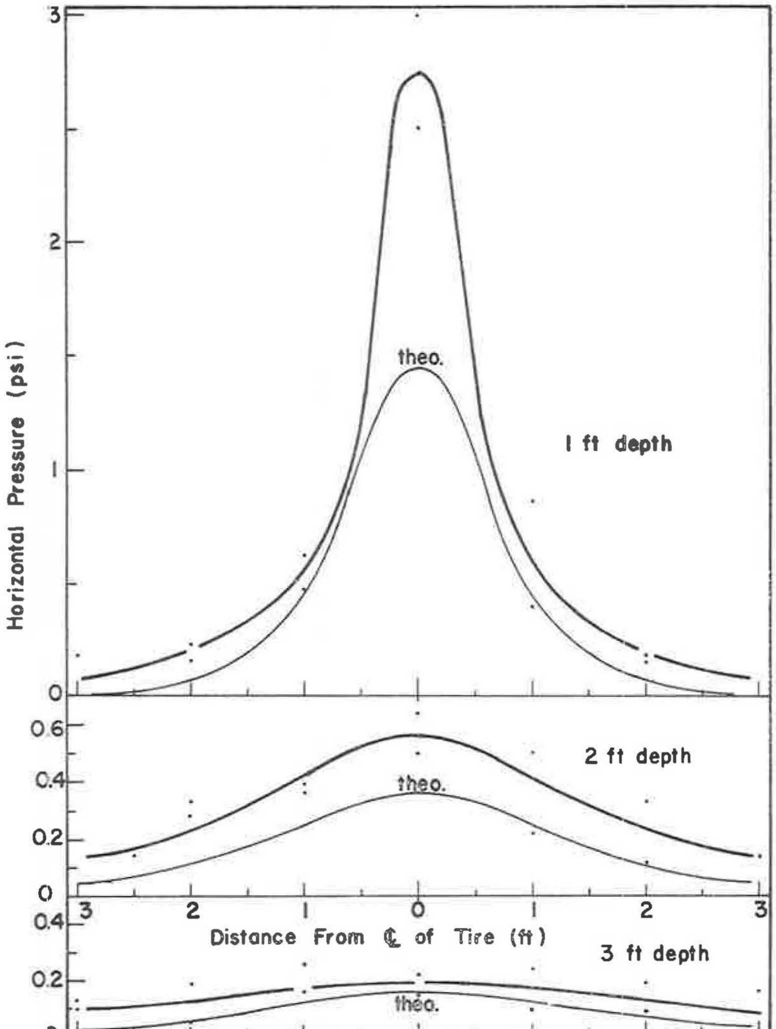

Figure 23. Distribution of lateral pressure at rigid wall for truck front tire (native).

