EXPERIMENTAL DETERMINATION OF PRESSURE DISTRIBUTION UNDER A COMBINED FOOTING

Research Performed In Partial Fulfillment Of
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- INTRODUCTION -

The purpose of these experiments was to determine the distribution of pressure under a relatively long, narrow reinforced concrete footing of the combined type and to interpret the results in order to establish a new type of design practice.

At the present time design practice is to assume a uniform distribution of pressure under a spread footing although it is known that this is not the case. Professor Frederick J. Converse in a paper, "Distribution of Pressure Under a Footing", printed in Civil Engineering, April, 1938, showed that pressure under a square spread footing is not uniformly distributed and that the maximum pressure may be twice the uniform pressure assumed in practice. Professor Converse's experiments were performed at the California Institute of Technology, and it was proposed in the present research to apply Professor Converse's method to a combined footing. The Metropolitan Water District of Southern California has carried out experiments on a section of cut and cover conduit, the results of which indicated that the usual assumptions as to distribution of earth pressures on a conduit were in error.

It was believed that the difference in stresses resulting from the actual distribution of pressure as contrasted with the assumed uniform distribution would be of such a magnitude as to warrant an investigation with the purpose of determining more accurate design procedures.

Work on this research problem was started by Samuel Y. Johnson and Homer J. Scott in 1933. Their results were presented in 1934 in a thesis, "Experimental Determination of Pressure Distribution Under A Combined Footing", Johnson and Scott performed two tests on the combined footing which had been designed by them. In the first test the footing was loaded in its original position as poured. In the second test the earth had been removed from the side walls of the footing. Their results indicated wide unsymmetrical variation in pressure, which they attributed to a difference in the moisture content of the soil at the two ends of the footing. Johnson and Scott concluded that further verification and experimentation was needed.

Work was continued by Milo C. Ketchum and Darrell H. Sluder in 1934. Their results were presented in 1935 in a thesis entitled, "Experimental Determination of Pressure Distribution Under a Combined Footing". Ketchum and Sluder performed a series of tests on the footing for symmetrical and non-symmetrical loads up to a total load in each case of thirty tons. The results of their tests indicated a marked similarity of pressure distribution under both symmetrical and non-symmetrical loading. Since this did not seem reasonable to them, Ketchum and Sluder hoisted the footing up in the air and proceeded to calibrate the pressure cells, an operation which took all of their remaining time. Ketchum and Sluder concluded that the pressure cells used were not adequate to give quantitatively accurate measurements.

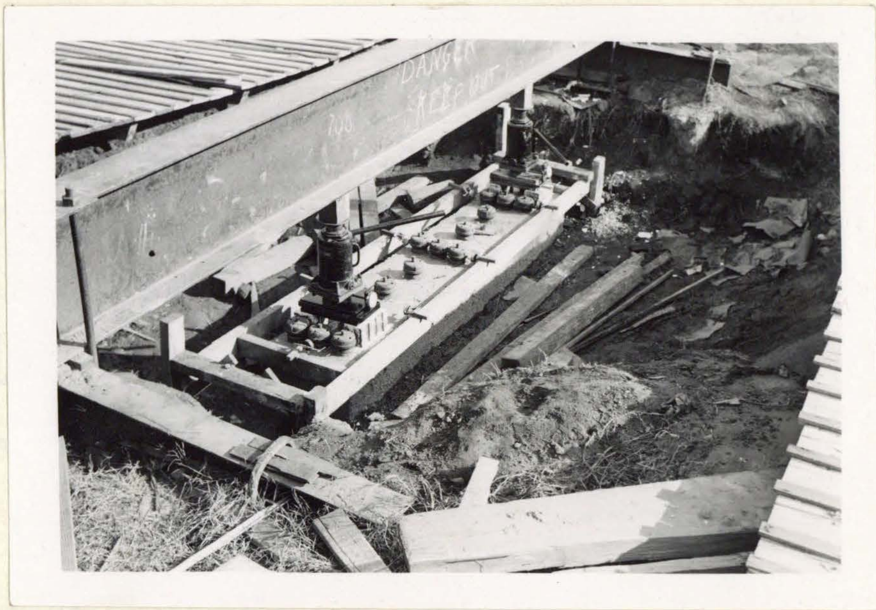
In 1937 work was resumed by Jack Schwartz, who developed a new type of pressure cell. Schwartz, however, left the Institute before he had finished his experiments.

