IMPORTANT CONSIDERATIONS IN THE DESIGN AND USE OF SOIL PRESSURE CELLS

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SYNOPSIS

Study of the performance of pressure cells of the pneumatic type indicates that the problem of accurately measuring soil pressures is a difficult one. Tests show that when the cell does not have a rim around the pressure sensitive face, the pressures that it is apt to record in soils will vary directly as the perimeter-area ratio of the cell and that as its thickness is increased the effect of size becomes more pronounced, i.e., the smaller the cell and the greater its thickness the higher the recorded pressures will be.

The presence of a rim around the pressure sensitive face serves to compensate for the effect of cell thickness. The report suggests that the problem of measuring pressures can best be approached by systematic study of the design features of cells that satisfy practical requirements as to dimensions and materials to the end that these may be used with a full knowledge of their accuracy and other characteristics.

The design of most engineering structures must, of necessity, take into consideration the quality and the nature of the support offered by the soil on which the structure is to rest. Usually, the uniformity of the support is more important than the actual unit pressure value although both are of interest. Many and varied have been the theories proposed and the experiments performed in attempting to evaluate soil support and, in order to provide experimental data, soil pressure measuring devices of numerous types, sizes and characteristics have been designed and used.

For some time the Public Roads Administration has been studying the problem of pressure measurement in soils in connection with its possible application to the development of rational methods for designing nonrigid road surfaces. As a part of this study it seemed only logical to investigate the accuracy, consistency and other characteristics of some of the devices that have been proposed and to determine the importance of some of the design features that affect the accuracy with which soil pressures may be measured.

This report describes certain preliminary or exploratory tests in which the attempt has been made to develop information concerning the factors that effect the performance of one type of pressure-measuring device, the pneumatic cell developed by the Public Roads Administration many years ago [1].

That little importance has been attached to the external features of design of soil pressure cells is evident from even a casual survey of the literature on the subject. Apparently, the overall size of such devices has been governed more by the space requirements of the internal pressure measuring element than by other considerations. Moreover, in some cells the pressure receiving face is separate and distinct from the side walls and base section, in others, it is integral with these parts.

The material presented in Table 1 indicates the extent to which the dimensional and structural features of some of the more recent designs for soil pressure cells vary. While the list is not complete, it serves to indicate that in the design

[1] A. T. Goldbeck and E. B. Smith, "An Apparatus for Determining Soil Pressures," *Proceedings*, American Society for Testing Materials, 1916.

of soil pressure cells no great consideration has been given to the possibility that the physical dimensions might seriously affect the accuracy with which they would indicate soil pressure.

It is only reasonable that the introduction into a soil mass of assumed homogeneity of a foreign object having

TABLE 1

Type of cell	Thickness	Diameter	Rim width
	inches	*inches*	*inches*
Pneumatic[a]	1 25	5 50	1.0
Vibrating wire[b]	2 67	5 52	About ½
Carbon disks[c]	0.25	0 50	Thin bakelite ring[f]
Rubber diaphragm[d]	0 62	4 00	0 25
Dynamometer[e].. .	8.50	8 00	Not indicated

[a] A T. Goldbeck, "Measurement of Earth Pressure," *Proceedings*, Highway Research Board, Vol. 18, part II, (1938)

[b] I F. Morrison and W. E. Cornish, "Measurement of Earth Pressure," *Canadian Journal of Research*, Vol. 17, sec. A.

[c] M G Spangler, "Wheel Load Stress Distribution Beneath Flexible Type Pavements," *Proceedings*, Conference on Soil Mechanics and Its Application, Purdue University, July 1940.

[d] F Kogler and A Scheidig, "Druckverteilung im Baugrunde" *Die Bautechnik*, No 29, July 1, 1927

[e] W. H. Evans, "Dynamometer for Measuring Earth Pressures." *Engineering*, Vol. 149, No. 3876, April 1940

[f] Thickness somewhat less than that of measuring element

radically different elastic properties will disturb the distribution of pressure in the vicinity of the object. It is, therfore, rather surprising that so little attention has been paid to this point in the design of pressure-measuring equipment.

Kogler and Scheidig[2] first called attention to the difficulties of measuring soil pressures accurately with a pressure cell. They pointed out that a cell more rigid than the soil would indicate pressures greater than those present in the soil and, conversely, a cell more compressible than the soil would give pressures less than those in the soil. This fact was also recently recognized by Goldbeck.[3] There can be little question as to the correctness of this reasoning and the natural inference is that if a device is to indicate true soil pressure, it must possess in itself the same elastic properties as those of the surrounding soil. In other words, it must deform in all directions to the same extent as the soil.

EXTERNAL DESIGN FEATURES OF PRESSURE CELLS IMPORTANT

With the possible exception of the rubber diaphragm cell, the cells listed in Table 1 are essentially rigid in character. This means that the pressure which is indicated by them is likely to exceed the true pressure in the soil in which they are installed. The extent to which the indicated pressure might deviate from the true pressure probably would vary as some function of the thickness or of the cross-sectional area of the cell. In connection with this aspect of the problem, it is of interest to speculate upon just what sort of forces are imposed upon a rigid type pressure cell when it is embedded in a compressible soil. It seems probable that they are analogous to those that resist the penetration of a rigid bearing block into the soil. It has been found that the pressure existing over the plane of contact between a bearing block and the supporting soil is not of uniform intensity. In the case of cohesive soils, the intensity is greater near the edges of the area of contact and in the case of granular soils it is greater in the interior

[2] F. Kogler and A. Scheidig "Druckverteilung im Baugrunde," *Die Bautechnik*, No. 31, July 15, 1927.