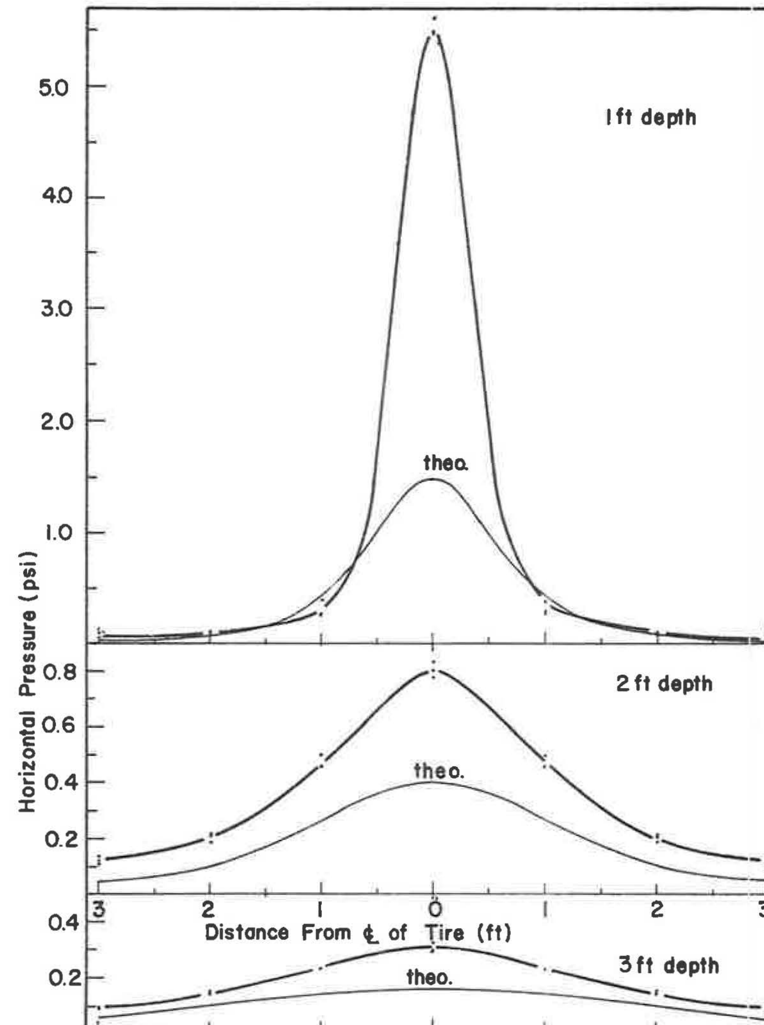

Figure 24. Distribution of lateral pressure at rigid wall for truck front tire (sand).

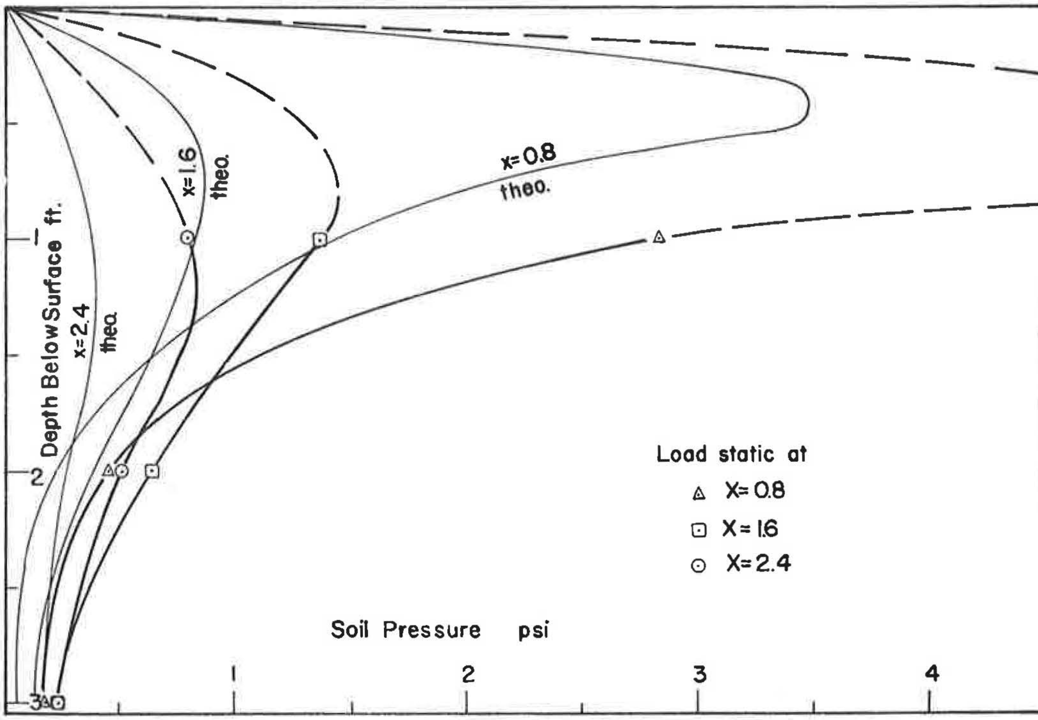

Figure 25. Soil pressure at rigid wall for different front wheel locations (native).

