# The Effect of Climate on Expansive Soils Supporting On-Grade Structures in a Dry Climate

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**An instrumented on-grade slab model was constructed on a site underlain by expansive clay soil located in a dry climate at Amarillo, Texas. The site was instrumented with moisture cells to measure changes in soil moisture content and thermocouple psychrometers to measure changes in soil suction as the seasons changed. The instrumentation was arranged so that changes in soil moisture and soil suction both vertically and horizontally could be measured, outside as well as beneath the covered surface. Surface elevation points were established at 3-ft centers over the entire site to measure changes in surface elevations and to relate the movements measured beneath the covered surface to those of the adjacent soil in response to the same climatological event. A series of deep bench marks at elevations of 2, 6.5, 9, and 14 ft was established to monitor the depths to which measurable soil shrink-swell occurred. All instrumentation and elevation measurements were recorded on a monthly basis. One complete year of measurements is reported. Surface and subsurface elevation changes and soil suction trends are presented, showing that the slab model at this dry climate site has developed into a well-defined edge lift distortion mode, heaving a maximum of more than 2 in. around the perimeter of the covered surface.**

Almost all clay soils swell when they get wet or shrink when they dry. Those soils that do so to an excessive degree are termed expansive soils. Despite their expansive nature, that is, their tendency to change volume, these types of soil will seldom cause damage to on-grade structures supported on them if they are saturated. It is when they become only partly saturated that they become a problem for structures that are supported directly on the subgrade soil. From experience, the engineering community has found that expansive soils in geographical regions that are predominantly wet cause the most severe problems during extended periods of dryness or drought; conversely, expansive soils in regions that are predominantly dry usually cause more problems during periods of unusual wetness. For climate or environmental conditions that fall between these two extremes, it is known that expansive soils will swell following periods of wetness and will subsequently shrink when extended periods of dry weather follow the wet periods. This shrinking and swelling is cyclical in nature but usually not to the extremes described by the drought and excessively wet conditions previously noted. Thus, unlike other geotechnical engineering design problems, designing grade-supported structures to be constructed over expansive soils also requires a consideration of the climate, a nontraditional engineering design parameter.

Although swelling or shrinking of the soil beneath grade-supported structures could occur at almost any point—and often does—it has been observed that there are two predominant distortion modes *(1–6)*. The first of these is a concave upward shape, often described as dishing or edge lift because the soil is heaving around or near the edge of the grade-supported structure. The second distortion mode is a concave downward shape, often termed doming or center lift because the soil is swelling beneath the center of the grade-supported structure. This second distortion shape could also be caused by the soil around the edge drying out or shrinking, or could even be the result of a combination of both conditions, that is, shrinking around the edge and swelling in the center.

The shrinking or swelling of the soil in and by itself may not cause distress to the structure if the heave or shrink is uniform; in these instances, the structure is likely to ride up or down with the soil as it heaves or shrinks. The structure becomes distressed and suffers the most damage when it is subjected to differential shrinking or swelling such as that which occurs during the center lift or edge lift distortions previously described. Thus, a principal concern of the design professional (with the exception of exaggerated amounts of uniform shrink or swell) should be the differential movement to which the structure will be subjected as the soil on which it is supported moves in response to changes in climate.

In an effort to study the effect of climate on producing differential movements beneath an on-grade supported structure, two instrumented experimental sites were constructed. One site was located in College Station, Texas, and the second site was located in Amarillo, Texas. The College Station site was selected because of its relatively wet geographical location; Amarillo was chosen because of its principally dry climate. Each site was instrumented with thermocouple psychrometers to measure changes in soil temperature and changes in soil suction, and moisture cells to measure changes in soil moisture content. Changes in surface and near-surface elevations were also measured to determine the magnitude of shrink or swell that the slab model was experiencing and the depth to which this movement occurred. The purpose of this paper is to present some of the results obtained from the dry site at this intermediate point in the term of the project.

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## DESCRIPTION OF THE TEST SITE

### Slab Model

The purpose of the field experiment was to measure the type and degree of distortion occurring beneath a covered surface as a result of differential swelling or shrinking of the soil under and adjacent to the covered surface. Thus, the slab needed to be flexible so that it would not impede or restrict differential soil movement. A conventional concrete slab would be too stiff to achieve this objective; consequently, a heavy plastic membrane was placed over the test site to represent the covered surface presented by a conventional concrete slab. Being impervious, the plastic would provide the same interruption in moisture flow into and out of the soil at the surface as would a concrete slab. To protect the membrane from wind and puncture, a 2-in. (50-mm) thick layer of clean sand was placed over it.

The dimensions of the slab were selected to be sufficiently long so that the distance over which the soil moisture change occurred could be captured and wide enough so that the instrumentation would be reasonably safe from being significantly influenced by moisture changes from the lateral direction. Based on published observations of this edge penetration or edge moisture variation distance *(1, 6–9)*, it was believed that a distance of 10 ft (3 m) would be a sufficient buffer for the lateral protection of the instrumentation. Thus, a width of 24 ft (7.3 m) and a length of 40 ft (12.2 m) were selected as the slab dimensions.

One subobjective of the project was to investigate the effect perimeter stiffening beams have on slabs-on-grade with respect to influencing the lateral loss or gain of soil moisture and the lateral distance over which this change occurs. To study this effect, an 18-in. (450-mm) deep grade beam was constructed around the east edge of the slab model. Thus, the 40-ft (12.2-m) length of the slab model would permit the 20 ft (6.1 m) making up the west end of the covered surface to respond to the climate-induced soil movements without being influenced by a perimeter grade beam while the eastern 20 ft would measure the grade beam effect.

### Instrumentation

Two types of instrumentation were selected for use on the project: thermocouple psychrometers and soil moisture cells. However, the moisture cell results will not be presented in this paper. The psychrometers were individually calibrated using a wide range of NaCl solutions. The calibration procedure followed was that recommended by the manufacturer and used individual calibration chambers.