In the following pages, much descriptive material that can be found in the papers of the previous men, has been left out. The reader is referred to the two preceeding papers.

- DESCRIPTION OF THE APPARATUS -

The Footing

The footing upon which this research was conducted consisted of a reinforced concrete block, eight feet long by one and one half feet wide by one foot deep. The foundation of the footing was placed at the same level as the surface of the immediately adjacent soil. The reinforcing



Photograph (1)

used in constructing the block was far in excess of that necessary to support the loads applied to it. For a description of the design, the reader is referred to "Experimental Determination of Pressure Distribution Under a Combined Footing" by Samuel Y. Johnson and Homer J. Scott, 1934.

BLOCK PLAN

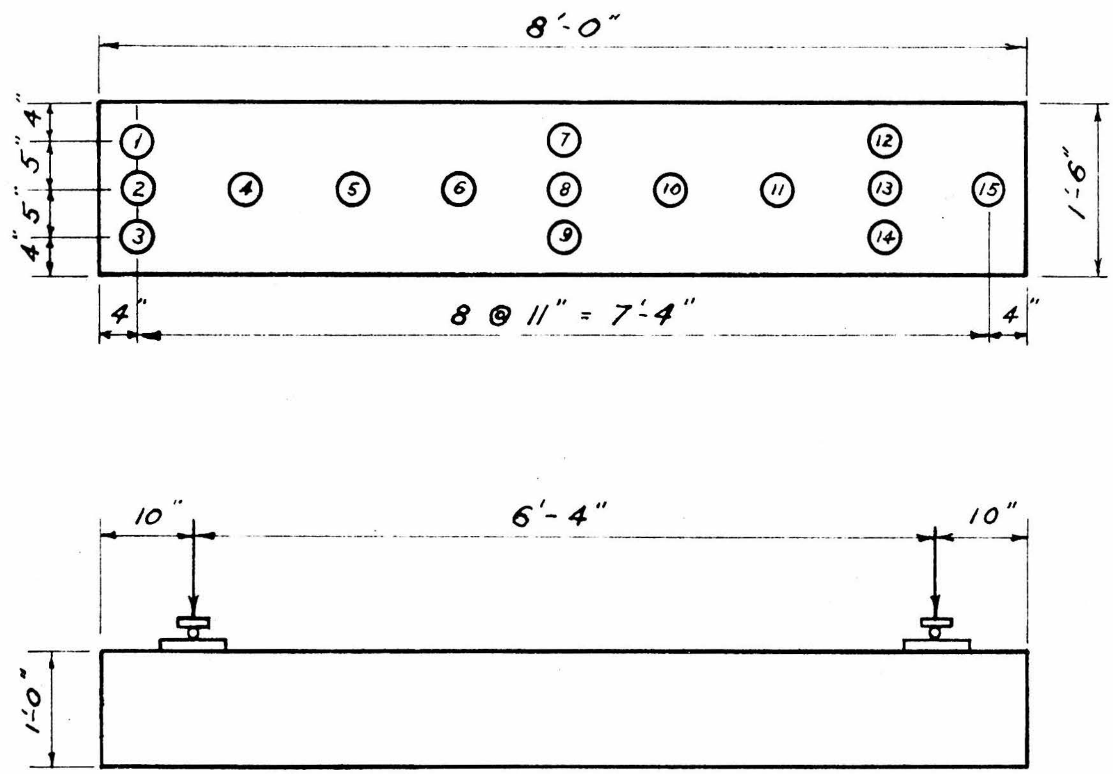
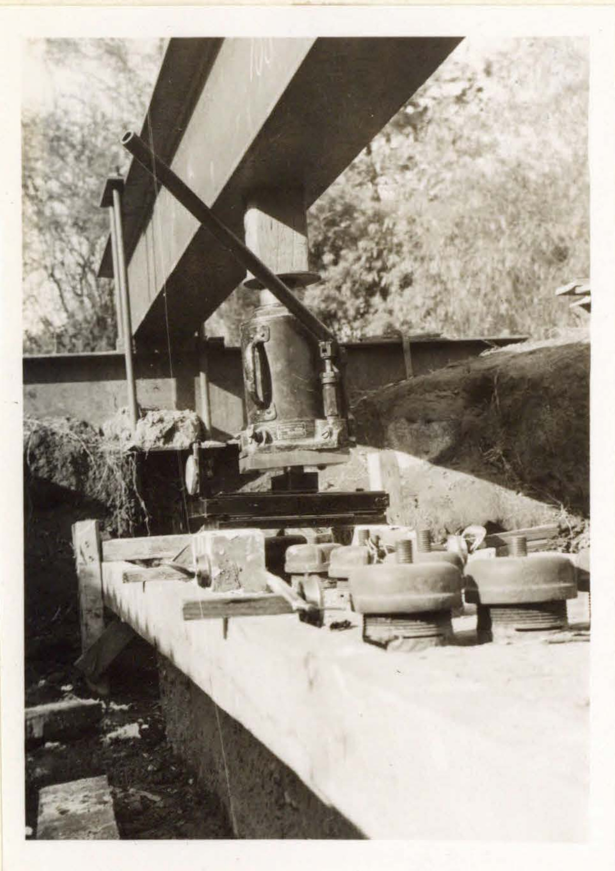