[3] Studies of Subgrade Pressures under Flexible Road Surfaces. *Proceedings* Highway Research Board, Vol. 19 (1939)

portion of the area. This explains the observed fact that the resistance offered to the penetration of a circular bearing block into a cohesive soil varies inversely as the diameter of the area while, for a granular soil, it varies more or less directly as the diameter of the area.

Thus, if it is assumed that the forces imposed upon a pressure cell are essentially the same as those resisting the penetration of a body into the soil, it would be expected that the pressure indicated by cells of different size would vary with the area and would be different for cohesive and granular materials

In this discussion it has been assumed that the cell is of tangible thickness and that the pressure receiving face is not encompassed by a rim section It seems reasonable that the presence of a rim around the pressure-responsive area would disturb the pressure-area relationships because it would tend to alter the distribution of pressure on the central area

Another point to be considered when cells with a rim around the pressure face are being used is that difficulty may be experienced in seating the cell upon the soil in such a manner that the same intimacy of contact exists over both the rim and the pressure-sensitive face If uniform bearing on the two sections is not secured, the indicated pressure might be considerably in error.

In planning these exploratory tests, consideration was given to the several points mentioned in the above discussion. Pressure cells of the pneumatic type developed by the Public Roads Administration, but modified with the detachable rim and piston sections as shown in Figure 1, were used in the study. Detachable pistons, not shown in Figure 1, were also used on cell No 7 In all cases the diameter of the pistons was the same as that of the pressure-sensitive area, referred to in the text and tables that follow The important dimensional features of these cells are given in Table 2.

It will be noted that the diameter of the pressure-sensitive areas varied from 1 to 5 05 in and the perimeter-area ratios from 4 0 to 0 79 The construction made it possible to study the performance of these cells in a number of different

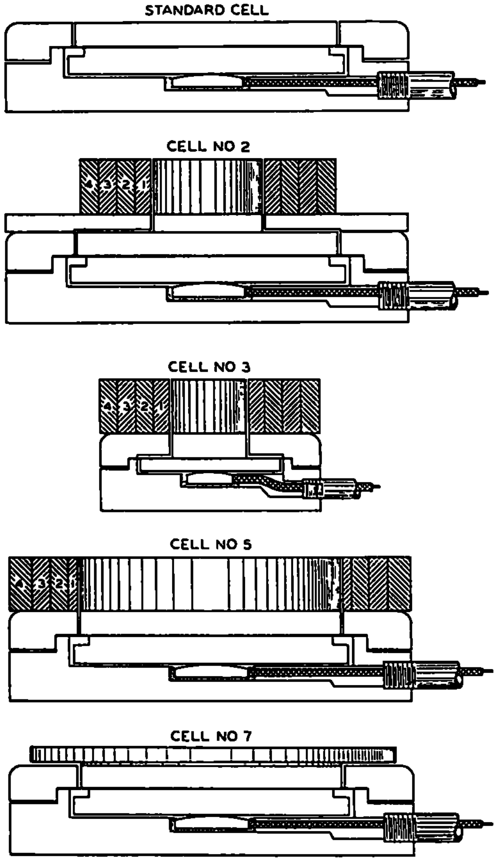

Figure 1. Pneumatic Soil Pressure Cells and Attachable Sections

ways For example, they could be placed face down on a soil, or any other plastic material, and loaded, or they could be installed in a container that could be filled subsequently with a soil and loaded in any manner desired In tests of the first type, the effect of variations in the width of the rim section was studied. In tests of the second type the cells proper were set flush with the base section of a cylindrically shaped soil container and, by means of the attachable parts, studies were made of the effects of thickness and facial area of the cells as well as of the effect of variations in the width of rim. In these latter tests the type and condition of the soil through which load was transmitted to the cells could be varied as desired.

TABLE 2

Cell	Pressure-sensitive area		Cumulative width of attachable rim section			
	Diameter	Perimeter-area ratio	1	2	3	4
	inches		*in*	*in*	*in*	*in*
Standard	3.57	1.12				
3	1.00	4.00	0.25	0.50	0.75	1.00
2	1.50	2.67	0.25	0.50	0.75	1.00
5	3.57	1.12	0.16	0.41	0.66	0.97
7	5.05	0.79				

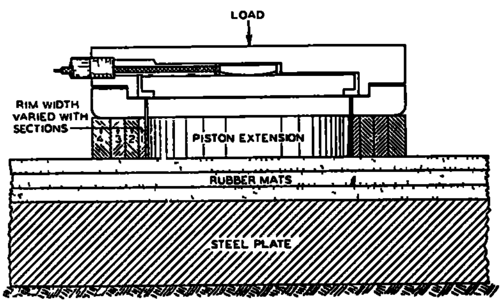

Figure 2. Test Set-up for Studying Effect of Width of Rim of Pressure Cell When Supported by Rubber Cushions.

The first series of tests concerned the performance of cells 2, 3 and 5 when placed face down upon rubber cushions and loaded individually as shown in Figure 2 Two distinct types of rubber mats were used, ordinary soft sponge mats, $\frac{3}{8}$ in. in thickness, and firm fabric-reinforced mats about $\frac{1}{4}$ in. in thickness. In the test a load was applied to each of the cells in suitable increments and the indicated pressures were measured, first, with only the piston extensions bearing on the test materials, and second, with the several rim extensions added one at a time.

The difference in performance of the cells when in contact with the two grades of supporting material was striking. In the case of the soft yielding sponge rubber, the pressure intensity indicated by the cells was always equal to that computed for the load and the contact area in question. This was true regardless of the width of the rim around the pressure-recording piston. In other words, the pressure intensity over the contact plane remained uniform. When the firm fabric mat material was employed an entirely different condition resulted. With this material difficulty was experienced in securing the same intimacy of contact beneath the central piston and the surrounding rim sections before the load was applied to the cells. This meant that in one instance more of the load was transmitted to the test material through the piston section; in another more through the rim section. This difficulty made it impossible to develop definite information regarding pressure distribution between such a material and the pressure cells when their size and rim width was changed. In contrast, the sponge rubber behaved much like a fluid or semifluid medium and slight differences in the relative elevation of the piston and rim section apparently did not affect the pressure intensity indications.