The instrumentation was placed beneath the covered surface in two identical parallel rows spaced 4 ft (1.2 m) apart with each row 10 ft (3.0 m) inward from the edge of the covered surface. The rows were aligned parallel to the longitudinal dimension of the slab model and were symmetrical about the transverse centerline. The plan view of the instrument locations is shown in Figure 1. Thermocouple psychrometers were placed in each location at depths of 1, 3, 5, 7, and 9 ft (0.3, 0.9, 1.5, 2.1, and 2.7 m) below the surface. All but the three centermost instrument locations in each row also had moisture cells installed at depths of 1, 3, and 5 ft below the surface. Figure 2 shows the vertical arrangement (termed a stack) of one row of the instrumentation.

### Elevation Measurements

Upon completion of the surface cover installation, elevation points were established on a 3-ft (0.9-m) grid pattern to measure changes in surface elevation. The grid extended to a distance of 6 ft (1.8 m) outside the edge of the covered surface in order to monitor surface changes occurring in the uncovered soil adjacent to the slab model.

Five bench marks were established adjacent to the site. Each bench mark was set at a different depth: 2, 6.5, 9, 14, and 27.5 ft (0.6, 2.0, 2.7, 4.3, and 8.4 m). The groundwater table was determined to be well below 27.5 ft, at least 50 ft (15.2 m) and perhaps as much as 100 ft (30.5 m) deep according to local engineers and city officials. Thus, the deepest bench mark was believed to be sufficiently deep not to be affected by climate-

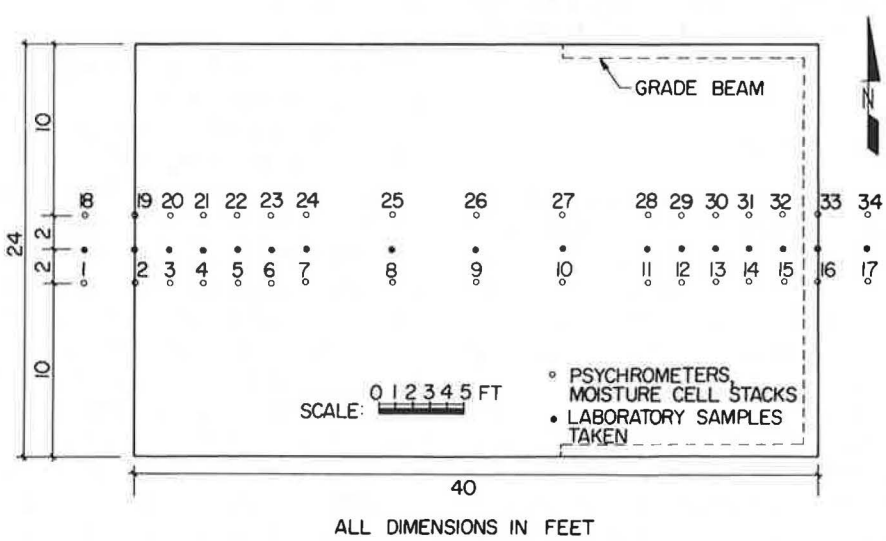


**FIGURE 1 Plan view of slab model showing arrangement and location of the 17 twin instrument stacks (borings 1–34), location of borings taken for soil classification and laboratory testing, model dimensions, and location of perimeter grade beam.**

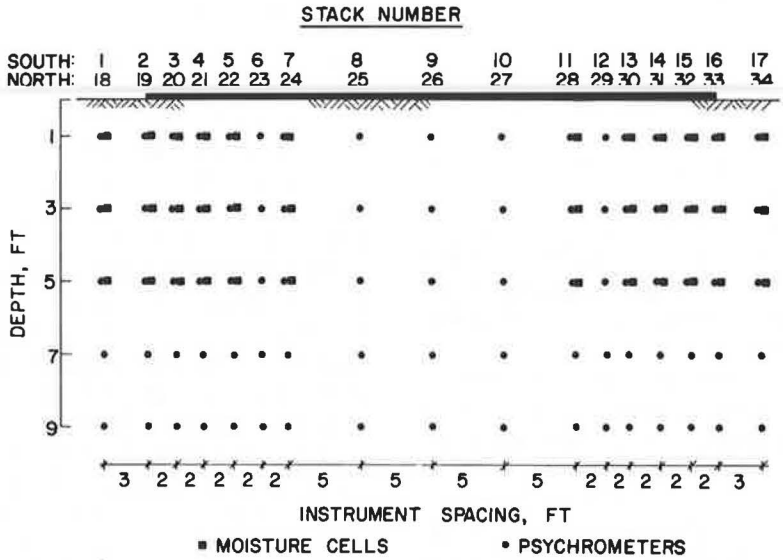


**FIGURE 2 Elevation view of the arrangement and distribution of subsurface instrumentation along either of the lines of borings 1–17 or 18–34.**

induced shrink/swell, but not so deep as to be influenced by a rising groundwater table. All elevation changes are referenced to the 27.5-ft deep bench mark.

Each bench mark was constructed of ¾-in. (20-mm) diameter steel pipe placed inside a 4-in. (100-mm) diameter polyvinyl chloride (PVC) liner pipe driven approximately 6 in. (150 mm) into the soil at the bottom of the boring. A slurry made up of bentonite and diesel oil, having a unit weight of approximately 100 lb/ft$^3$ (15.72 kN/m$^3$), was then poured into the annular space between the outside of the PVC pipe and the boring walls, completely filling the volume to the ground surface. Approximately 1 ft (0.3 m) of the slurry was also poured inside the PVC pipe. The purpose of the slurry was to prevent intrusion of water into the bottom of the boring as well as to prevent the bottom of the boring from drying out. Each PVC liner pipe extended above the ground surface and was capped to prevent direct intrusion of water, such as rain, for example.