Fig. 1

The Loading Apparatus

The loading apparatus consisted of an arrangment of beams and piling as shown in Figure (2). A thirty ton hydraulic jack between the beam and footing at each of the two points indicated in the figure applied load to the footing. The load was carried through the two beams to the piling where it was passed on to the soil in the pulling resistance of the piles.



Photograph (2)

Photograph (3)

Each jack rested on a beam gauge, which in turn rested on two bricks, illustrated in photographs (2) and (3), placed on the footing so that the point of application was as shown in Figure (1). A ball and socket joint was placed between the jack and the beam gauge, and a four by four block six inches long on top of an eighth inch steel plate was placed between the jack and the loading beam above.

LOADING APPARATUS

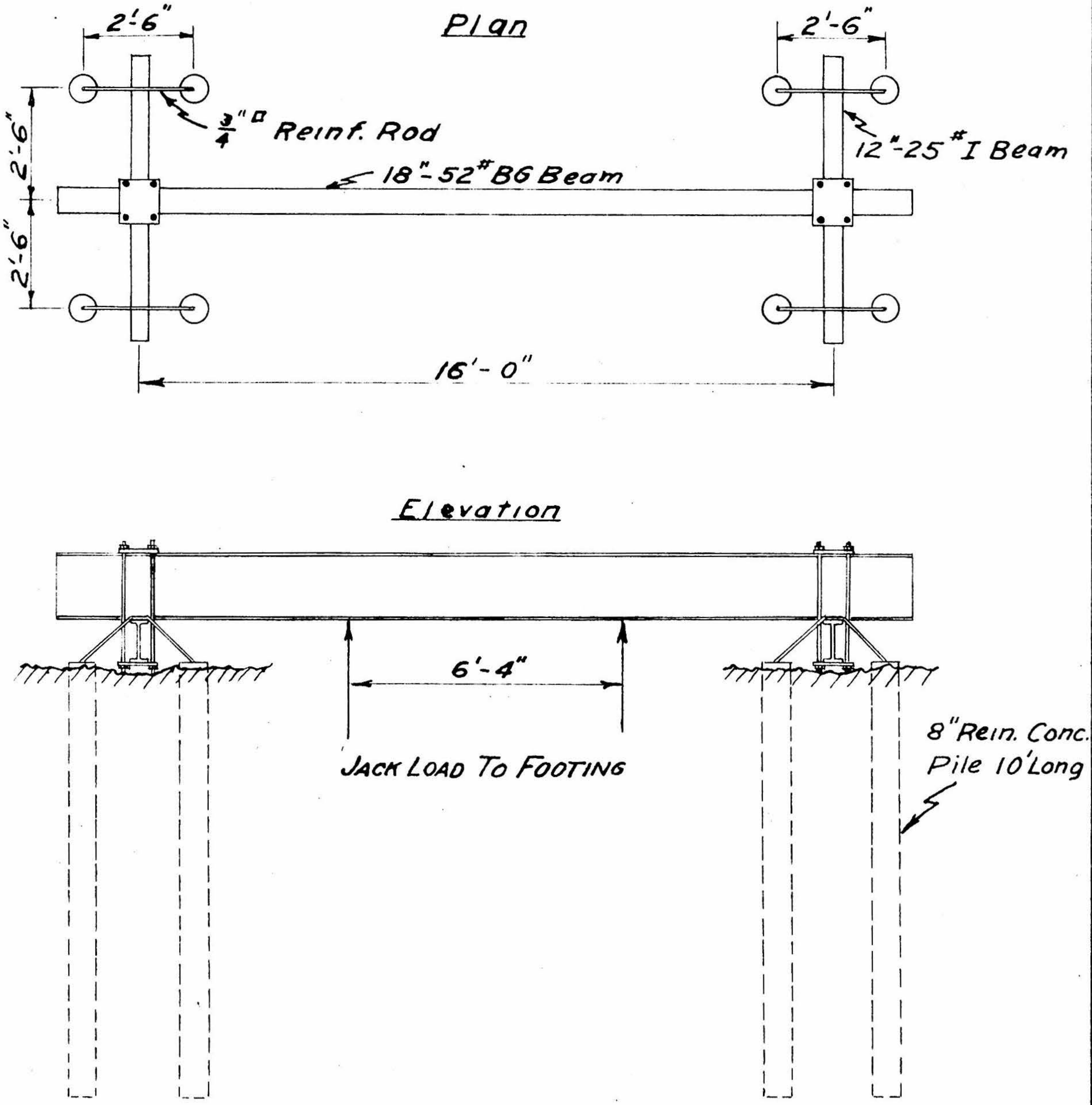
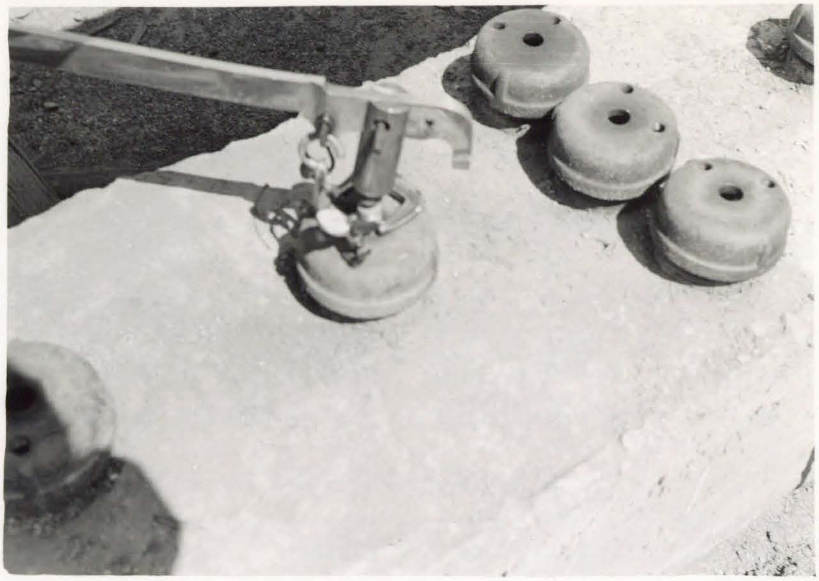


