MOVEMENT STUDY OF BRIDGE PIERS
(Structure X12 - 33045E, I 496 over
C&O RR and Holmes Street, Lansing)

MICHIGAN
HIGHWAY RESEARCH LABORATORY SECTION

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

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(Structure X12 - 33045E, I 496 over
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Introduction

This report covers instrumentation and results of measurements made to evaluate the performance of a "fixed bearing pier" design incorporated in the structure carrying I 496 over ramps, a service road, the C&O railroad, and Holmes St in Lansing (X12 of 33045E).

The thermal expansion and contraction of bridge spans is of significant magnitude. Normally this movement is accommodated by the use of rockers, rollers or sliding plates between the span and supporting piers. These designs are based on the assumption that the spans are free to move back and forth over the piers and consequently forces induced into the piers are limited, although they may be high. This structure was designed with "fixed bearing piers," whereby the spans are assumed to be secured to the pier tops and thermally induced movements "rock" the piers and their footings, bend the pier columns, or both. Although a "fixed bearing" principle was assumed, 2-in. neoprene bearing pads were incorporated in the design to absorb beam rotation and some of the translation. This particular structure has independent pier columns and footings, and also has a steel cap-beam resting on the columns (Fig. 1).

It is the purpose of this study to determine how the thermally induced motion of the span is accommodated by the bearing pads, columns, and footings of the structure.

Scope

The two outside columns and footings of piers 4E and 5E were instrumented during and after construction. Measurements are confined to these two columns and their connecting span. Measurements have been made to determine all appropriate span, pier, and footing movement; soil pressures; and air temperatures at times of observation.

Objective

The objective of this study is to determine what takes place in one span of a "fixed bearing" structure; specifically, to measure span, column, and footing movements, the temperature variations causing these movements, and the pressure variations under the corners of the footings resulting from the forces at the tops of the piers.

Instrumentation and Measurements

Instrumentation to obtain the desired measurements was located as shown in Figure 1.

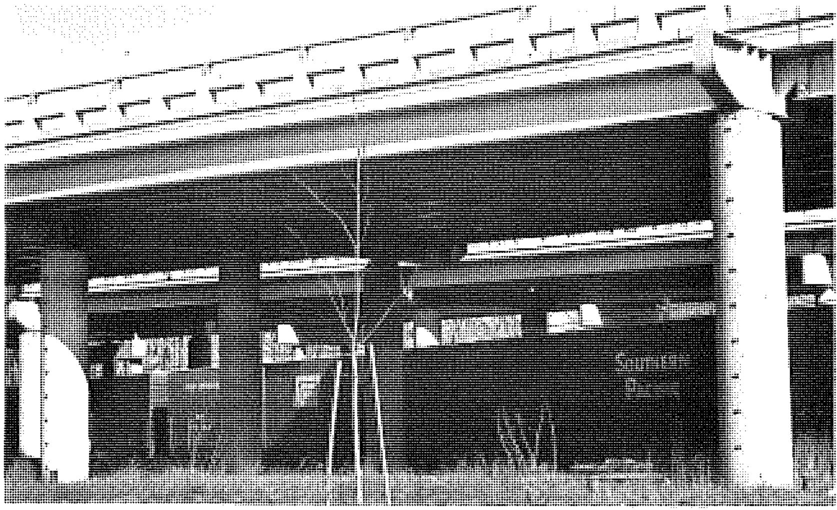
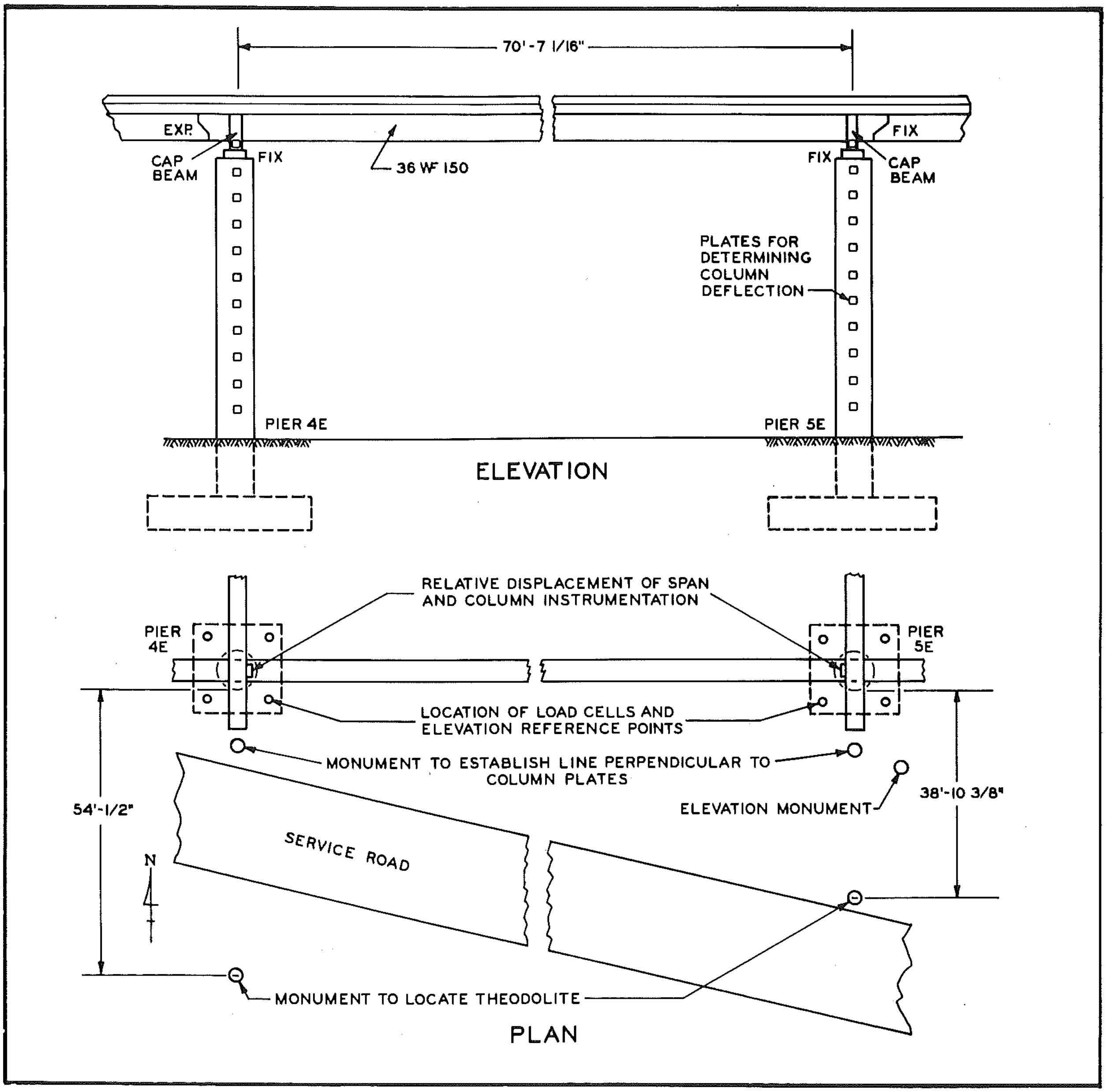


Figure 1. Location of instrumentation and view of instrumented span.