Another factor entering into such tests concerns the manner in which pressures are measured with the pneumatic type of cell. The piston or weighing face is subject to some outward movement when the cell is expanded and a pressure balance is obtained. If the material supporting the rim-piston face is strictly nonyielding in character, this movement, even though infinitely small, would tend to shift all the load to the weighing face. Goldbeck[1], in a series of special tests made with damp sand soil, found that the error due to this movement was extremely small. However, it is believed that the magnitude of the error would be dependent upon the stiffness or deformation modulus of the material in question.

CARE IN INSTALLING RIM-TYPE PRESSURE CELLS NECESSARY

Data showing the effect of variations in the seating of a cell on various soils, with its pressure-rim face down, are shown in Figures 3, 4, 5 and 6. The curves in Figure 3 show pressures that were recorded in a test in which two of the standard cells (Fig. 1) were placed face down in different ways upon different soils and loaded with dead weights as shown. When the two cells were placed directly upon a smooth, flat surface of firm loam soil in the field, the relation between applied and indicated pressures varied widely. With an applied unit load of 20 lb. per sq. in., the pressure intensity indicated by cell A was about 12 lb. per sq. in. and by cell B about 33 lb. per sq. in. Apparently, in the case of cell A, a greater percentage of the applied load was transmitted through the rim section and less through the pressure-sensitive area than in the case of cell B. In an attempt to improve the degree of uniformity of contact between the cells and soil, an intermediate thin layer of the moist soil fines was introduced and this resulted in some improvement, cell A indicating a pressure of 18 lb per sq in. (for a unit load of 20 lb. per sq. in.), cell B showing no appreciable change.

In another test, the same two cells were placed on an extremely moist, plastic loam soil, and the pressures indicated by the two cells were in close agreement although about 20 percent less than the calculated pressure intensity. In this test, it appears that there was a concentration of pressure near the perimeter or upon the rim section of the cells.

The data shown in Figure 4 were obtained in another test designed to show the effect of variations in the seating of pressure cells of the rim type on a soil. Eight of the standard cells were placed

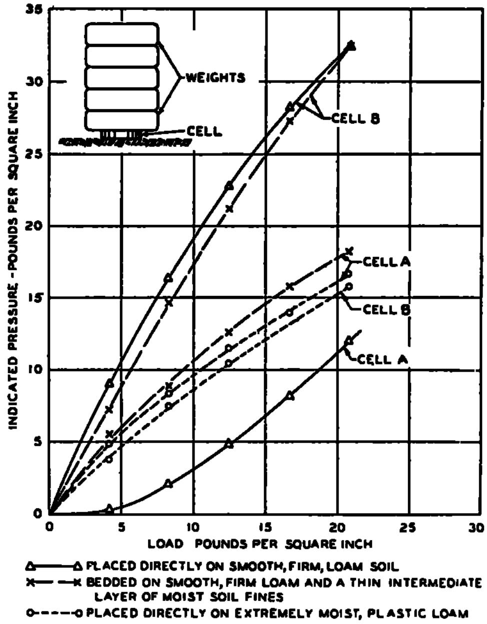

Figure 3. Results of Pressure Cell Tests on Soil in the Field

reasonably close together on a thin bed of the moist soil fines laid over a uniform soil formation and loaded in the manner indicated As the data in Figure 4 show, the indicated pressures varied considerably between cells.

The data in Figures 5 and 6 further emphasize the fact that when several pressure cells having rims are placed face down on a soil and loaded equally, there is likely to be considerable dispersion in the pressure values indicated by the various cells in the group. In the tests referred to as series A in Figure 5 four identical cells were spaced symmetrically around a central cell, then a bearing block 18¾ in. in diameter was cast centrally over the group; that is, the cells proper became an integral part of the bearing block. Series B tests referred to in the same figure differed from series A in one important respect, in that the cells were set into the soil rather than cast in the bearing block. The bearing blocks in each series were loaded in the manner illustrated. The data obtained in these tests likewise show an extremely wide dispersion in the pressure values indicated by the individual cells. The average indicated pressure for a given load is somewhat greater in series B than in the series A tests. This would indicate that the soil around and between the cells did not transmit its proportionate part of the load. This point was given further study in later tests.

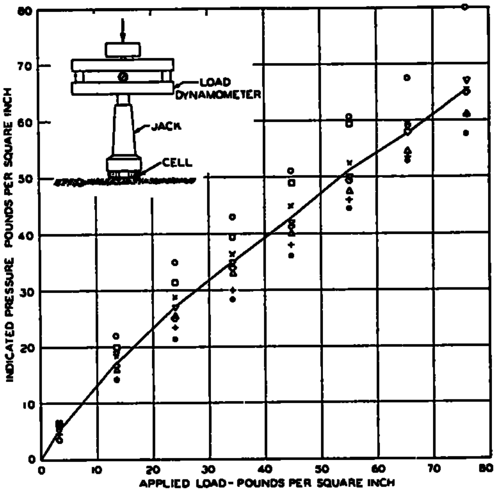

Figure 4. Results of Pressure Cell Tests on Soil in the Field

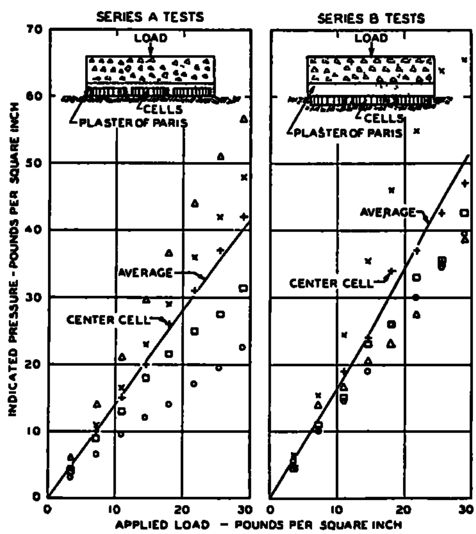

Figure 5. Performance of Standard Cells When Placed in and Beneath Rigid Bearing Blocks.