## PROPERTIES OF THE SITE SOIL

The site was located on the property of the Family Hospital Center in Amarillo. Four separate soil strata were identified at the site. The top 10 to 18 in. (250 to 450 mm) consisted of fill material that was partially topsoil and partially construction residue that had been graded over the site following completion of the hospital facility a number of years ago. This material consisted of a predominantly reddish brown silty clay. Underlying this top stratum was a dark gray silty clay that was approximately 2 ft (0.6 m) thick. Both of these upper strata were classified as CL in the Unified Soil Classification System and as A-6 in the AASHTO Soil Classification System. The third stratum was a light gray silty clay approximately 3 ft (0.9 m) thick that was underlain by another very similar light gray clay to at least 27.5 ft (8.4 m) that was slightly more sandy and slightly less plastic; both were classified as CH in the Unified system and A-7-5 in the AASHTO system. The mean Atterberg limit values as determined from multiple tests, and the ranges for the percentages passing the No. 200 sieve and the clay content as determined by the hydrometer test, are reported for each foot of depth in Figure 3.

Two in situ properties were determined from the soil recovered during sampling. The in situ moisture content was determined at each foot of depth for each of the 17 continuously sampled borings. The mean of the 17 moisture contents at each depth is shown in Figure 3. The moisture contents indicate that at the time of installation, the soil at the site was very dry near the surface but became progressively wetter to a depth of approximately 6 ft (1.8 m), whereupon the moisture content became a fairly constant value. With one exception, the in situ moisture content was found to be several percent below the plastic limit.

The second in situ property determined was soil suction. This was accomplished using the filter paper method suggested by McQueen and Miller *(10)*. The suction value was determined using S&S No. 589 White Ribbon filter paper and the McKeen calibration curve *(11)*. The means of the 17 soil suction values for each foot of sampling depth are also shown in Figure 3. X-ray diffraction analysis of each of the soil strata was also performed. This analysis indicated that the predominant clay mineral for each layer was smectite, with percentages ranging from 32 to 45 percent of the clay content.

Russam and Coleman *(8)* showed that there is a fundamental relationship between climate, as measured by the Thornthwaite Moisture Index (TMI), and soil suction. The TMI is a convenient measure to use because it is completely rational; that is, it requires only three pieces of data to calculate the index: total monthly precipitation, average monthly temperature, and north latitude of the location. Because of its convenience, the TMI was also selected to be used to measure climate in this investigation. Although Amarillo has an official National Oceanographic and Atmospheric Administration (NOAA) na-

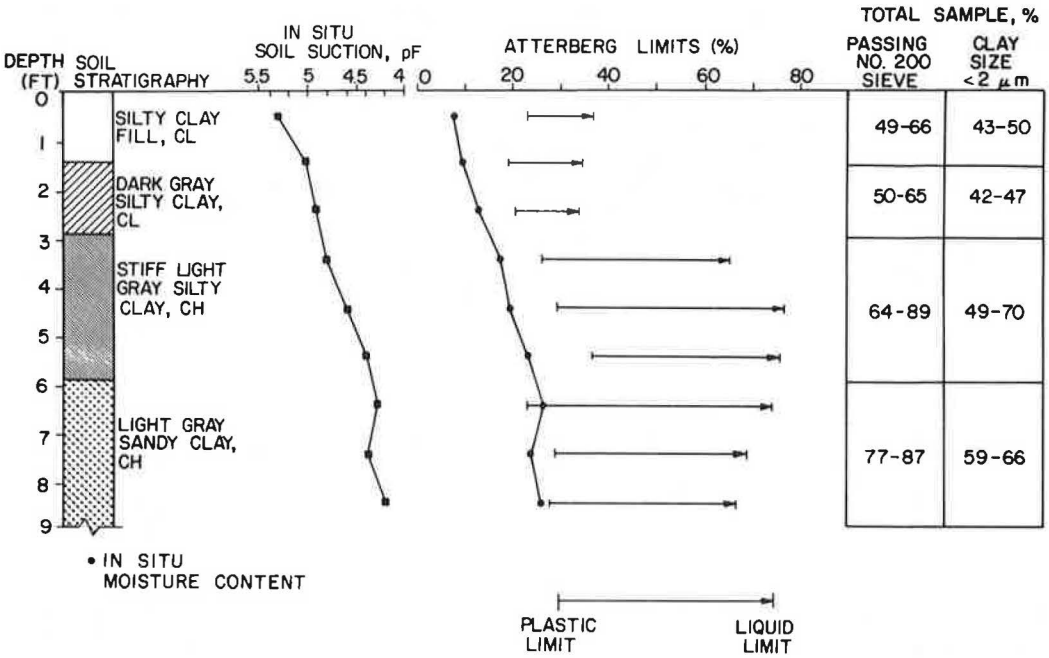


**FIGURE 3 Site stratigraphy and in situ soil characteristics.**

tional weather service measurement station, it is located at the Amarillo Airport, which is approximately 10 mi (16 km) from the experimental site. However, radio station KGNC in Amarillo, located approximately ¼ mi (0.4 km) from the experimental site, maintains a small weather station for its newscasts. Its personnel kindly volunteered to record the temperature and precipitation for the project on a daily basis. Thus, the weather data used in calculating the TMI for the experimental site are considered to be site specific. KGNC began recording this data March 1, 1985. The precipitation that has fallen on the site is shown on a monthly basis in Figure 4. The precipitation amounts shown in Figure 4 before March 1985 were obtained from the NOAA weather station in Amarillo. The TMI for Amarillo was calculated using the NOAA records for the period 1941–1984. The mean TMI for this 44-yr period was found to be –21.9 in./yr (–56 cm/yr). The minus sign indicates that there is an annual water deficit (i.e., if there were an additional 21.9 in. of water available, the soil would give up that amount to the atmosphere each year through plant transpiration and evaporation). The annual TMIs ranged from the wettest value of +2.5 in./yr to the driest value of –41.8 in./yr (+6 cm/yr to –106 cm/yr). The TMI calculated for 1984, the year before the site installation, was –23.8 in./yr (–60 cm/yr) and for 1985 was –17.2 in./yr (–44 cm/yr), which suggests that