Relative displacements of span and column at the neoprene bearing pad are obtained by measuring from a reference fixed to the pier top. References were established by welding a fixture to one of the steel angles fastened to the column top near each side of the bearing plate (Fig. 2). Measurements are made with a depth micrometer. The micrometer is positioned on the stainless steel reference plate and the distances to either the plate or beam are measured (Fig. 3). Measurements to the bearing plate are made directly, in the longitudinal direction only, to determine how much movement is absorbed by the neoprene bearing pad. Transverse and longitudinal beam-movement measurements are made from the reference plates to blocks welded on top of the bottom cap-beam flange. These measurements determine the total relative displacement of the beams and the top of the column.

The two outside columns of piers 4E and 5E were instrumented to determine bending and rotation. Eleven stainless steel plates were installed at each pier, ten on the column and one on the end of the cap-beam. Figure 4 shows the installed plates and a drawing of the target assembly. Holes were drilled in the column at 2-ft intervals vertically and the backing plates installed with lead anchors and flat-head bolts. Stainless steel plates with inscribed cross-hairs were then clamped on the backing plate, positioned to correct vertical and horizontal alignment and welded to the backing plate. After welding, the clamps were removed.

Column bending measurements are made with a Wild T-2 theodolite capable of measuring vertical and horizontal angles to fractions of a second of arc. References from which to base the movements were established in January 1970 and June 1971 for piers 5E and 4E, respectively. The latter installation was delayed by the contractor's earthwork near pier 4. Two monuments as shown in Figure 5 were installed near each instrumented column in a line perpendicular to the column plates. The monument farthest from the column is the one over which the theodolite is located, the one closer to the column is used to establish a reference line from which to measure the angles. Column deflections are computed from the measured angles.

Vertical displacements of the footings are determined by taking level readings with a K&E precise level equipped with an optical micrometer capable of readings to 0.0001 ft. Fixtures as shown in Figure 6 were installed on top of the footing near each corner. The points on which measurements are taken consist of chrome plated 1-in. diameter by 5-in. long steel rods drilled and epoxy grouted into the footing. The top of the reference points are machined to accept a mating recess on one end of an invar bar. When measurements are made, the invar bar is lowered into the pipe and placed on top of the reference point, it is then plumbed and held in posi-

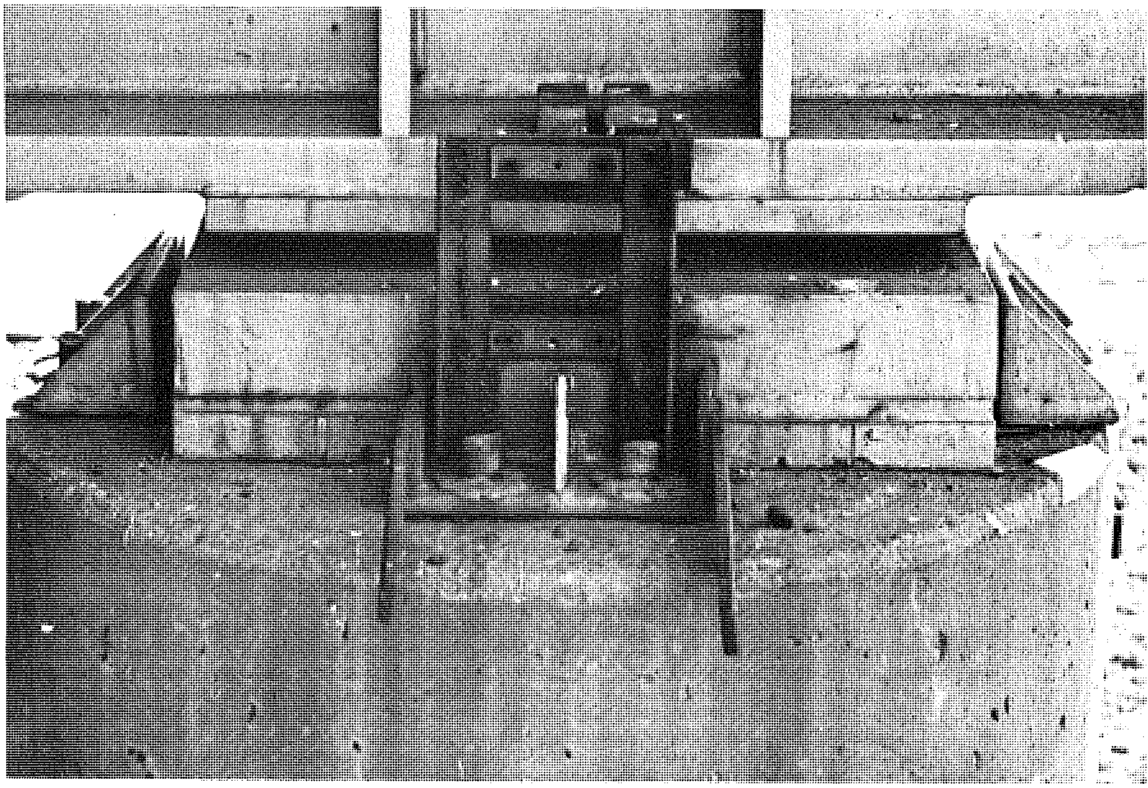


Figure 2. Reference fixture used to obtain measurements of relative displacement between span and top of columns.