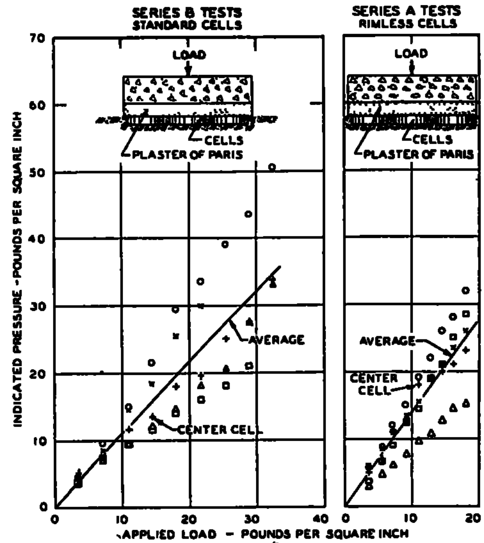

Figure 6. Results Obtained by Testing Performance of Cells Beneath Rigid Bearing Blocks.

The possibility that much of the dispersion in pressure values indicated by different cells when tested in the same manner was caused by lack of uniformity in seating them on the soil was investigated in another group of tests, the results of which are shown in Figure 6 In the series A tests referred to in this figure, cells with the rims eliminated (cell 7, Fig 1) were installed beneath the bearing block. It is to be expected that there should be less difficulty in properly seating cells without rims and, in general, the data indicate this to be the case With the exception of data from one of the outer cells, the values for the various cells are reasonably close together, in contrast to those of series B, in which the standard rim-type cells were again used, and in which the individual pressure values are scattered to about the same degree as in the earlier tests The fact that the average pressure indicated by the cells in the series A tests is higher than that in series B is probably due to the greater cell thickness Other tests were made to investigate this matter more fully.

RIGID PRESSURE CELLS IN A COMPRESSIBLE SOIL SERVE TO DISTURB THE CONTINUITY OF STRESSES

The tests thus far described clearly indicate that considerable trouble may be expected in seating a pressure cell of the rim type on soil so that the same initial intimacy of contact obtains beneath the rim and pressure-recording area This appears to be true even though the cell is bedded on a thin intermediate layer of moist soil fines Thus, in cases where it is necessary to place the cell on a soil such as, for example, a prepared section of road subgrade, rather than place the soil upon the cell as in a fill, the presence of a rim might cause appreciable errors in the pressure indications Also, the presence of a rim might affect in another way the accuracy with which the cell will indicate pressure because the soil when loaded will tend to flow around the foreign object and, under these circumstances, the pressure intensity on the object would not be uniform from edge to center If such soil movement tends to form a concentration of pressure around the perimeter of the object, the presence of a rim on the pressure cell should serve to reduce correspondingly the pressure intensity that is indicated by the cell, and this indicated pressure intensity will be less than the average applied over the entire entire face of the cell If, on the other hand, there is a concentration of pressure in the central area of the cell face, as might be the case with granular material, the pressure intensity indicated by the cell may be higher than the average for the entire cell face.

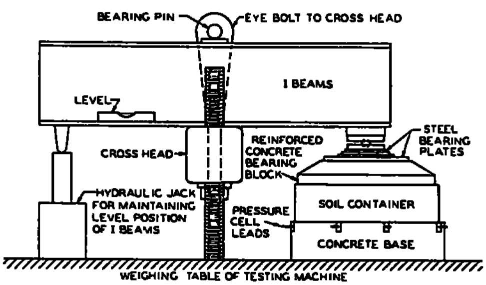

Figure 7. Plan of Loading Set-up for Soil Container Tests

Earlier in the report mention was made of certain tests in which the pressure cells were installed in a container that was later filled with soil to which load was applied These tests were designed primarily to develop information concerning the effect on pressure indication of some of the factors just discussed Figure 7 shows how the equipment was arranged on the table extension of the testing machine that was used to apply known forces on the soil surface

The soil container consisted of a steel hoop or cylinder 30 in in diameter and 8 in high placed on a concrete base which, in turn, was supported on the table of the testing machine The cells were arranged in the bottom of the container in the pattern shown in Figure 8 Loads were applied to the soil with a concrete bearing block that covered the soil surface. Three soils varying in character from a heavy plastic moist clay to a cohesionless dry sand were used in the study. The gradings and soil constants of the material are listed in Table 3. The loam soil was used both in a dry and in a moist condition.

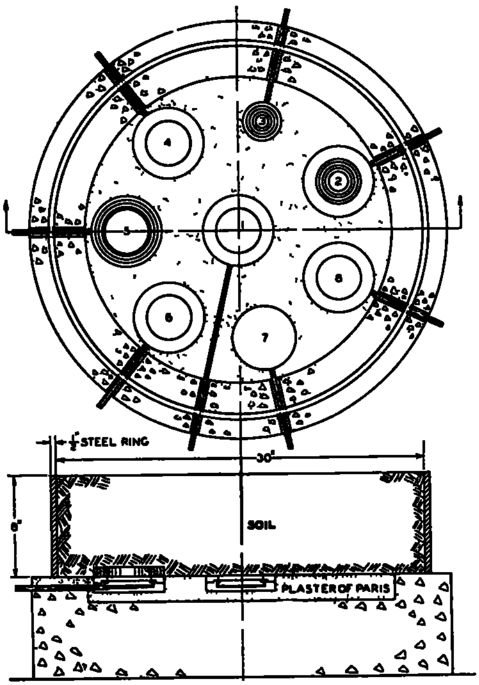

Figure 8. Layout of Cells in the Test Container

It is recognized that in these tests with the container, the soil through which the pressure was transmitted to the cells was restrained from lateral movement and was thus forced to behave somewhat differently than it would under normal field conditions.