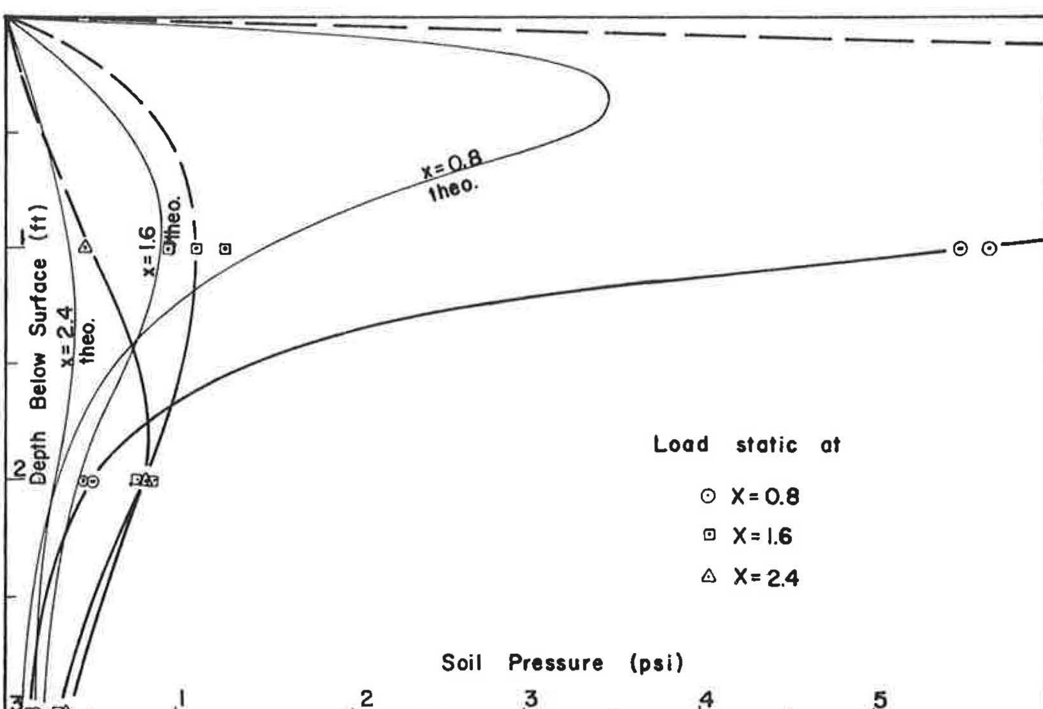

Figure 26. Soil pressure at rigid wall for different front wheel locations (sand).

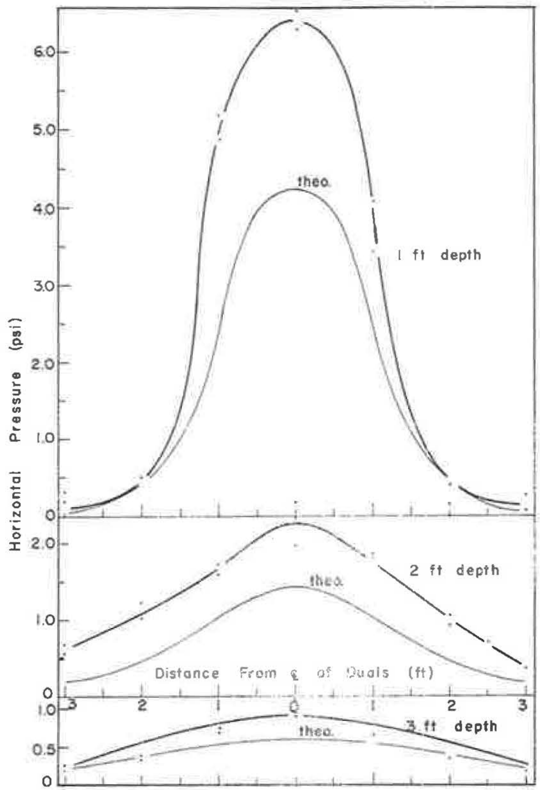

Figure 27. Distribution of lateral pressure at rigid wall for truck rear dual tires (native).