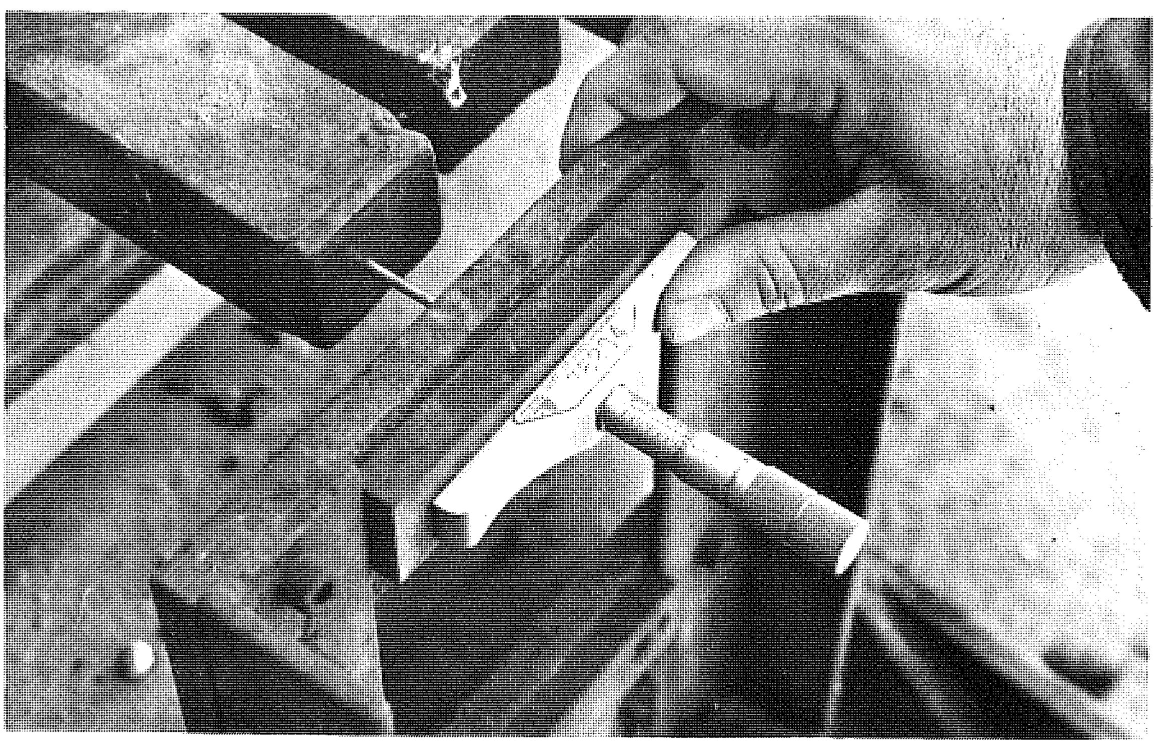
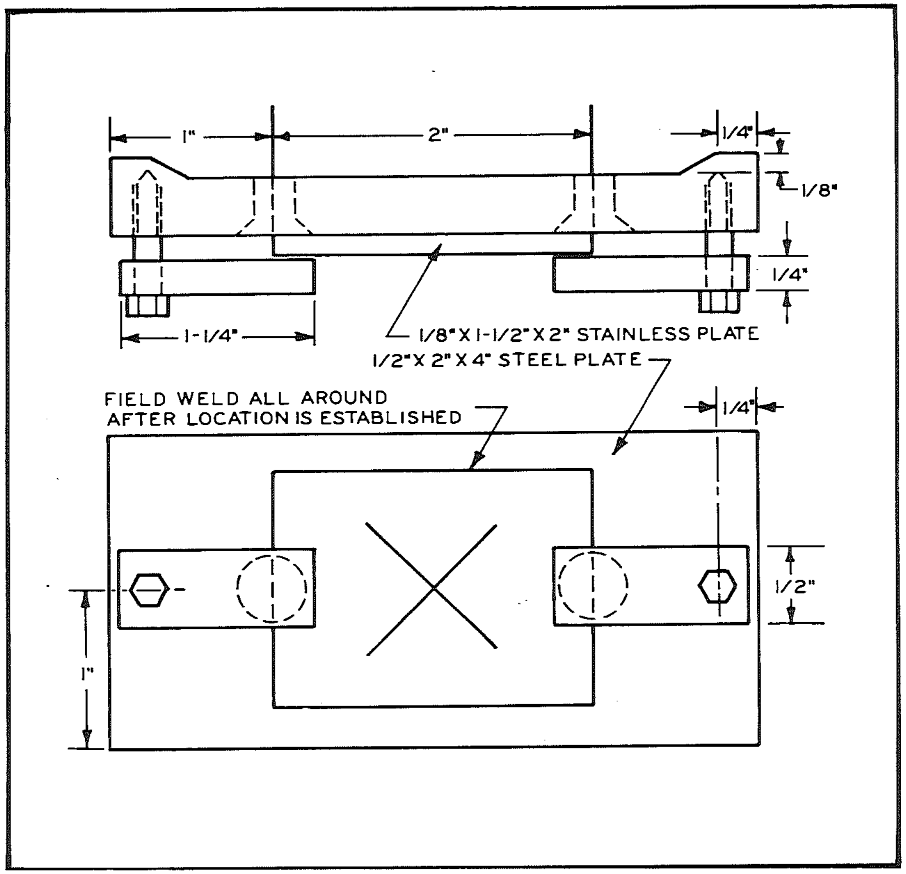


Figure 3. Obtaining measurements of relative displacement using a depth micrometer.