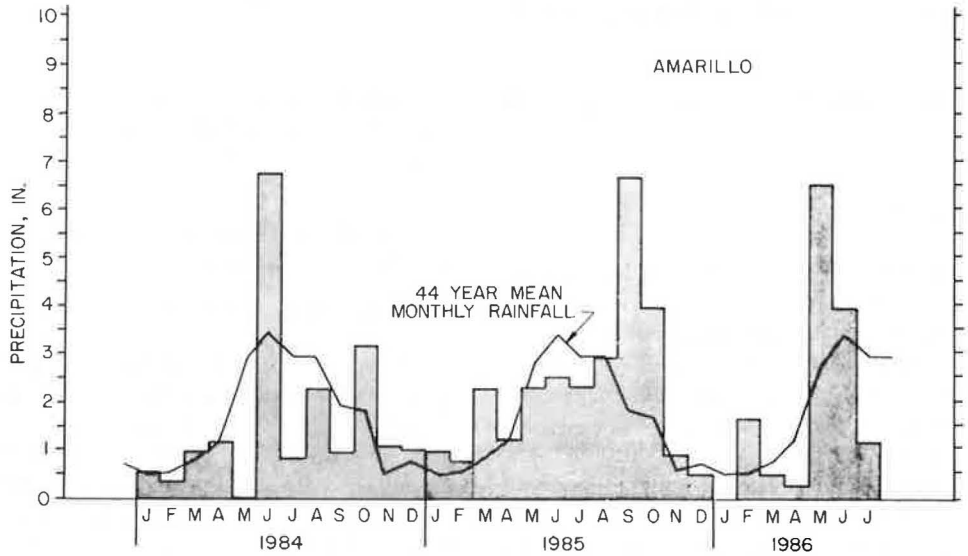


**FIGURE 4 Monthly distribution of precipitation at the Amarillo site and the 44-yr monthly mean rainfall.**

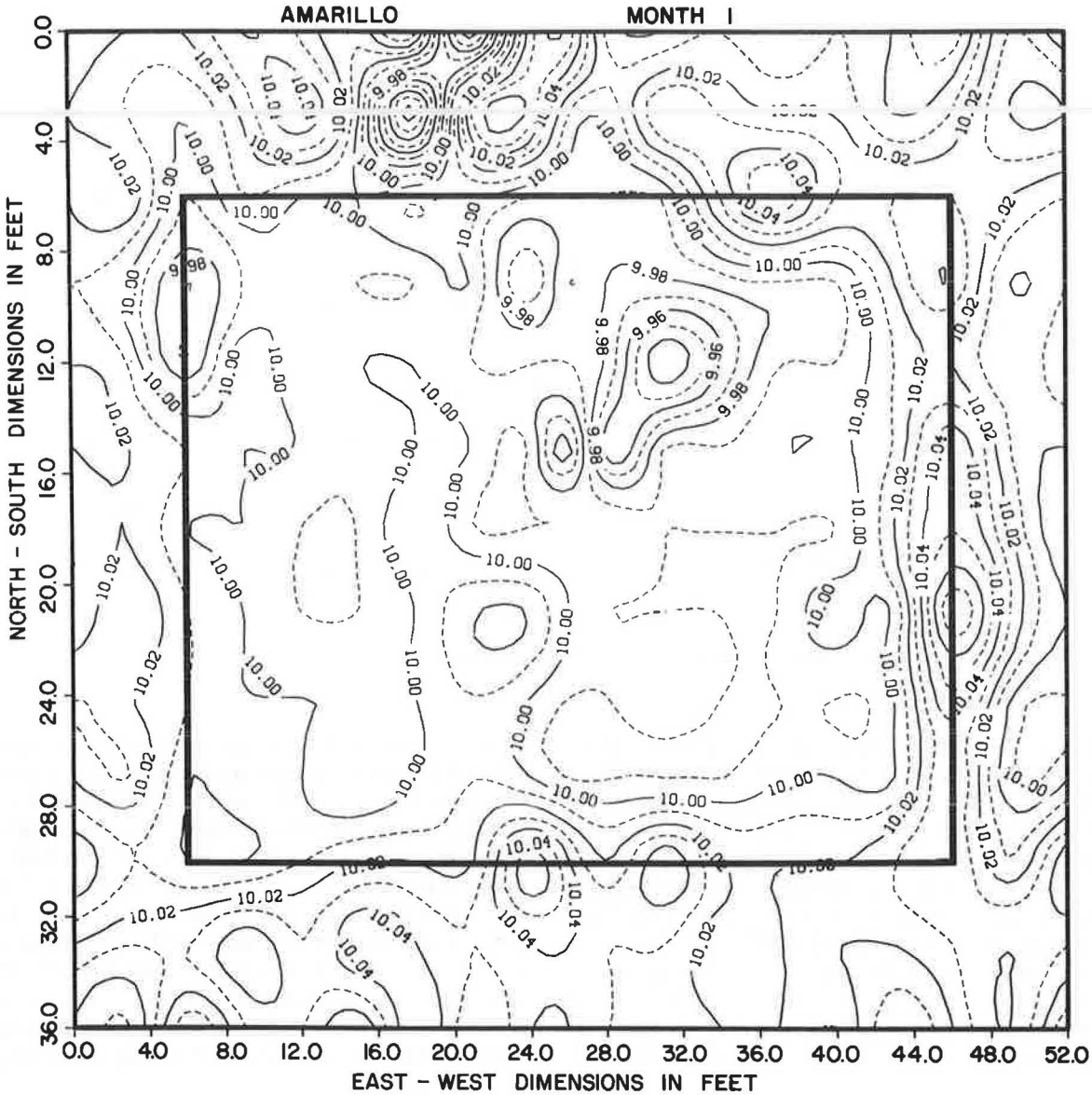


**FIGURE 5 Contours of relative surface elevations at Amarillo showing changes in elevations with respect to the elevation at the time of site installation after 1 month.**

1985, overall, was a wet year for Amarillo with respect to climate.