Fig. 2

The Pressure Cell

Pressure cells were placed in the footing at definite points in the footing as shown in Figure (1), in order to determine the pressure distribution under the footing. These cells were constructed as shown in Figure (3), by inserting three inch pipes in the forms at the desired points in such a manner so that when the concrete was poured, the bottoms of the pipes were flush with the bottom of the footing. In the original construction, the top of the pipes extended above the top of the footing only a fraction of an inch. By the method used in the present research a threaded section of pipe of the same size as those in the concrete had to be added in order that three inch pipe caps could be screwed on firmly. Through these caps three holes were drilled; as shown in photograph (4), one three quarter inch unthreaded hole in the center and two three eighths inch threaded holes on a circumference near the outer edge of the cap. Through the three-quarter inch center hole a three-quarter inch steel rod extended down to a piston, a solid steel cylinder of a diameter such that it fitted snugly in the pipe cylinder and from two to three inches in height. The rod was threaded at both ends, one of which was screwed into a threaded hole in the top of the piston, on the other end a combination of nuts was screwed, two below the cap and one above.

Into one of the three-eights inch threaded holes was screwed a one inch long bolt into the top of which an eighth inch rod was fixed so as to form a post about an inch high above the bolthead. Onto this post a "Last Word" deflection dial was fastened so that its deflecting finger rested on the upper nut or a clamp on the center rod. In this manner relative deflection between the piston and the c ap of the pressure cell could be measured. Into the other three-eighths inch threaded hole was screwed a threaded rod about an inch long, on the top of which was fastened a loop of heavy wire.