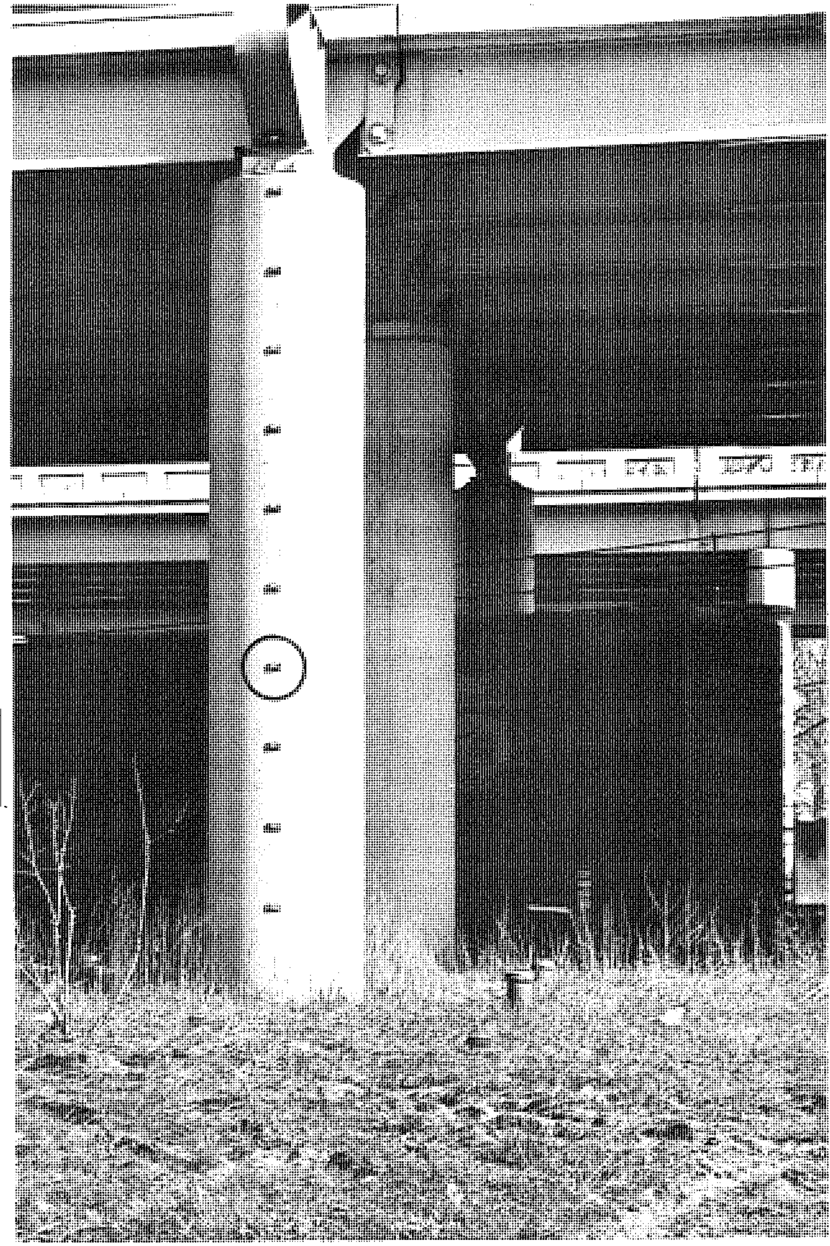
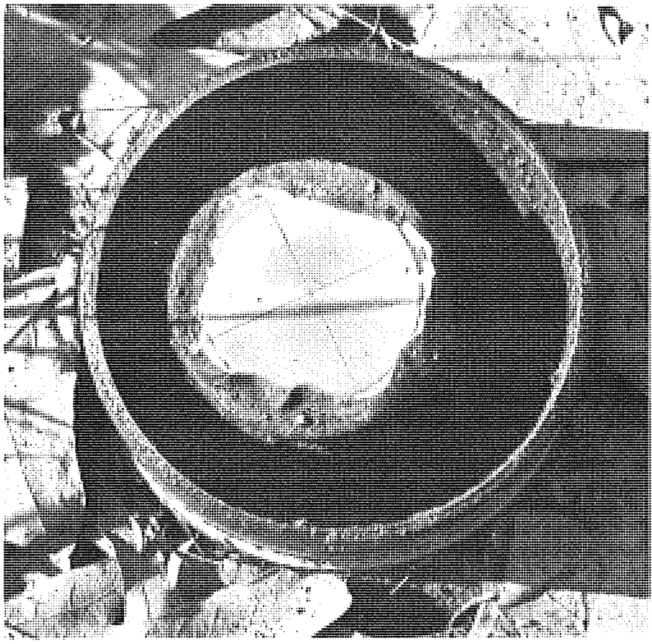
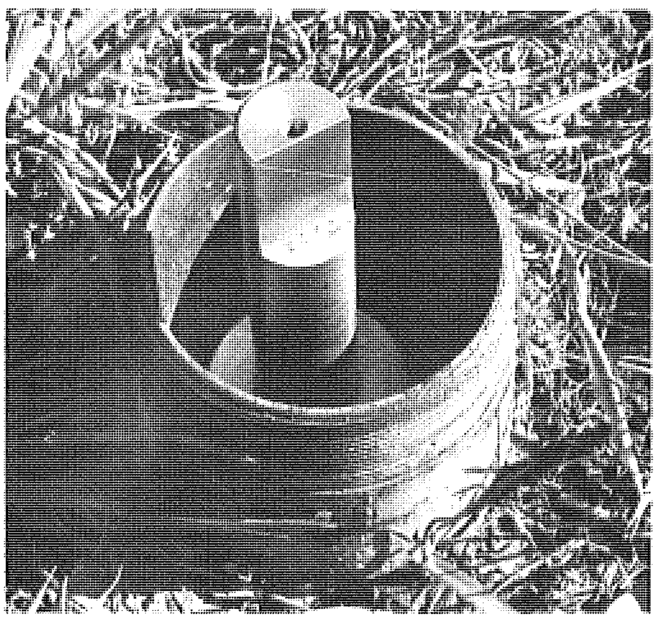


Figure 4. Target assembly (above) and view of plates (circled in photo) installed at 2-ft intervals.





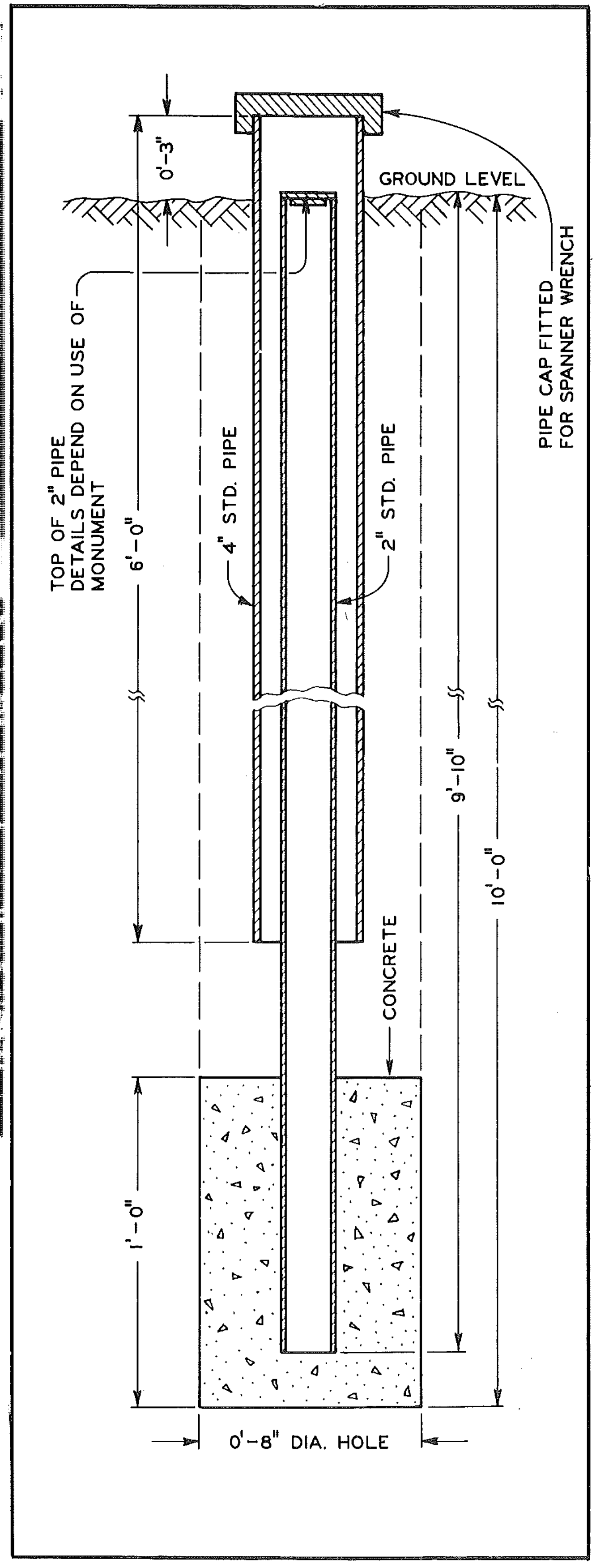


Figure 5. A typical monument cross-section is shown at right. Upper photo shows the top of the monument used to locate the theodolite, lower photo shows the top of the monument used to establish line-of-sight.