## DATA MEASUREMENTS

All measurements were taken on a monthly basis. This frequency of measurement was selected with the intention of trying to capture soil suction and soil moisture content changes closer to the event that precipitated the change. Measurements taken during each monthly site visit included soil temperature, soil suction, soil moisture content, and surface and near-surface elevation measurements.

The elevation of each surface elevation point (a total of 247 points) was determined using conventional engineering surveying techniques with an engineer's level and a survey rod with 0.01-ft (3-mm) graduations. Also, the elevation of each deep bench mark, with respect to the 27.5-ft bench mark, was determined on each visit. Field data were converted into calibrated data in the laboratory during the days following each visit.

## DISCUSSION OF MEASUREMENTS AND INDICATED TRENDS

### Changes in Surface Elevations

The actual surface of the site slopes slightly (approximately 1 percent) from northwest to southeast. However, to make interpretation of the elevations more meaningful, each elevation point was normalized to an elevation of 10.00 ft. Thus, all elevations are actually relative elevations referenced to the elevation of the measurement point at the time of installation (July 1985). Figures 5–7 show elevation contours on a plan view of the instrumented site. The interior rectangle depicted by the heavy line represents the limits of the covered surface.

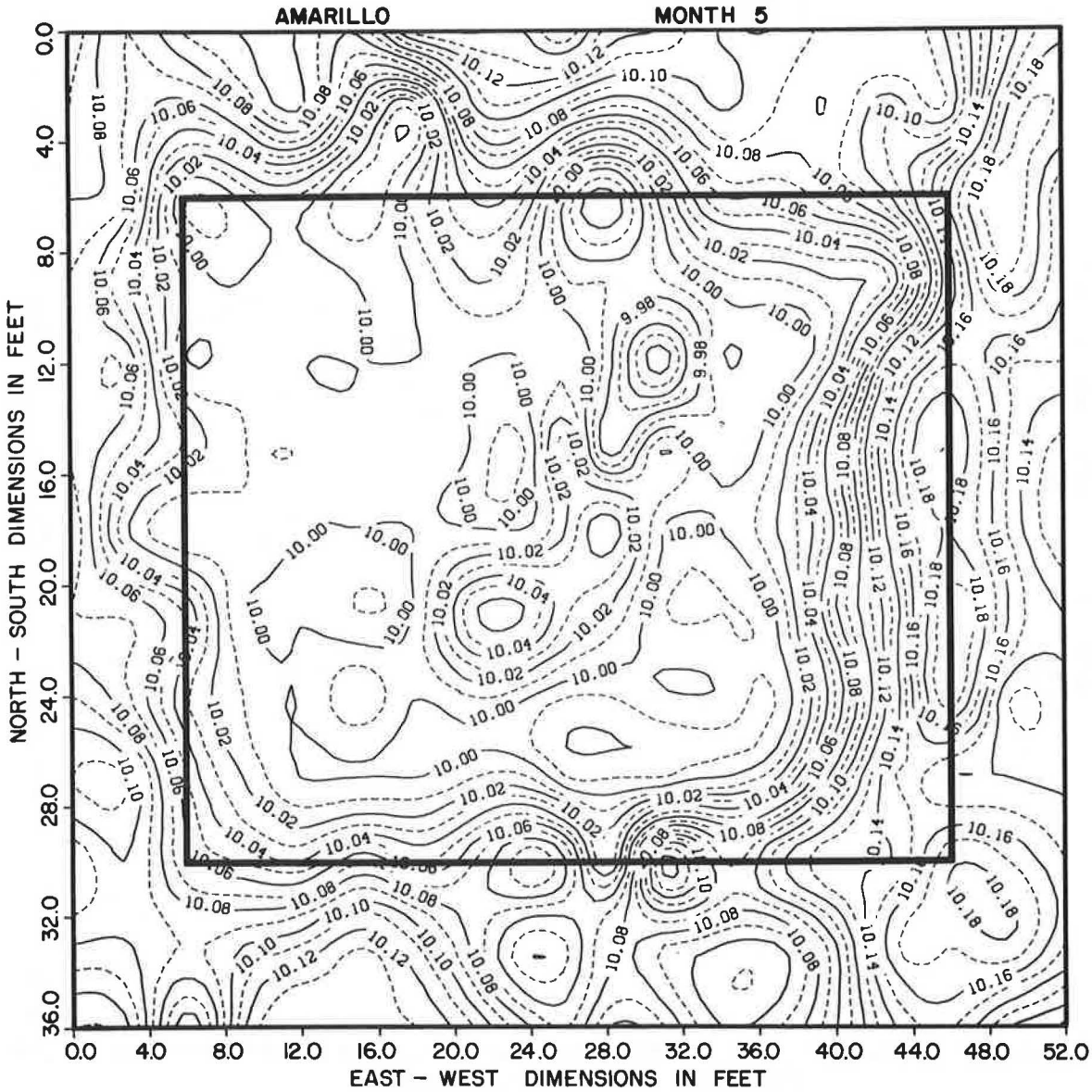


**FIGURE 6 Contours of relative surface elevations at Amarillo showing changes in elevations with respect to the elevation at the time of site installation after 5 months.**

Four days after installation, 1.53 in. (39 mm) of rainfall fell on the site and an additional 0.68 in. (17 mm) fell over the next 4 days. A total of 5.31 in. (135 mm) fell on the site during the 39 days between installation completion and the first measurement visit. That the dry soil had already begun to respond to this rainfall by the time of the first measurement visit is apparent in Figure 5. The months of September and October (Months 2 and 3, respectively) were very wet as indicated by comparing the rainfall for each of those months to the historic mean monthly rainfall. The site soil continued to respond to this period of wetness. Figure 6 shows the change in the elevation contours only 5 months after site installation (December 1985). This figure suggests that a definite edge lift (dishing) condition had begun to develop. However, beginning in November (Month 4), the heavy rainfall ceased and only nominal amounts of precipitation (either rainfall or snowmelt) occurred subsequently. Over the next 6 months, little change in the shape of the distortion occurred. Figure 7 shows the Month 12 (July 1986) elevation contours. Based on the historical mean monthly rainfall, it was expected that the edge heave so strongly shown in Figures 6 and 7 would begin to ameliorate in the late spring and early summer months. However, as can be seen from Figure 4, greater than average amounts of rain were received on the site during February, May, and June 1986 (Months 7, 10, and 11). Undoubtedly, this moisture has permitted the soil adjacent to the covered surface to retain sufficient moisture to avoid its expected reduction in elevation.