The test procedure was briefly as follows. With the pressure-sensitive areas of the cells flush with the surface of the base section, the container was, as a general rule, filled twice in succession with each of the four soils; the load was applied to the bearing block in suitable increments and the indicated pressures were recorded. Then, to cells 2, 3, 5 and 7 the $\frac{3}{4}$-in. piston extensions were attached and the tests repeated. This was followed by similar tests in which the rim or ring sections were added one at a time to cells 2, 3 and 5

Throughout these tests the pressure-sensitive face of standard cells 1, 4, 6 and 8 remained flush with the base of the container. In the case of cell 7 the $\frac{3}{4}$-in.

TABLE 3

MECHANICAL ANALYSIS

Material	Particles larger than 2 0 mm	Particles smaller than 2 mm (percent by weight): Coarse sand 2 0 to 0.25 mm	Fine sand 0 25 to 0 05 mm	Silt 0 05 to 0 005 mm	Clay smaller than 0 005 mm.	Colloids smaller than 0 001 mm.	Passing no 40 sieve
Sand..	0	75	22	1	2		56
Loam	0	14	34	31	21	8	94
Clay	0	2	3	24	71	49	99

PHYSICAL TEST CONSTANTS OF MATERIAL PASSING NO 40 SIEVE

Material	Liquid limit	Plasticity index	Shrinkage		Moisture equivalent	
			Limit	Ratio	Centrifuge	Field
Sand .						
Loam	24	6	15	1 9	18	18
Clay	78	51	15	1 9	43	29

thickness piston extension was left in place.

The moisture content of the damp loam and moist clay soil was held practically constant throughout the tests, being about 15 and 30 percent, respectively. With the exception of the moist clay, which was hand tamped in place in order to eliminate large void spaces in the final specimen, the soils were placed in the container without artificial compaction. After test, the compacted specimens of the moist and dry loam soil were broken up by passing through a ¼-in. mesh sieve preparatory to being used over again.

With this method of test the effect of size of the pressure-recording device, both with and without encompassing rim sections, could be studied. In contrast to the tests described earlier in the report, the use of the container permitted the soil to be placed or molded against the pressure-sensitive face of the cells.

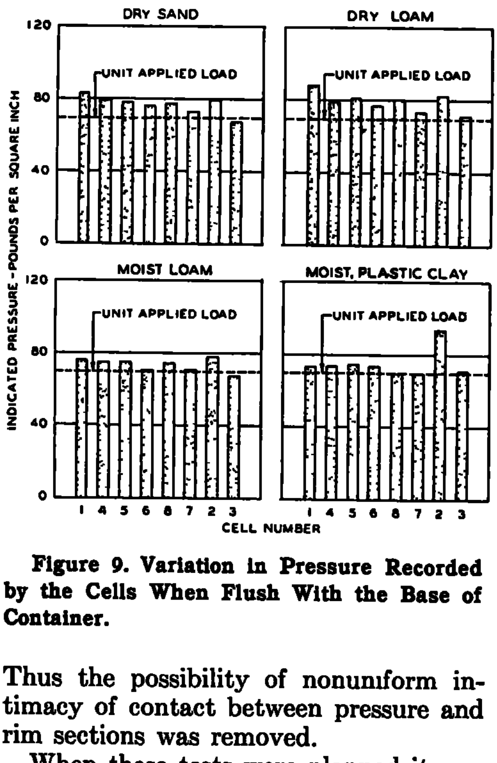

Figure 9. Variation in Pressure Recorded by the Cells When Flush With the Base of Container.

Thus the possibility of nonuniform intimacy of contact between pressure and rim sections was removed.

When these tests were planned it was thought that the intensity of the pressure transmitted through the soil to the base section, at points radially equidistant from the center of the container, would be uniform or at least would not vary to such an extent that the performance of one cell could not be compared directly with another. However, it was found that when the cells were installed flush with the base, differences of appreciable magnitude existed in the pressures indicated by the various cells. The data obtained in the tests with the cell faces flush with the base are given in Figure 9. Although it was noted that the differences were greatest between cells of different size and that they were less when plastic soil was used than they were when granular types of material were employed, still no relations could be developed that would permit the direct comparison of the several individual cells.

It was decided, therefore, to use the data obtained with each cell in these tests as a basis of comparison with data obtained with the same cell in future tests in which the individual cells had been altered in various ways. For example, the cell face could be extended into the soil various distances and the effect of varying amounts of rim area could be studied, always comparing individual cell data with those obtained with the same cell set flush with the surface of the base.

PERFORMANCE OF RIMLESS PRESSURE CELLS DEPENDS UPON THEIR SIZE AND THICKNESS

In general, the pressures indicated by the cells were found to be directly proportional to the applied load. This is evident in the typical load-pressure relationships shown in Figure 10 for the moist loam soil. These data show the pressures indicated by cells 2, 3, 5 and 7 for the following physical conditions. (1) Zero thickness, or with the pressure face flush with the base section; (2) ¾-in. thickness, or with the piston extensions attached, and for the ¾-in. thickness plus; (3) one-rim section, (4) two-rim sections; (5) three-rim sections; and (6) four-rim sections. Each plotted value represents the average of two tests.