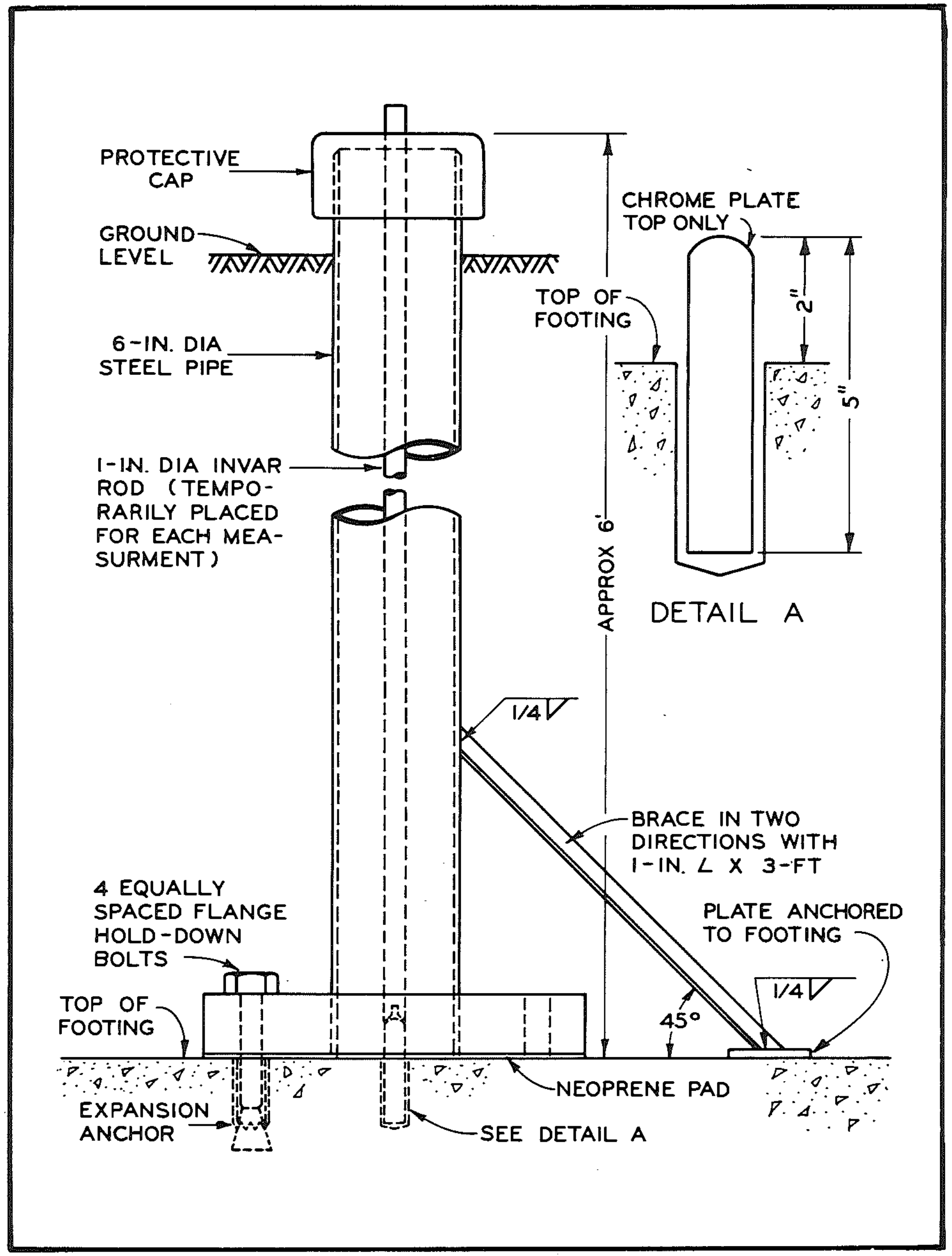


Figure 6. Cross-section and installation of device used for obtaining elevation changes.

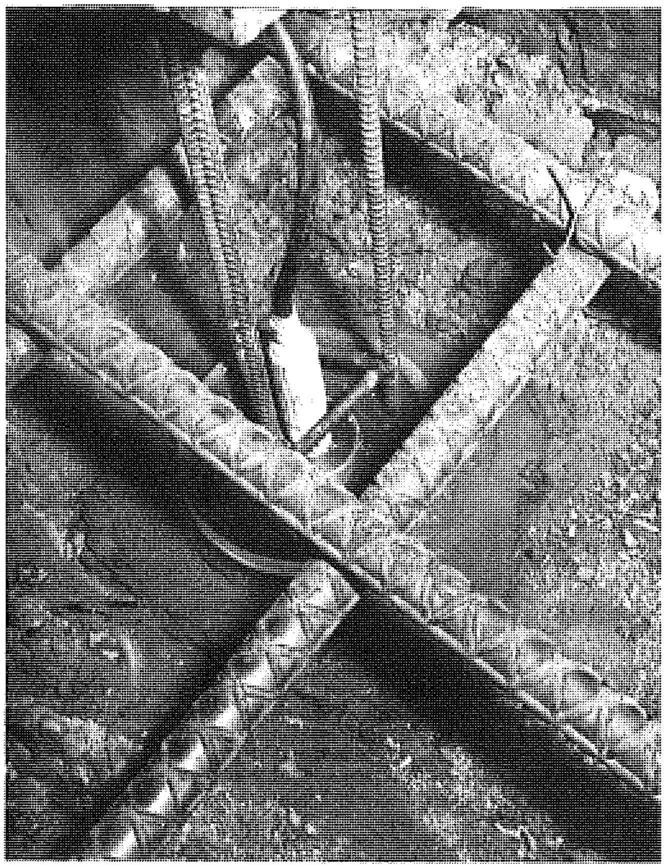


Figure 7. Carlson load cell on mortar bed.

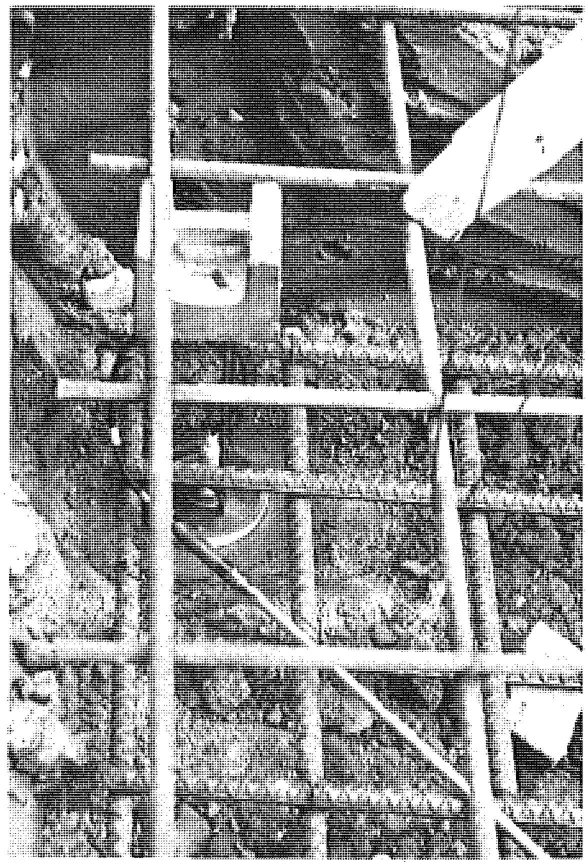


Figure 8. Prior to pouring the footing, a 50-lb weight held the load cell in place.