Photograph (4)

This loop of wire served to hold the tensional force applied by the lever arm, shown in photograph (4), as was used in the first method of measuring the load on the pressure cells. By this method the footing was loaded, as described above, then a load was applied to the end of the lever arm so that, using the loop of wire as a fulcrum, a load was applied to the center rod of the pressure cell. Load was added until the dial on the cell showed a deflection. The applied load at this point, which was measured by a spring scale, was recorded as the load exerted by the soil on the piston.

A second method of measuring the cell pressures is illustrated in photograph (5). After the footing had been loaded, a screw jack was placed upside down on the top of the piston rod of the pressure cell. Between the jack and the loading beam, 18" BG 52#, a small beam gauge was inserted. Then load was applied to the cell, by raising the jack, until a deflection was recorded on the cell dial. The load at this point shown by the small beam gauge dial was recorded as the pressure exerted on the cell piston by the soil.

Photograph (5)

THE PRESSURE CELL

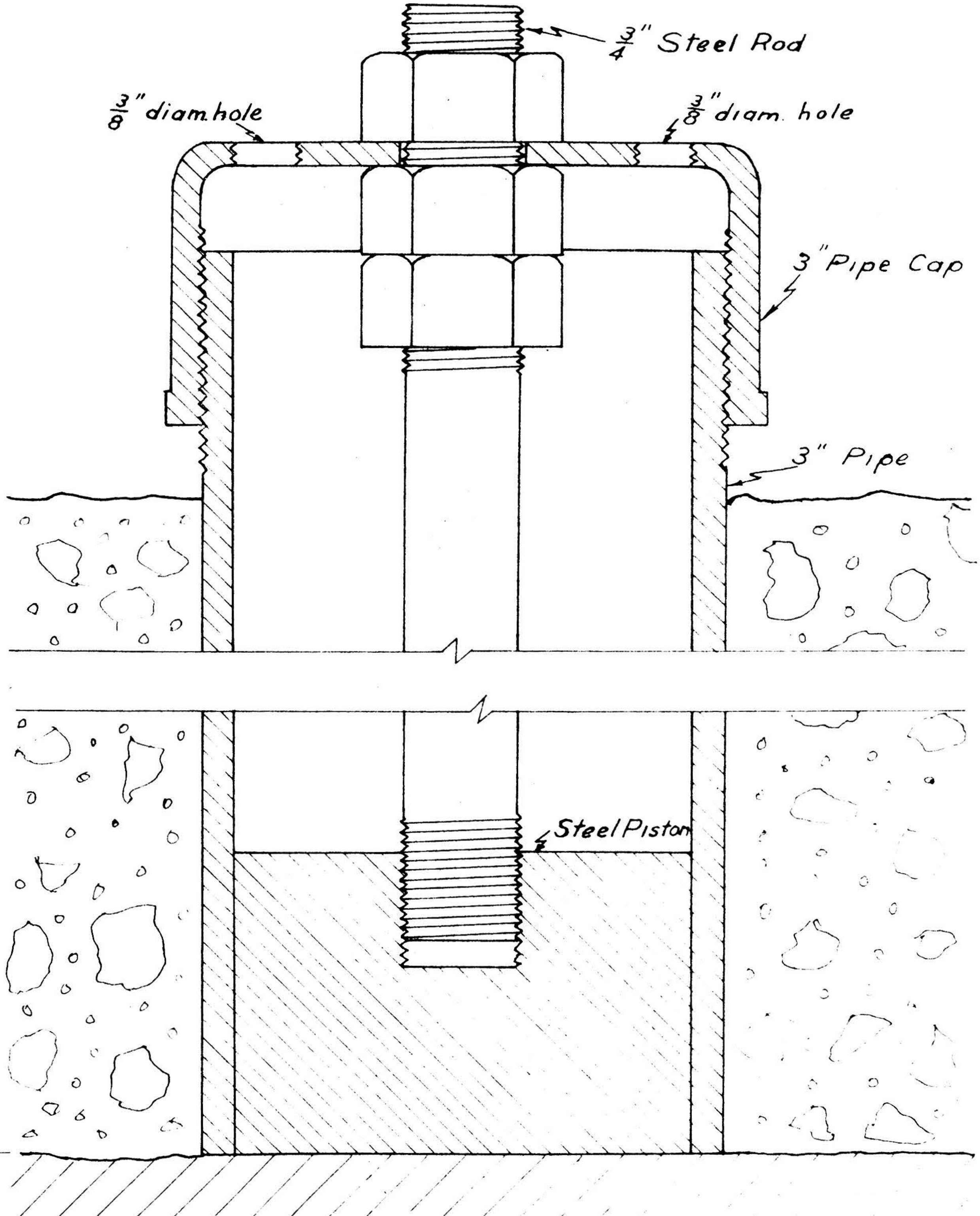


Fig. 3

The Deflection Measurements

In order to measure vertical deflection of the footing under load it was necessary to locate Ames dials at definite points on the footing edge fastened to a framework surrounding the footing as shown in photographs (1), (2) and (3). There were eight dials, one at the middle of each end of the footing, one on each side of the center, opposite cells (12) and (14), and between cells (4) and (5), numbered as in Figure (1).