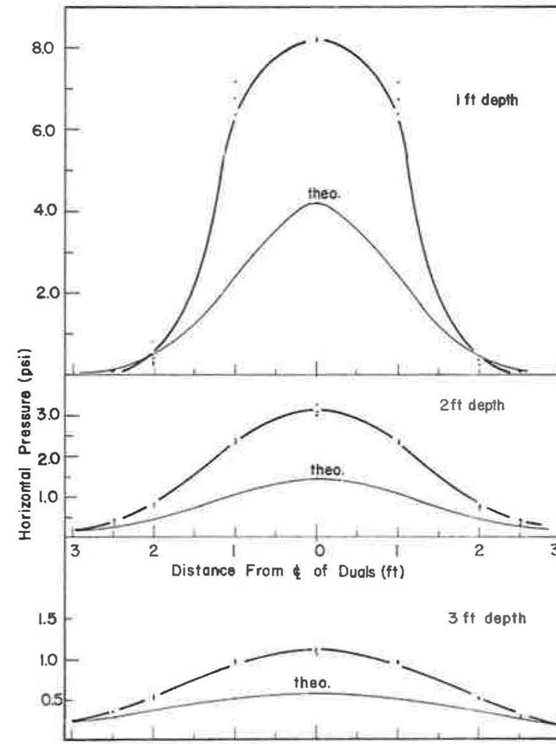

Figure 28. Distribution of lateral pressure at rigid wall for truck duals (sand).

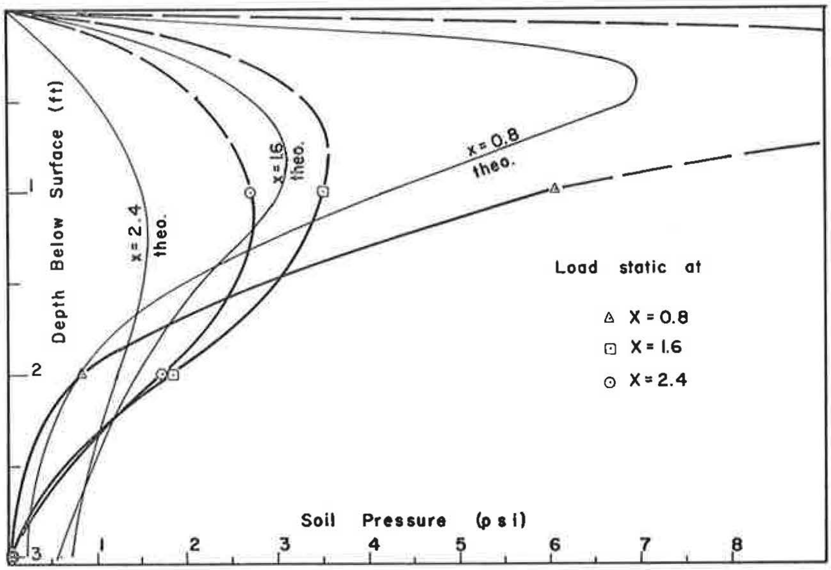

Figure 29. Soil pressure at rigid wall for different rear wheel locations (native).