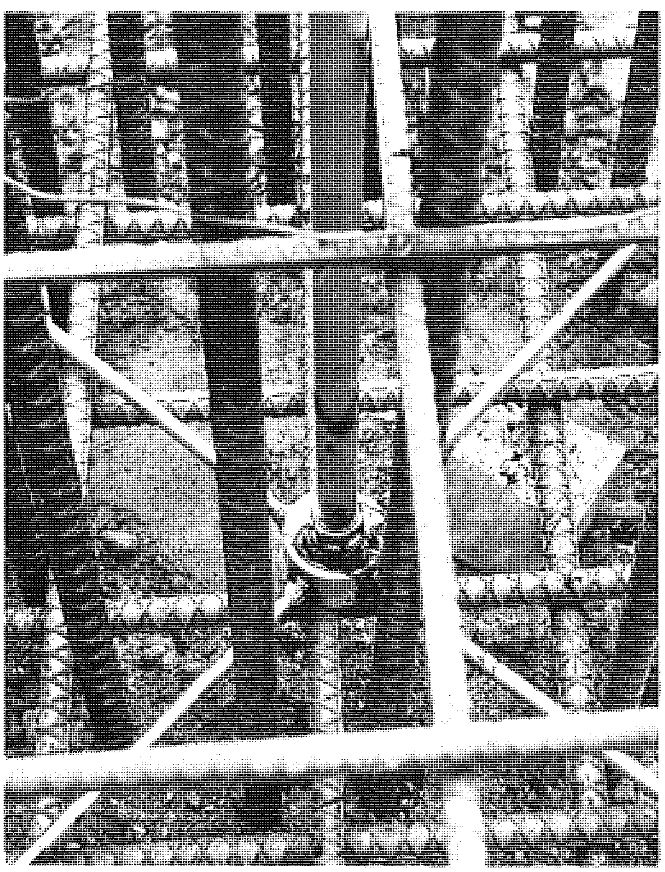


Figure 9. Junction box at center of footing and conduit riser extending upward through the column.

tion by a specially built fixture. An invar level rod is positioned on top of the invar bar and the level measurements taken. An elevation monument was installed to provide a reference on which to base the level readings. (Invar metal has a thermal expansion coefficient very nearly zero. This material was used to prevent inaccurate readings due to length change in the instrumentation from summer to winter).

Soil pressures under the footings of the two outside columns of piers 4E and 5E are determined by use of Carlson soil pressure cells. A total of eight pressure cells (four under each footing) were installed at the time of construction. The four cells under pier 4E were placed near the corners one foot in from each side. The instrumented footing under pier 4E was constructed by forming the sides while the footing under pier 5E was constructed without forms. The pressure cells under the instrumented footing of pier 5E are located 6 ft 6 in. from the centerlines of the footing. Spacing between cells is the same for both footings. Figures 7 thru 9 show the load cell installation prior to placing the concrete. In order to obtain uniform bearing on the undisturbed ground, the load cells were placed on a thin layer of mortar. During pouring of the footing, care was taken not to disturb the positioned load cells. A tripod extension and a 50-lb weight were used to hold the cells stationary as recommended by the manufacturer. Concrete was placed around and over the cells by hand.

The leads from each cell were run through conduit to a junction box in the center of the column and all joints waterproofed. From the junction box, the leads were brought up through the column and out at a point approximately 4 ft above final grade. At this point, a small traffic signal control box was installed which contains a terminal block with each of the wires from the cells identified and connected in the proper sequence for obtaining the pressure cell readings. Variations of pressure cell output are monitored by use of a strain meter.

<u>Discussion of Measurements</u>

Figure 10 graphically illustrates span, column, and footing movements at the instrumented span.

Span Movements - The average summer-winter seasonal displacements of the span relative to the top of column were 0.055 and 0.037 in. for piers 4E and 5E, respectively. These movements include displacements absorbed by the neoprene bearing pad which were 0.054 in. at pier 4E and 0.034 in. at pier 5E. From the above, it can be concluded that virtually all displacements of the span relative to the top of column, are being absorbed by the neoprene bearing pad and there is little rocking of the cap-beam taking place. The total measured average seasonal movement of the span relative to the top of the piers was approximately 0.09 in. at an average temperature variation of 63 F. Approximately 60 percent of the movement is taking place at pier 4E.

Laterally, the cap-beam exhibited average movements of 0.033 in. at pier 4E and 0.036 in. at pier 5E, relative to the pier tops.

Column movements - As can be seen on the graph (Fig. 10), the seasonal movement of the column top at pier 4E totals approximately 0.2 in. This column was instrumented 18 months later than the one at pier 5E due to the final grading not being completed. The fact that the zero reference line was established in the summer is the reason contraction (winter) movements are shown only to the east with the column being in a "vertical" indicated position during warm weather. Note also that the scale for vertical displacement of the footings has been expanded by a factor of ten, in order to show the relatively small displacements.

The column at pier 5E was instrumented shortly after the superstructure was completed. This column showed movements to each side of the zero reference line during the first year only. It appears that a permanent displacement took place sometime after the first year the column was instrumented. After this time, the column is moving about a point approximately 0.1 in. east of its original position. Note also, from the top right of Figure 10, that there was a net slippage of the beam relative to the column top, equal to about 0.1 in. The average summer-winter movements of the column top at pier 5E total about 0.1 in.

Relative movements between the cap-beams and pier tops measured by the theodolite correlate quite well with those obtained by micrometer readings, indicating that the theodolite measurements of the pier motion are indeed accurate.

Footing movements - The maximum vertical movement exhibited by either footing has been 0.01 in. from the established zero reference. Generally, the movements correspond in direction to what is taking place above grade level. However, displacements are too small to be meaningful. Figure 10 shows the movements measured since instrumentation was completed. For all practical purposes, the footings have remained stationary. This particular structure has columns approximately 30 ft high on spread footings about 15-ft wide. A structure with shorter columns on similar footings would be effectively stiffer, and probably would exhibit a different response to the forces at pier-top. Shorter columns could not accept such large deflections in elastic bending without transmitting more rotation to the footings.