- FIELD PROCEDURE -

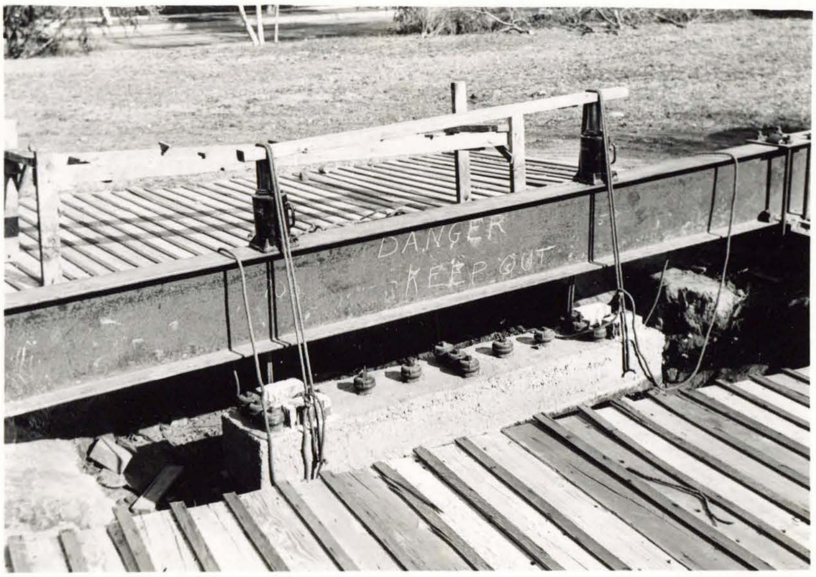
The procedure followed in the field was as follows:

(1) The dials for measuring the deflection of the footing were attached to the timber deflection frame and initial readings of the dials taken.

(2) The footing was loaded by means of the hydraulic jacks until the desired load, as indicated by the beam gauges, had been reached.

(3) After the footing had stopped settling appreciably, the final readings of the deflection dials were taken.

(4) Then, proceeding down the footing one cell at a time, individual load readings on the cells were determined, keeping the jack loads constant.



Photograph (6)

Several times during the course of the research, it was necessary to raise the footing off the ground for various reasons to be described later. The footing was raised and lowered by means of ropes passed over the loading beam as shown in photograph (6).

The precautions observed in the field were as follows:

(1) The footing was carefully centered under the loading beam when it was being placed on the ground preparatory to running a test .

(2) Every effort was made to secure a smooth, level soil surface upon which the footing was carefully levelled.

(3) The jacks were centered in the middle of the footing and were loaded and unloaded at the same time so as not to cause a moment due to eccentricity of loading.

(4) Care was taken not to disturb the timber deflection frame during the course of a test run.

(5) Using the first method of determining individual loads on the cells as shown in photograph (4), an attempt was made to keep the lever arm from rotating sideways and to make sure that the force exerted on the cell rod was as nearly axial as possible.

(6) Using the second method of determining individual loads on the cells as shown in photograph (5) the screw-jack was centered and levelled over the cell rod.

- DESCRIPTION OF TESTS -

At the beginning of the present research, it was found necessary to raise the footing and clean the cells. The footing was then replaced and allowed to stand for two weeks before testing.

The tests made upon the footing were as follows:

Test Number I

Load: Two equal loads totaling 24,000 pounds placed as shown in Figure (1).

Procedure: The cells were prepared for the test by screwing the cap on the pipe down until a good contact was secured between the under-surface of the cap and the nut on the rod. Deflection readings and individual load readings on all fifteen cells were taken. In taking readings of the cell loads the reading was taken at the point when the cell deflection dial indicated a deflection of approximately .0002 of an inch or the smallest definite movement that could be perceived by the observer. This was considered to be the point at which the contact between the nut and the cap had been broken and, therefore, the force pressing down on the piston was the same as that pressing up.