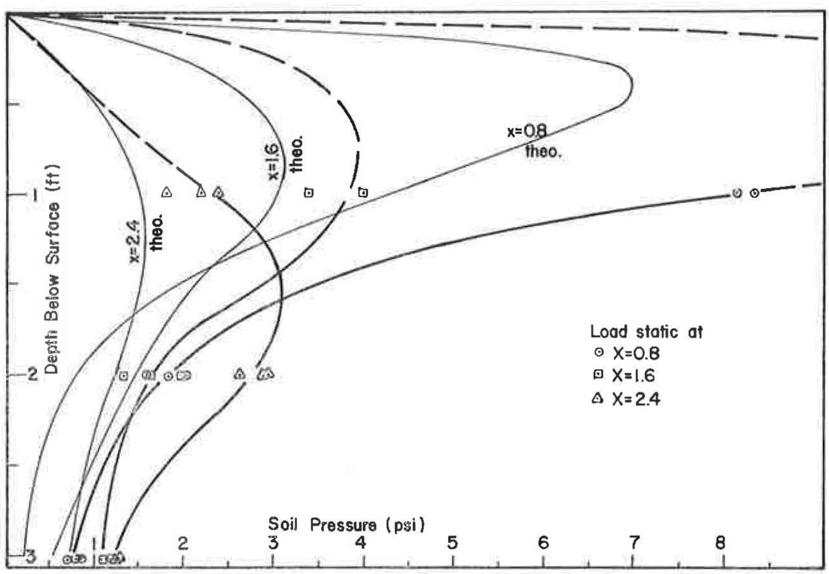

Figure 30. Soil pressure at rigid wall for different rear wheel locations (sand).

The pressures measured in the native backfill were similar in characteristics except that the pressures were approximately 150 percent of the theoretical value. The front wheel load caused a greater increase in pressure at the 1-ft depth, which was 190 percent of the theoretical value.

It is apparent that the experimental pressures at the soil-wall interface, i.e., against the wall, were 133 percent greater in the sand backfill than in the native soil backfill, with the exception noted.

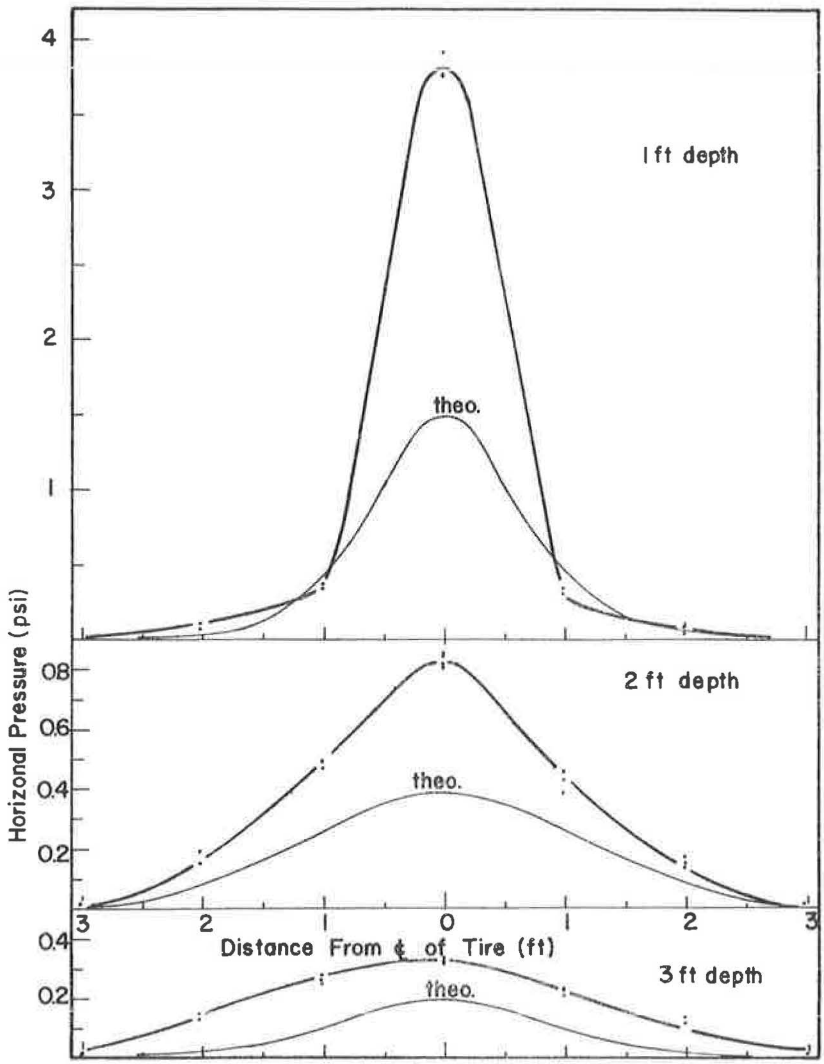

Figure 31. Distribution of lateral pressure at flexible wall for truck front tire (sand).