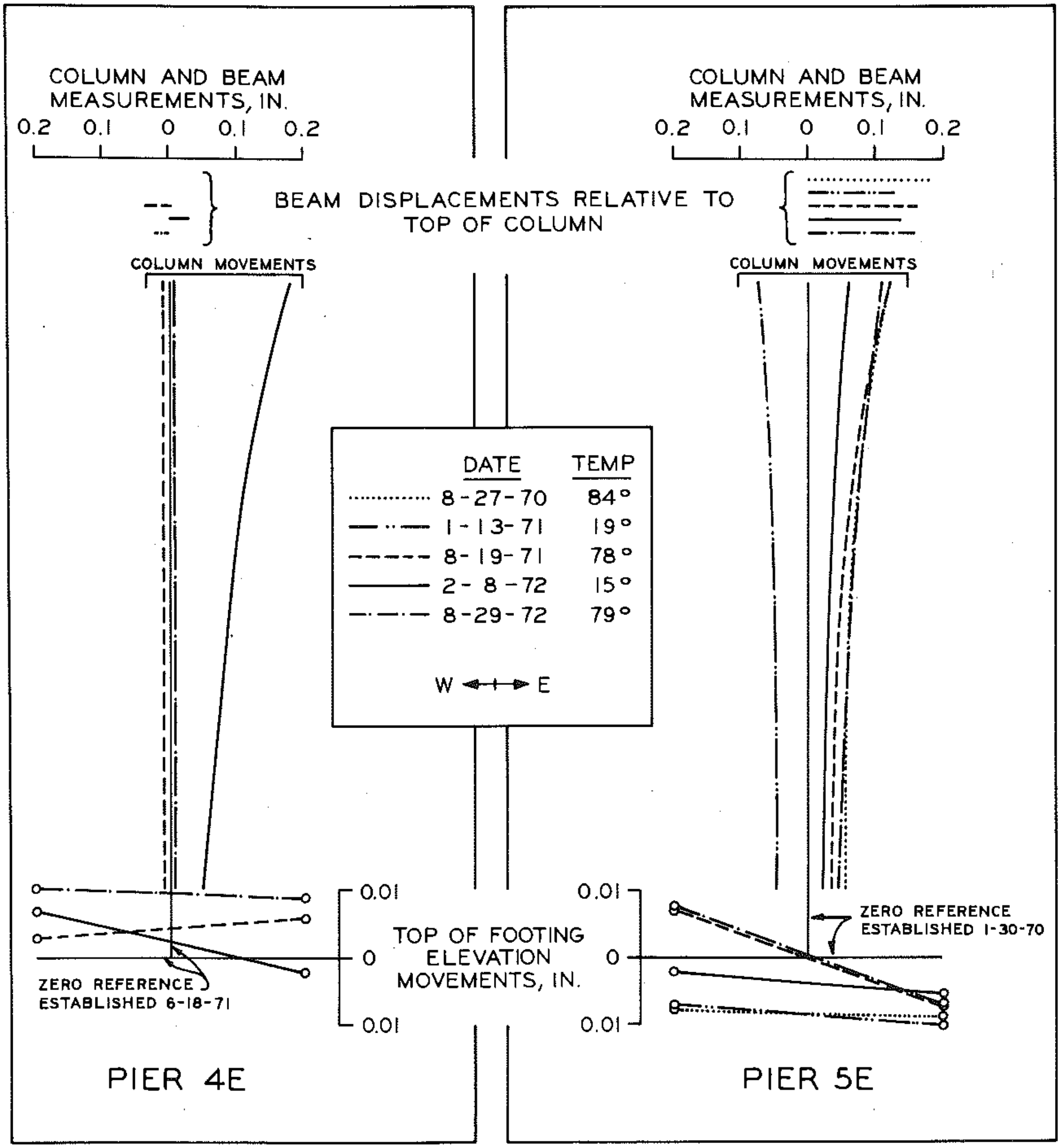


Figure 10. Span, column, and footing movements.

Soil Pressure - Figure 11 shows the soil pressure variations with respect to time. For each pier, the readings of the two east and the two west cells were averaged since this is the direction in which the largest variations occur. As can be seen, the load cell stresses gradually increased as various portions of the structure were completed. Once the structure was finished, the only significant variations in load cell stress are those occurring between seasons. At pier 4E, the average soil pressure under the load cells is 20 psi in the winter and 26 psi in the summer. The footing under pier 5E shows soil pressures of 14 and 20 psi for winter and summer readings, respectively. At this time no positive explanation can be offered for the seasonal overall variations in footing pressure. However, it seems probable that thermal gradients in the structure cause warpage that shifts weight among the three independent supports at each pier location. It is also possible that these indicated pressure variations are due to some malfunction of the pressure cells, although they supposedly are temperature compensated.

Figure 12 shows the results of the "rocking" action of the footings caused by seasonal movements of the superstructure. In winter, when the span is contracted, the pressure on the west side of the footing at pier 4E decreases an average of 4 psi more than the east side and in summer increases approximately 3.5 psi. The footing at pier 5E does not exhibit as much pressure variation as the one at pier 4E; however, this correlates with the fact that pier 5E does not show as much movement. The average variations between the east and west sides of the footing at pier 5E are 1 psi.

Temperature Variations - The temperatures given in the various graphs are the maximum air temperatures recorded on the bottom beam flange, in the shade, during the time readings were being taken. Generally, the readings were taken during extended periods of warm or cold weather in order to minimize the lag in temperature variation experienced between steel-concrete masses and air.

The most accurate measurements are considered to be those concerning location and displacement of the structure. Pressure measurements are far less direct, and are included here only to indicate possible trends, not absolute values. The pressure cells were chosen as the only reasonably applicable devices under the constraints present at the time of construction. Values derived from the pressure cells have been somewhat erratic and, although possibly correct, are not readily verifiable.

On the other hand, cross checks between measurements made by the micrometer depth gage and the theodolite have shown the two systems to be in very good agreement, thereby giving credibility to the physical displacement measurements derived for movement of the piers.