In these and subsequent figures and in the test where the term "cell thickness" is used, this dimension refers to the amount of the extension of the cell piston

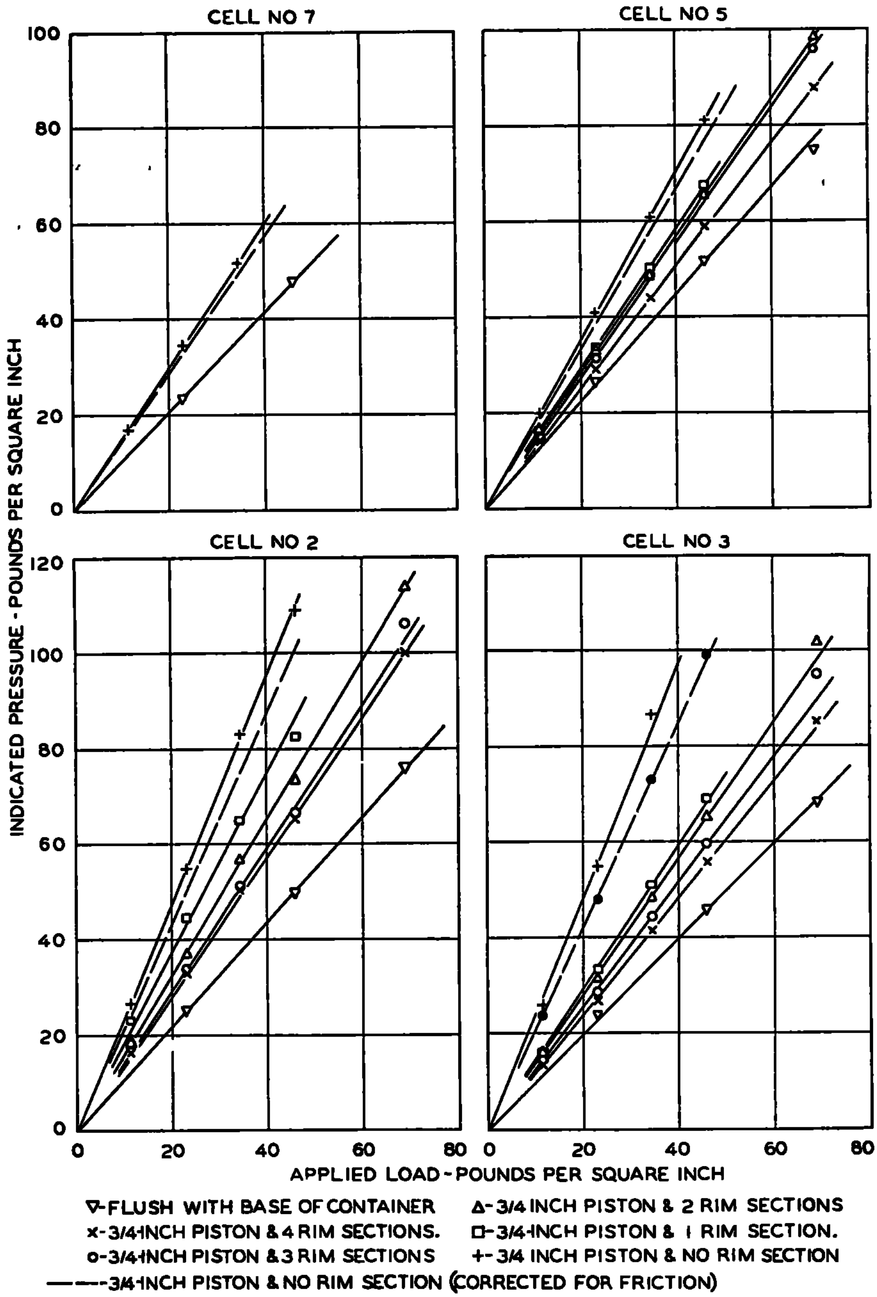

Figure 10. Load-Pressure Relationships for the Moist Loam Test Soil

or the cell rim into the soil in the container and does not refer to the dimension of that part of the cell which is embedded in the plaster of paris

In connection with this figure, attention is called to the relationship shown by a broken line for each of the cells. This represents a corrected value of the relation shown by the vertical crosses by which the element of friction on the lateral surface of the piston extension was eliminated The correction was arrived at by test data obtained with cell 3, in which duplicate tests were made with and without a very thin metal sleeve surrounding the piston extension. It was considered that this sleeve served to eliminate friction between the lateral surface of the piston and the soil Thus the increase in pressure due to cell thickness alone was determined Assuming that the intensity of this lateral frictional force would be unaffected by the diameter of the cell, the values of pressure that would have been indicated by the other three cells, had not friction been present, were computed.

From such data for the four test soils, it was possible to express on a percentage basis the pressure intensity indicated by the cells when they extended up into the soil, in terms of that recorded when the pressure area was flush with the base of the container The relationships are shown in Figure 11.

With the exception of the test data obtained with the moist plastic clay soil, the trend of the data is very consistent and strongly indicates, first, that as the size of a rimless type pressure cell is decreased, the pressure intensity that the cell will indicate, in soils that displace vertically above and around them, may be expected to increase to a marked degree, and second, that the presence of a rigid rim section around the pressure-sensitive area tends to compensate for the effect of cell thickness.