The increase in pressure in the sand backfill can be made more apparent by comparing Figures 25 and 29 with Figures 26 and 30. These figures, which show the variation in pressure with depth, exemplify the increase in maximum pressure in the sand at the soil-wall interface.

Test Series E. —Test series E compares the pressures against the rigid wall for the front wheel of the truck on the sand backfill to the pressure created against the flexible wall for the front wheel of the truck on the sand backfill.

Figure 31 shows the distribution of lateral pressure against the flexible wall for the front wheel of the truck on the sand backfill. At a 1-ft depth on centerline, the experimental pressure was 259 percent of the theoretical value; at a 2-ft depth, 222 percent; and at a 3-ft depth, 188 percent.

Comparison of Figure 24 and Figure 31 shows the pressures at the soil-wall interface of the rigid wall at a 1-ft depth was 133 percent greater in magnitude than at the 1-ft depth against the flexible wall. The effect of the flexible wall was not in evidence in the pressures measured at 2- and 3-ft depths, because these pressures were the same for both walls.

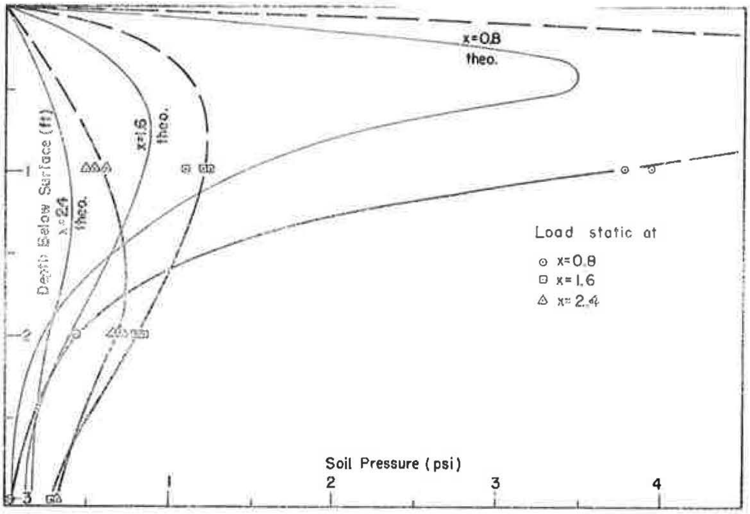

Figure 32. Soil pressure at flexible wall for different front wheel locations (sand).