Results: The results were doubtful because (1) some difficulty was found in determining the point at which cell load readings should be made and (2) the readings did not give a reasonable curve of pressure distribution, nor did the integrated sum of the cell loads equal the total load on the footing by a large margin. Several cell dials exhibited a very erratic motion, moving the wrong way, deflecting steadily as soon as any load was applied, or failing to return to zero position upon removal of the load.

It was believed that upon application to the top of the piston of a load infinitesimally greater than the soil pressure on the bottom of the piston that the cell dial should show a sudden perceivable deflection marking the point desired. Furthermore, upon release of this load the cell dial should return to its zero position. It was decided that perhaps better results could be obtained from the use of a larger load on the footing.

Test Number II

Load: Two equal loads totaling 60,000 pounds placed as shown in Figure (1).

Procedure: The precedure was the same as in Test Number I.

Results: The results were obviously worthless, as the movements of the cell deflection dials were so erratic as to give no criteria for determining the point at which the total pressure on the bottom of the cell had been reached. It was felt that there was no basis whatsoever for plotting a curve of pressure distribution.

In these first two tests, the finger of the cell deflection dial had been placed on a nut loosely screwed onto the projecting portion of the piston rod so that the cell dial measured the relative deflection between the cap and this nut. It was noticed that the fit of these nuts on the rods was not very tight, so that it was possible for the nut to rotate slightly, thus accounting for the erratic movements of the deflection dials.

Test Number III

Load: Same as in Test Number II.

Procedure: Same as in Test Number II, except that the finger of the cell deflection dial was placed on a clamp securely tightened on the projecting portion of the piston rod. This method was used in all subsequent tests.

Results: The movements of the cell deflection dials were as erratic as in Test Number II and no worthwhile results could be secured.

It was decided to test the cells under a known condition of loading by using a platform scale to apply a load of known magnitude to the bottom of the piston and measuring the cell load at the top by the cell deflection dial and lever arm apparatus. As a preliminary, the footing was raised to enable the platform scale to be placed under the cells.

Test Number IV

Load: The platform scale was used to exert a load of 300 pounds on the bottom of the piston of each cell tested.

Procedure: The cell loads were measured as in the previous tests.

Results: The erratic movements of the cell dials were as bad as in the previous tests. If previous assumptions were correct, there should have been observed a sudden, small deflection of the cell dial when the known load on the piston had been reached. At or near this load, however, no criterion to mark this load from any other could be observed. The dials moved in the wrong direction, jumped suddenly at various loads, and moved steadily from the moment any load at all was applied. It was felt that there was only one logical explanation of this phenomenon. Since the cell deflection dial measured relative deflection between the cap and the clamp on the rod, it was decided that other deflections due to loose connections must have been obscuring the deflection that was sought. As a result of this conclusion, the caps were screwed down firmly with a pipe wrench in a permanent position to avoid any possible rotation under the forces due to the lever arm loading method, the rods were screwed firmly into the pistons and the bottom surface of the pistons was located permanently flush with the bottom surface of the footing by placing a nut and lock-nut on the rod in contact with the lower surface of the pipe cap as indicated in Figure (3).

In placing the footing back on the ground, a three-quarter inch layer of course sand was placed on top of the soil to avoid the conditions shown in photographs (7) and (8), and to furnish a good contact between the pistons

Photograph (7)

Photograph (8)

and the ground. The position of the footing was such that during a rain, water entered the soil under the footing through a porous layer. As a result of the method previously used to secure a contact between the piston and the soil by screwing the cap down on the nut until the piston was forced into contact with the soil, the piston had been forced during successive tests into the saturated soil a maximum of one-half inch in some places as shown in photographs (7) and (8).

Test Number V

Load: Two equal loads totaling 60,000 pounds placed as shown in Figure (1).

Procedure: The procedure used was the same as that used in Test Number III, except that the pistons were fastened permanently flush with the concrete as stated above.

Results: The cell deflection dials moved too erratically to obtain any figures. To account for the poor results it was decided that there must still have been a source of undesired deflection.

Test Number VI

Load: Same as in Test Number V.

Procedure: This test differed from the others in that two deflection dials were used to determine possible rotation of the cap. These two dials were attached to two stands that rested upon the concrete, the finger of one dial resting on the cap near the edge and the finger of the other dial resting on the cap near the hole in the center.

Results: No rotation of the cap could be detected. No cell load readings could be determined.