Inspection of Figures 5, 6, and 7 shows that the amount of heave that has occurred on the east end of the slab model—the grade beam end—is significantly greater than that which has occurred on the west end. A comparison of the edge heave magnitudes shows that the east end experienced a very rapid heaving, reaching a heave of 0.18 ft (2.2 in., 55 mm) by the

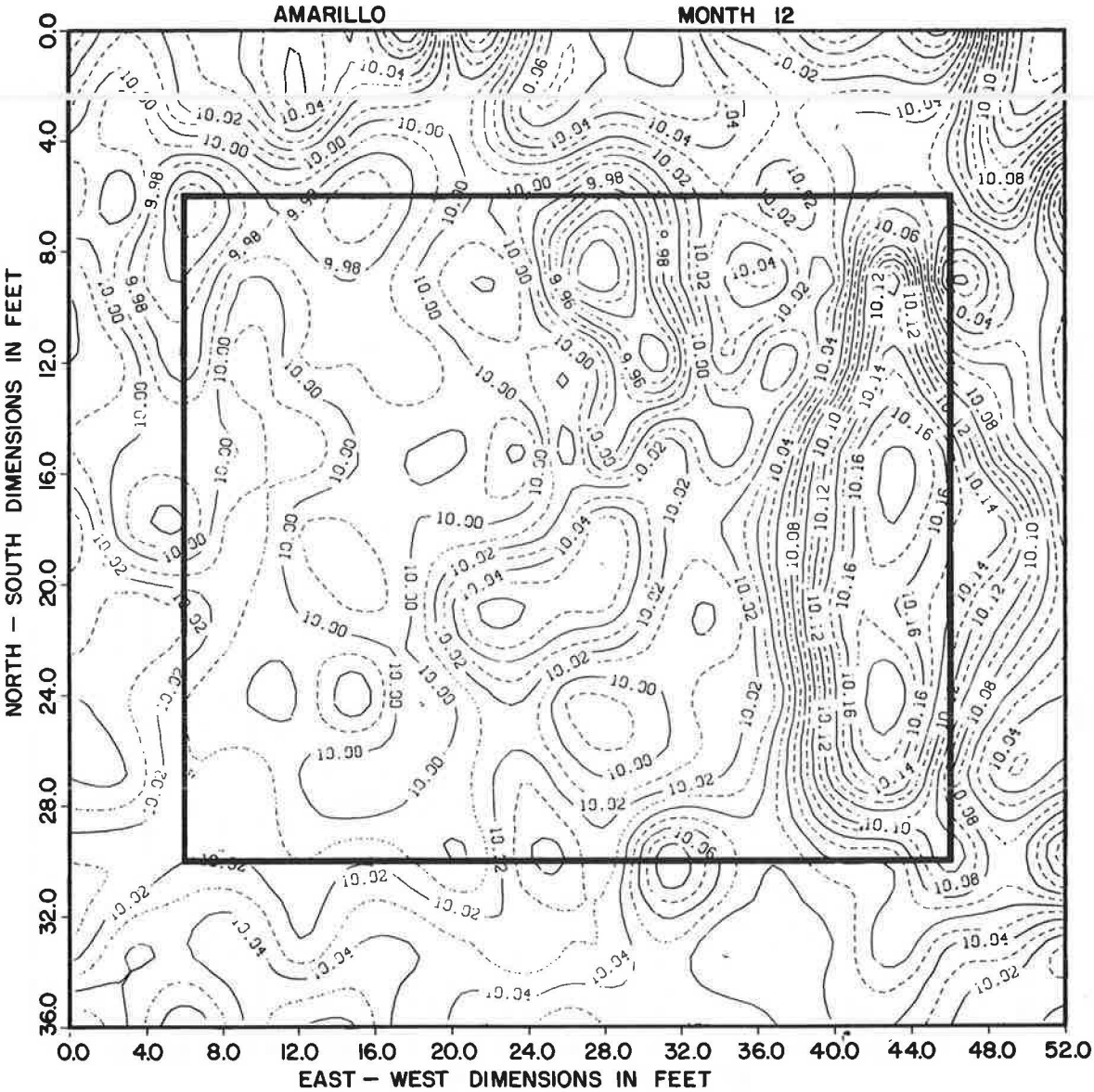


**FIGURE 7 Contours of relative surface elevations at Amarillo showing changes in elevations with respect to the elevation at the time of site installation after 12 months.**

time of the Month 3 measurement visit. The west end of the covered surface, however, experienced a heave of only 0.08 ft (1.0 in., 24 mm) during this same period. The heaving experienced on the east end was also projected back under the covered surface to some distance, suggesting that either the 18-in. (450-mm) deep grade beam has very little influence on the intrusion of water beneath the covered surface or that the depth of the intrusion extended much deeper than the 18 in. depth of the perimeter grade beam.

Figure 8 depicts the change in surface elevation on a month-by-month basis along the longitudinal centerline of the site. Points 7 and 20 are 6 ft and 3 ft (1.8 m, 0.9 m), respectively, outside the covered surface, whereas Point 33 is at the edge but on the covered surface. Points 241, 228, and 215 occupy similar positions, respectively, on the east end of the site. These figures show the rapid initial response of the uncovered soil, particularly at the east end, to the rainfall that occurred shortly after the installation of the site and the subsequent response to the period of wetness during Months 1, 2, and 3 (August–October 1985). These figures also show, with the exception of one point (Point 137), an inclination by the covered soil to remain fairly stable within the interior of the covered surface. The heave that showed immediately (Month 1) and then persisted at elevation point 137 cannot be satisfactorily explained, although, as can be seen in Figures 5, 6, and 7, it is localized. A careful inspection was made of the membrane in the vicinity of this point to see if a puncture could be contributing water to the soil beneath the cover in that location, but none was discovered.