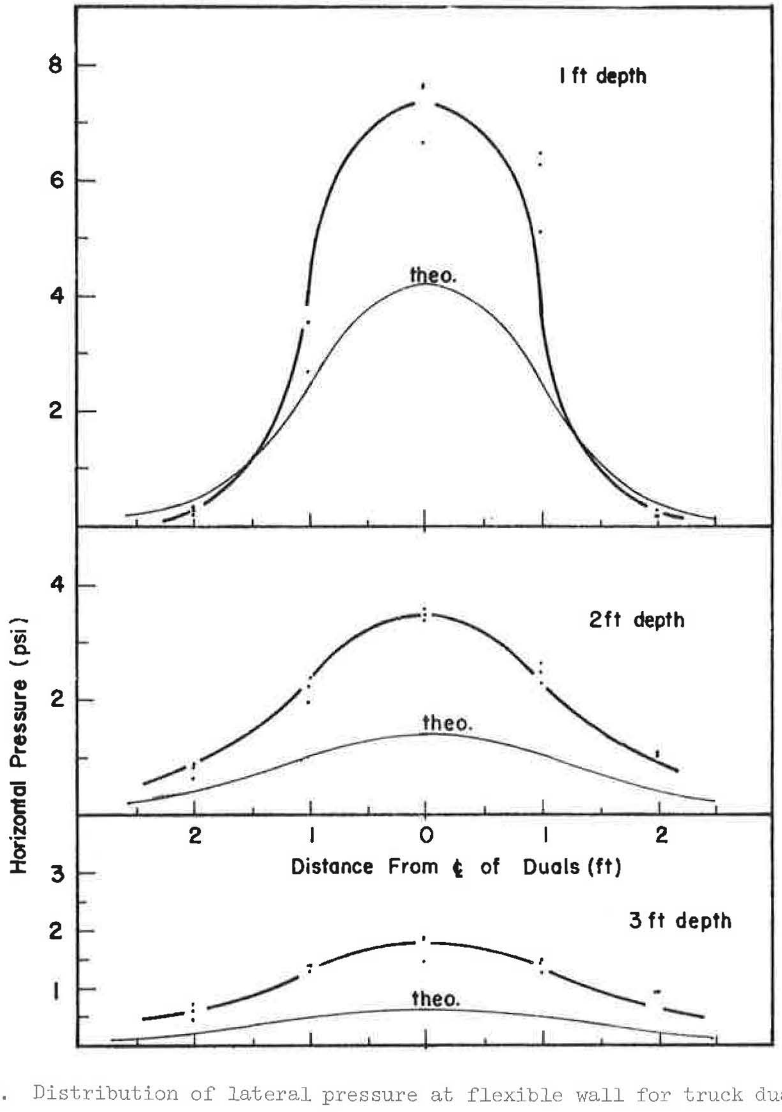

Figure 33. Distribution of lateral pressure at flexible wall for truck duals (sand).

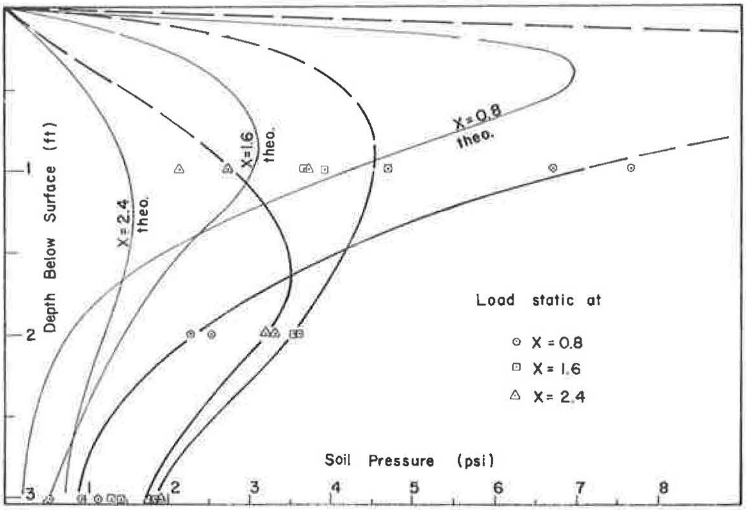

Figure 34. Soil pressure at flexible wall for different rear wheel locations (sand).

The movement of the flexible wall was found to be small. The measured deflections of the top of the wall at the point of the load were approximately 0.0005 in. for each 1,000 lb of wheel load applied at the surface of the backfill for both front and rear wheels.

Figure 32 shows the pressures against the flexible wall for different front wheel locations on the sand backfill. It is evident that the effect of movement did not alter the pressure distributions. The movement only affected the maximum pressure at the 1-ft depth.

Test Series F. —Test series F compares the pressure against the rigid wall for the rear dual tires of the truck on the sand backfill to the pressure against the flexible wall.

Figure 33 shows the distribution of lateral pressure against the flexible wall for the rear dual tires of the truck on the sand backfill. At a 1-ft depth on centerline, the experimental pressure was 179 percent of the theoretical value; at a 2-ft depth, 236 percent; and at a 3-ft depth, 232 percent.