The behavior of the moist plastic clay in these tests was quite different from that of the other three soils Its moisture content was such that apparently the material behaved nearly as a fluid with essentially the same pressure intensity present throughout the confined mass of soil It was observed in all of the tests with this soil that the material, in contrast to the other soils, actually flowed out from the $\frac{1}{8}$-in. clearance space be-

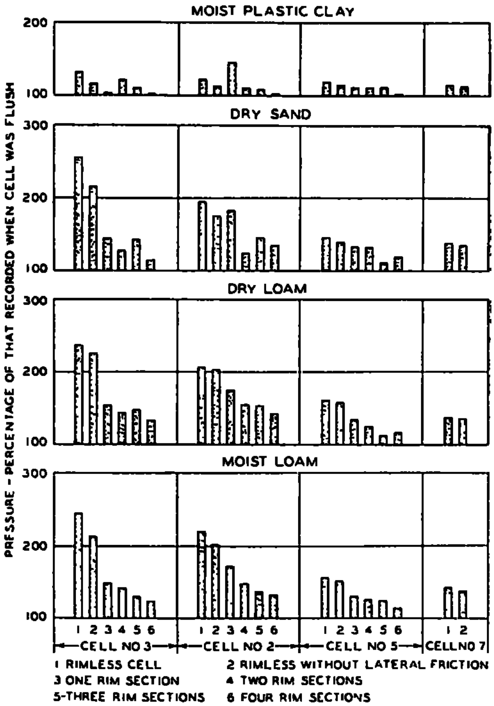

Figure 11. Performance of Cells With and Without Rim Sections

tween the bearing block and the walls of the container

Figure 12 shows a portion of the same data plotted in such a manner as to indicate the effects of the physical dimension of cells of the rimless type on the manner in which they performed under the described conditions of test In this graph the pressure intensity, expressed as a percentage of that obtained with the cells set flush, is plotted against the perimeter-area ratio of the recording units, for cell thickness or piston extensions of $\frac{3}{8}$, $\frac{3}{4}$ and $1\frac{1}{8}$ in, respectively. It was considered advisable to include more than one thickness of cell unit in order properly to evaluate this factor. The relationships shown are considered indicative rather than absolute However, the indications are believed to be significant It is evident that for the dry sand, dry loam and moist loam the the pressure (100 percent) indicated by the cells when flush with the base of the container. It may be assumed that for this soil the increased pressure intensity indicated by the cells, with the piston extensions in place, was largely due to lateral friction.

The fact that tests with moist loam, dry loam and dry sand soil gave similar values was not entirely unexpected. In these tests the body of soil as a whole

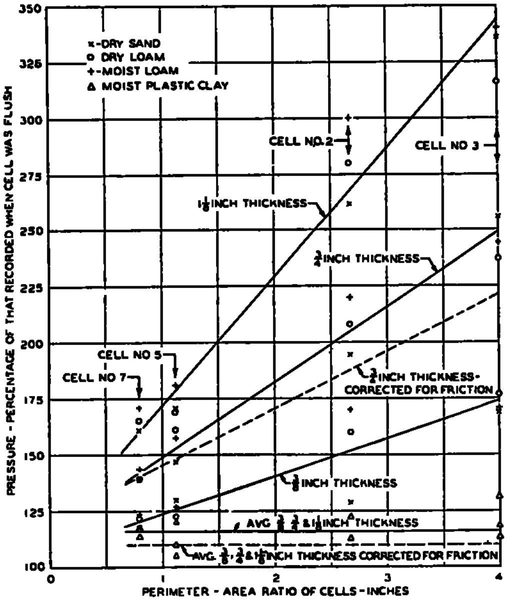

Figure 12. Effect of Size and Thickness of Cells of the Rimless Type

physical dimensions of the cells, as measured by the thickness and by the perimeter area ratio are quite directly related to the accuracy with which they will indicate pressure intensities In the case of the plastic clay, on the contrary, the physical dimensions of the cells apparently do not affect the accuracy of the pressure indication as is shown by the horizontal line which averages the test values obtained with the plastic clay. It is to be noted that, when this value of 117 percent is corrected for lateral friction, it remains somewhat greater than could move or displace only in the vertical direction Had the tests been made in a way such that the material could behave in a natural manner; i.e., displace laterally, in the cells, dry sand might have behaved somewhat differently than the loam soil It is known that the resistance offered by granular soils to the displacement of loaded bodies varies more or less directly with the size of the loaded area, the displacement under the same unit load decreasing as the size of the area is increased From this, one would expect that, under normal conditions, the pressure recorded by cells in granular soils would increase as the pressure-sensitive area of the cell is increased, which is contrary to the relation found by the tests made in the rigid container. Some further evidence indicating that the restraining effect of the container was responsible was obtained from a limited series of tests made in a container whose side walls were not strictly rigid. With this type of container when dry sand was used, the pressure indicated by cells of $\frac{3}{4}$-in. thickness decreased as their areas were decreased. In fact, for the smallest cell, 1 in. in diameter, the pressure recorded was less when the cell thickness was $\frac{3}{4}$-in. than when the pressure-sensitive area was flush with the base of the container.

In spite of the fact that the tests were made in a container that restrained the soil body from lateral movement, it is believed that the data shown in Figure 12 clearly indicate that, unless a soil is so plastic that it behaves essentially as a fluid, the accuracy of cells of the general design studied may be affected to an important degree by both the thickness and the diameter.

It was remarked earlier in the report that the pressure intensities which rigid cells might indicate when embedded in and surrounded by soil might possibly vary in a manner similar to that which obtains under rigid bearing areas of different sizes. The data obtained in these experiments, as well as data obtained by Housel[4] and other investigators, indicate that this relation exists.

RIM SECTIONS ON RIGID PRESSURE CELLS COMPENSATE FOR THE EFFECT OF CELL THICKNESS

Referring again to the data given in Figure 12, it is of interest to note that the slope of the pressure intensity-perimeter area ratio curves increases as the thickness of the cell unit increases. In other words, as the cell thickness is increased, the differential in soil movement is greater and the effect of diameter (as measured by the perimeter-area ratio) becomes more pronounced.

Housel[4] in his tests with rigid bearing areas found that as the displacement of the bearing plate was increased, the slope of the pressure intensity-perimeter area ratio curves increased. It is believed that the same soil reaction is responsible in both experiments.