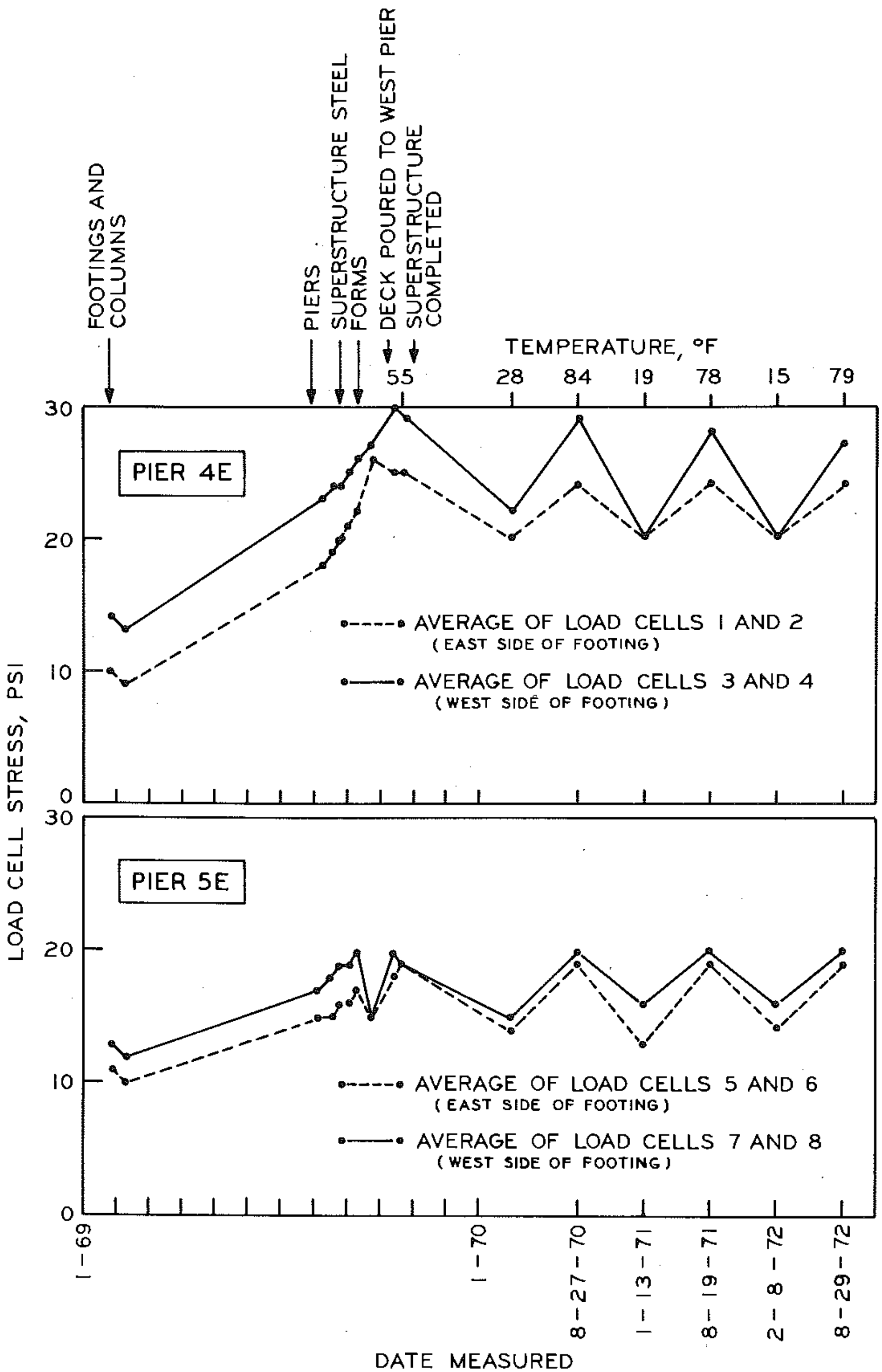


Figure 11. Soil pressure variations vs. time.

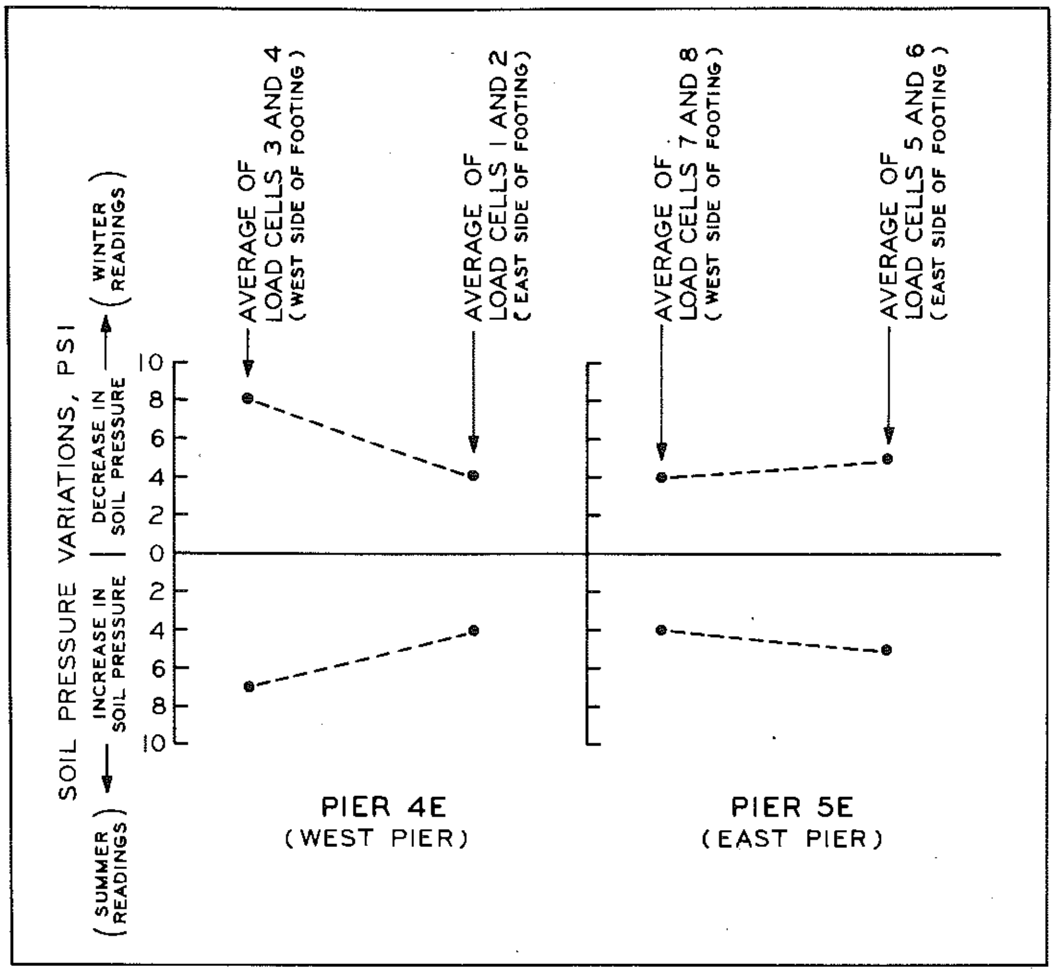


Figure 12. Average seasonal changes in soil pressure.

Conclusions

1. There has been a net slippage of approximately 0.1 in. between the cap-beam and the top of pier 5E, apparently accompanied by a small net rotation of pier 5 to the eastward.

2. There has been very little vertical movement of the corners of the footings.

3. The major portion of the displacement of the span has been accommodated by slippage of the plate on the neoprene pad and by elastic deformation of the pier, with relatively small amounts taken up in rotation of the footings and shear deformation of the neoprene pads.

4. There is some indication, though not sufficiently substantiated for definite conclusion, that there is periodic shifting of the steel superstructure loading, among the three independent portions of the piers.

Additional measurements will be made on the span to document future developments.