There are two possible explanations for the substantial heave observed at the east end. One explanation is that despite the best efforts employed during construction to prevent it, surface water still managed to get between the wall of the footing excavation and the plastic membrane that formed the outside

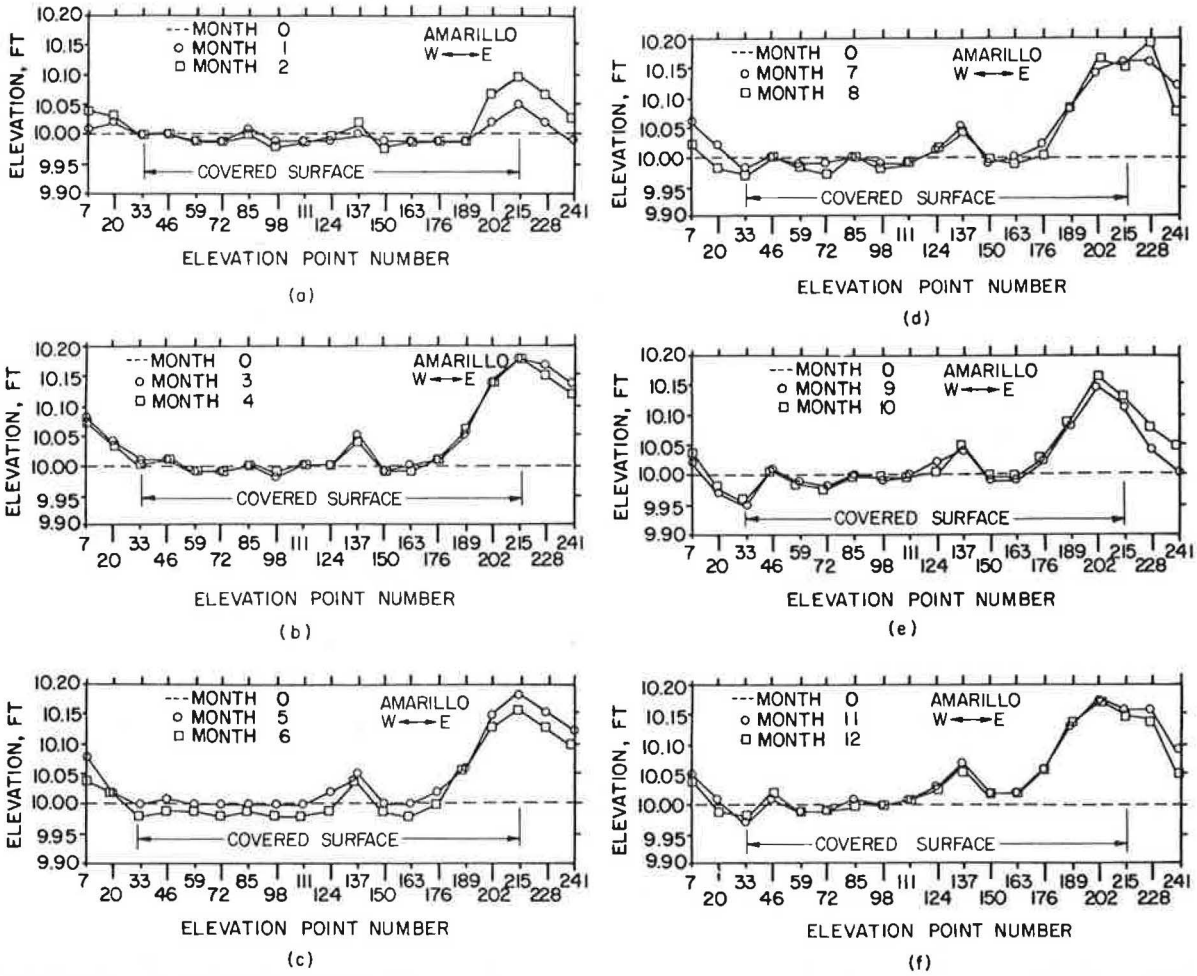


**FIGURE 8 Monthly changes in relative surface elevations along the longitudinal centerline of the slab model for months 0–12.**

wall of the grade beam and then under the grade beam. If so, then the entrapped water would have formed a reservoir and caused the observed heave. A second explanation is that one of the many surface fissures noted in the general area of the experimental site during installation, but not detected during the site layout despite a careful search, existed in the vicinity of this end of the covered surface and may have actually extended beneath the membrane. If so, this crack could have provided an access for surface runoff to penetrate below and beneath the covered surface and resulted in the observed heaving. A subsequent search for such a crack was made but none was found; however, due to the wet period of August–October 1985, most of the surface cracks noted in the area during the installation had either swelled shut or had contracted considerably. As of July 1986, many of these cracks had yet to open up to the widths and lengths observed in July 1985; thus, there is no certainty that such a crack near the east end of the covered surface does not actually exist.

A second observation that can be made about the month-by-month surface elevation changes concerns the distance measured inward from the edge of the covered surface over which change occurs. This observation can be accomplished by reviewing the month-by-month change in elevation of a specific point. Because of length limitations, only the points on the west end of the longitudinal centerline will be considered here. It can be seen from Figure 9 that the two points outside the covered area (Points 7 and 20) exhibit a fairly significant month-by-month change in elevation. Point 33, located at the edge of the covered surface, does not exhibit as dramatic a change in elevation as do the two uncovered points, but its trend follows that of the two outside points. The next innermost point, Point 46, is located 3 ft inside the edge of the covered surface. The month-by-month comparison of the elevation changes at this point shows little change, with the exception of a very slight heaving trend over the last few measurement months amounting to only 0.02 ft (6 mm). The next six elevation points (59, 72, 85, 98, 111, and 124), which extend 6, 9, 12, 15, 18, and 20 ft (1, 8, 3.6, 4.6, 5.5, and 6.1 m), respectively, from the west edge of the slab model, show only slight variations from the initial elevation. This might suggest that the edge penetration or edge moisture variation distance for this climate is between 3 and 6 ft (0.9 m, 1.8 m).