In Figure 13, cell thickness is plotted as a direct function of the pressure in-

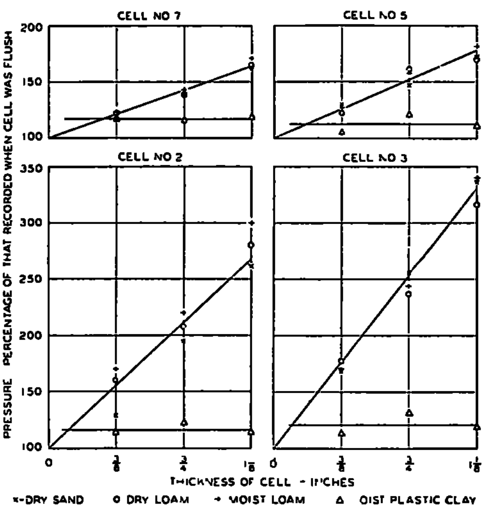

Figure 13. Effect of Thickness of Cells of the Rimless Type

dicated by each of the four cells for each of the soils tested. It is evident that, unless the soil is so plastic as to behave as a fluid, the indicated pressure intensity varies directly with the thickness of the cell. This effect of cell thickness is a very important one since for practical reasons the cell must have thickness and only in special cases can it be installed

[4] "A Practical Method for the Selection of Foundations Based on Fundamental Research in Soil Mechanics," Department of Engineering Research, University of Michigan, Bulletin 13, 1929

so that this thickness does not exert an influence

The result of increasing the effective rim width of the three cells of variable size, but of a constant ¾-in. thickness, is shown in Figure 11 These data show that as the width of rim was increased the pressure intensity indicated by the cell approached that indicated by the same cell when set flush with the base; in other words, that which would be shown by a cell of negligible thickness. This suggests the possibility of determin-

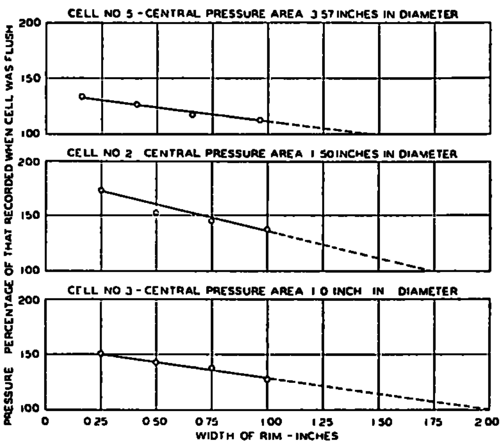

Figure 14. Effect of Width of Rim for Cells of Different Size

ing the width of rim necessary to just compensate for the errors in pressure indication that are caused by the cell thickness of ¾-in

In Figure 14 the data for each of the three diameters of cell (1 0, 1 5 and 3.57 in, respectively) are arranged for this purpose by averaging the values plotted in Figure 11 for the dry sand, dry loam and moist loam soils for the ¾-in thickness corrected for side friction Figure 14 indicates, first, that it is possible to adjust the rim width to compensate for cell thickness in cells of this type, second, that the rim width required for such compensation increases as the overall cell diameter decreased; and third, that for cells of this thickness the rim width required is appreciable.

SUMMARY

In appraising the significance and utility of the knowledge obtained in this study, it should be remembered that the tests having to do with the influence of the dimensional features on cell performance were made with soil that as a body was not free to move laterally and that was of rather limited depth How the cells might have performed in the same soils had there been no planes or barriers of discontinuity was not indicated by these tests, but it is probable that some differences would have been found

The question is intimately related with the state of initial density of the material. Increasing the density of a soil by artificial compaction will reduce its movement under load, although some movement is to be anticipated in even the densest soil materials. To indicate the true pressure developed in a soil by an external force, a pressure-measuring device, particularly a cell of the rimless type must either possess the same load displacement characteristics as the soil itself or it must have no tangible thickness In this connection it appears to be reasonable to assume that a slight amount of differential movement around a pressure cell in a compacted soil would impose as much additional pressure on the cell as would a relatively large movement in an uncompacted soil

It seems impracticable to attempt to design pressure indicating cells that will display the same load displacement characteristics as the soil because these are neither constant or known. The design of a cell that has no tangible thickness likewise presents practical difficulties It appears that the problem of measuring pressures can best be approached by systematic study of the design features of cells that satisfy prac-

tical requirements as the dimensions and materials to the end that these may be used with a full knowledge of their accuracy and other characteristics. It is believed that this exploratory study of the performance of cells of a single type, limited as it is, has served a useful purpose and has produced significant results.

It has been shown that when cells equipped with a rigid rim are placed on a soil, it is difficult, even with the greatest care, to secure the same initial intimacy of contact between the soil and the active and inactive areas of the soil face. As a result there is likely to be a rather wide variation in the pressure intensities indicated by identical cells installed in the same way on the same soil medium.

The tests indicate further that when cells of this type are used, the actual magnitude of the pressure intensity that the cell may indicate depends upon the amount of plasticity possessed by the soil. Where the soil used is so plastic as to act like a fluid under pressure, the cells give an accurate indication.

The accuracy of the indication of pressure intensity given by cells of this type is apparently affected to an important degree by the physical dimensions and by the external design features such, for example, as the relation between the size of the pressure-sensitive area and that of the total facial area exposed to pressure.

It appears to be possible to so design the cell that for given test conditions, the error in pressure intensity indication caused by the cell thickness can be compensated for by suitably proportioning the active and inactive areas of the cell face.

As it was stated at the beginning, this report describes the results of certain exploratory tests. The data obtained are not offered as conclusive. They do, however, point to the importance of a knowledge of the performance of pressure-measuring equipment if dependable data are to be obtained and it is hoped that the presentation of this report of progress will stimulate others to investigations of the characteristics of pressure indicators of other types.