One more possible explanation was found for the erratic movements of the cell deflection dials. The arrangement of the lever arm system used to load the top end of the rod in determining cell loads was such that the load exerted upon the rod was by no means always axial. The possibility existed that a component perpendicular to the rod caused lateral deflection of the rod and hence indicated relative motion on the dial without the presence of the vertical motion that was sought. Hence it was decided to use a new method of loading the individual cell rods that would give a more nearly axial load. The method developed using a screw-jack working between the cell rod and the steel loading beam, has been previously described.

Test Number VII

Load: Two equal loads totaling 60,000 pounds, placed as shown in Figure (1).

Procedure: In preparation for this test, the footing was raised, the soil smoothed, and the footing put back in place. The procedure was the same as before, except that the second method of loading the individual cell rods was used.

Results: There were no results from this test that could be presented as such. The erratic motion of the cell deflection dials was as evident as ever. In all cases it was found that the dials indicated an increasing deflection as soon as any load was applied to the top of the rod. There were cases in which the authors thought that they could tell the point at which the load applied at the top just overcame the load on the bottom, but the criterion for determining this point varied in each individual case and consisted in general of a change in the deflection rate. In some instances it was thought that when the load point was reached the piston rod slipped sideways, thus reversing the direction, stopping, or slowing down the indicated deflection. In other instances, a marked increase in the rate of deflection was observable at or near what was known to be approximately the load point. None of these, however, would serve as a scientific basis for measurement.

At the time of writing, the footing is being dismantled.

- DISCUSSION OF RESULTS -

During the course of the research, it was found that the pressure cells were by no means satisfactory. A great deal of trouble was caused by loose connections and only fair workmanship in the construction of the cells. The threads on the rods and in the pistons were found to be imperfect, with the result that there was a good deal of play between the various parts of the cell, giving rise to deflections other than the one sought. As a result, it was not found possible to isolate the deflection expected by loading the rod from accidental deflections, due to the poor construction of the cells. Furthermore, it was discovered that the holes drilled in the pipe caps and the tapped holes in the pistons were not centered accurately. In addition, the extra pieces of pipe that had been welded on top of the previous pipe, in order to adapt the cell to the new test procedure, were not leveled and centered. These imperfections in the construction of the cells were no doubt responsible to a great extent for the failure to secure any worthwhile results.

As mentioned previously, it was thought that when a load slightly greater than the soil pressure on the bottom of the piston had been placed on the top of the rod, an immediate small deflection on the order of two ten-thousandths of an inch would become apparent, and that before reaching this load there would be no deflection registered on the cell deflection dial. The use of this criterion had been suggested by Professor Converse who used it quite successfully in his experiments mentioned before. In the present research, however, it was found that the cell deflection dial began to register a deflection as soon as any load whatsoever was applied to the top of the rod. This circumstance prevented the authors from using the criterion suggested by Professor Converse, and made it very difficult to determine at just what point the proper load had been applied.

The footing had originally been poured in place and tested unsatisfactorily using a different type of pressure cell. The necessity had arisen, however, for uncovering and raising the footing in order to make some changes in it. At the beginning of the present research, the footing was resting on the ground surface and necessarily the original contact between the bottom of the footing and the soil had been broken. It would seem reasonable that having placed a certain total load on top of the footing, readings of the pressure cells could be taken, curves drawn and the load checked by integration of the pressure curves -- assuming a good contact existed between the footing and the soil. Using the second method, previously described, for preparing the pressure cells for the test, that of setting the pistons permanently flush with the bottom of the footing by adjusting the nut at the top, it was necessary before each test to raise the footing and replace it on a smoothed soil surface. The bottom of the footing was quite irregular as it had been poured in place, and it was not possible to make the prepared soil surface fit the footing, other than leveling it carefully. The result was that in some places the contact was not very good and the pistons would be loose in the pipe. To correct this, a settling load was placed on the footing previous to testing. This did not prove to be completely satisfactory, although most of the pistons tightened up, as would be expected, the irregularity was apparently great enough so that the remaining pistons were still loose. Obviously these pistons were not carrying their share of the load and were of no use in determining the pressure distribution.

- CONCLUSIONS -

1. The type of cells used are believed to be satisfactory for the purpose, but these particular cells were not, on account of their make-shift construction.

2. It is recommended that future tests be made on a footing poured in the original position, so as to secure good contact and conditions comparable with actual cases. The footing should not be moved from this position, if the tests can be expected to give any reasonable results.