Comparison of Figure 28 and Figure 33 shows the pressure against the rigid wall at a 1-ft depth was about 110 percent greater than the pressure at the same depth on the flexible wall. The effect of movement of the wall was not significant for the pressures measured at 2- and 3-ft depths.

Figure 34 shows the pressure against the flexible wall for different rear wheel locations on the sand backfill. The movement did not affect the pressure distributions, but only the maximum pressures.

CONCLUSIONS

The first problem investigated was that of determining the variation of pressure, measured both in the soil and at the soil-wall interface, due to variation of the soil characteristics. Test Series A and B were conducted for different wheel loads on the soil in order to determine the effect of wheel loads on the pressures created in the soil. The sand backfill tends to create greater pressure in the soil. The measured pressures in the sand backfill gave results closer to the theoretically computed values. The tendency of the sand to create greater pressure could be attributed to the fact that the sand was more uniform and was closer to being homogeneous. Series A and B show that the effect of different characteristics of the soils was predominant only to a 1-ft depth.

This phase of the investigation also included a study to determine the effect of soil characteristics on the pressures created at the soil-wall interface. The pressures measured in Series C and D show that the sand backfill transmitted larger pressures to the wall. The resulting pressures, even though two to three times the theoretical value, were consistent at all depths.

The resulting pressure distributions for Series A through D show that the soil pressure created by the concentrated load was distributed in accordance with the elastic theory. The pressures measured in the soil were less than the theoretical values for both the native soil and the sand backfill. The pressures measured at the wall show a large stress concentration caused by the discontinuity in the soil mass due to the wall. The relatively rigid wall interrupts the lateral strains within the soil mass and hence concentrates the stresses at the plane of the back face of the wall.

The second problem investigated was that of determining the variation in soil pressure with respect to the relative rigidity of the wall construction. Test Series E and F show that the pressure in the first foot of soil against the rigid wall was higher than the pressure against the flexible wall. The pressures measured at 2- and 3-ft depths were not influenced to any degree by the wall flexibility and were of the same order of magnitude. It can be concluded that for relatively flexible abutment retaining walls, the greatest effect of the flexibility on the soil pressure will be limited to the first foot of the backfill.

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REFERENCES

1. Andersen, Paul, "Substructure Analysis and Design." Ronald Press, 2nd Ed. (1956).
2. Jumikis, Alfreds R., "Soil Mechanics." D. Van Nostrand (1962).
3. Linger, Don A., "Effect of Vibration on Soil Properties." Unpublished report, Eng. Exp. Sta., New Mexico State Univ. (July 1961).
4. Peck, Ralph B., Hanson, Walter E., and Thornburn, Thomas H., "Foundation Engineering." John Wiley and Sons (1953).
5. Perry, C. C., and Lissner, H. R., "The Strain Gage Primer." McGraw-Hill (1955).
6. Sanborn Company, "Sanborn Equipment Manual." Cambridge, Mass. (1956).
7. Sowers, George B., and Sowers, George F., "Introductory Soil Mechanics and Foundations." Macmillan, 2nd Ed. (1961).
8. Spangler, M. G., "Horizontal Pressures on Retaining Walls Due to Concentrated Surface Loads." Iowa State College, Eng. Exp. Sta. Bull. 140 (1938).
9. Spangler, M. G., "Soil Engineering." International Textbook (1960).
10. Taylor, Donald W., "Fundamentals of Soil Mechanics." John Wiley and Sons (1948).
11. Timoshenko, S., "Theory of Elasticity." McGraw-Hill (1934).
12. Tschebotarioff, Gregory P., "Soil Mechanics, Foundations, and Earth Structures." McGraw-Hill (1951).
13. Weiskopf, Walter H., "Stresses in Soils Under a Foundation." J. Franklin Inst., Vol. 239, No. 6 (June 1945).
14. White, L., and Paaswell, G., "Lateral Earth and Concrete Pressures." ASCE, Vol. 65, No. 8, Part 2 (Oct. 1939).