The trends are also fairly clear on the east half of the slab model. However, they are unquestionably influenced by the water that caused the rapid 0.19 ft (2.3 in., 58 mm) of total heave at the east edge of the covered surface.

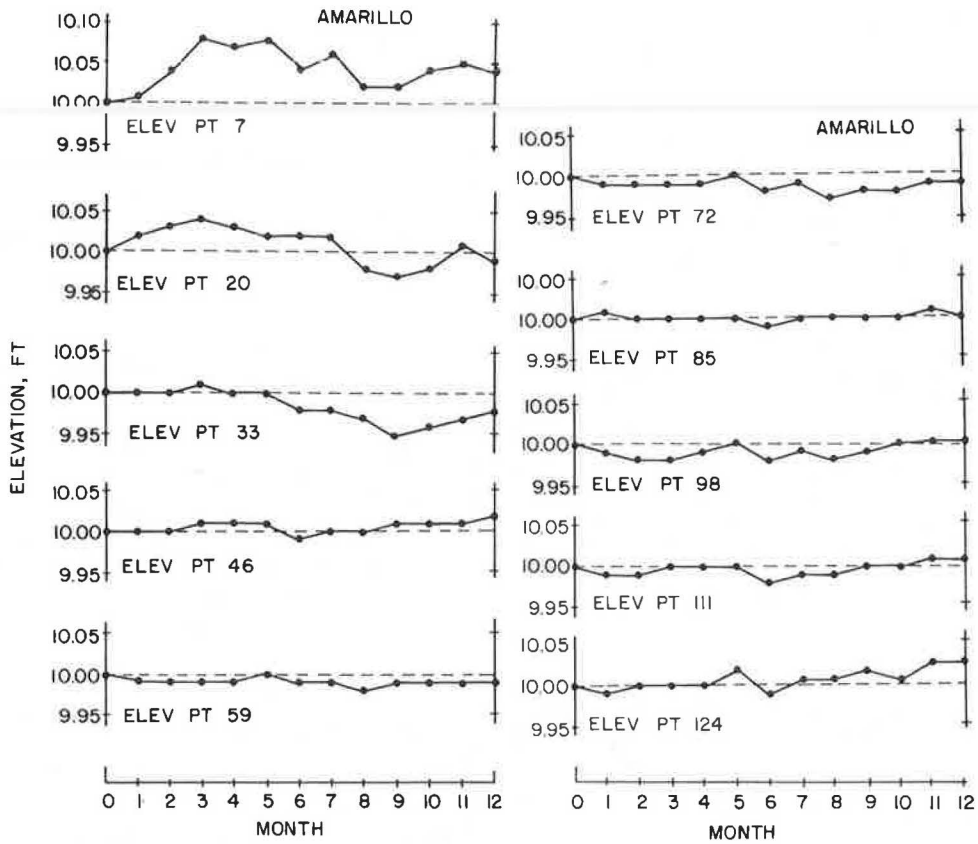


**FIGURE 9 Month-by-month changes in surface elevation of individual points on the west half of the longitudinal centerline of the slab model.**

### Changes in Deep Bench-Mark Elevations

Although the deep bench marks were originally planned to be placed at depths of 2, 5, 9, and 15 ft (0.6, 1.5, 2.7, and 4.6 m), the depths obtained during construction resulted in actual depths of 2, 6.5, 9, and 14 ft (0.6, 2.0, 2.7, and 4.3 m). It was expected that the 2-ft bench mark would show both the greatest amount of movement and the greatest number of changes. Both the magnitude and the number of movements were expected to decrease as the depth of the bench mark increased. The changes actually recorded are shown in Figure 10. As expected, the shallowest 2-ft bench mark recorded the greatest total movement (0.10 ft, 1.2 in., 30 mm) but the 6.5-ft bench mark showed the most erratic movement. Although the movement exhibited by the 6.5-ft bench mark was substantially less than that experienced by the 2-ft bench mark, it was more than the nominal 0.01 ft (3 mm) of vertical heave experienced by the 9-ft bench mark.

The 14-ft bench mark showed a 0.01-ft heave in Month 5 (December 1985), immediately followed by a 0.02-ft (6-mm) shrink the next month, which, in turn, was followed by another heave of 0.01 ft in Month 7 (February 1986). A possible explanation for this rather rapid but brief change in elevation at this depth may be that the heave measured in Month 5 was a belated response to the wetness of Months 1–3, followed by a slight drying during Month 6. However, a roundoff inconsistency by the instrument man in reading the surveying rod may be a more reasonable explanation for the deviation of these two points which are, respectively, +0.01 ft and –0.01 ft below the apparent equilibrium elevation. The 0.01-ft shrink that was noted in the last 2 months of measurements may be a response to the period of low precipitation that occurred between November 1985 and May 1986 (Months 4–10), or it may again be a surveying roundoff error. The bench-mark elevations recorded over the first 12 months of the project certainly indicate that the depth of the active zone (depth of soil over which shrink/swell occurs) extends to a depth below 9 ft and may actually extend to at least 14 ft if the shrink indicated by the measurements made in Months 11 and 12 are actually changes in soil volume and not surveying roundoff inconsistencies.

### Changes in Soil Suction

Plotting the in situ soil suction values as determined by the filter paper method at the time of installation (Figure 3) suggests that the equilibrium soil suction is below 9 ft (2.7 m). [Similar data from the companion wet-climate site suggest that the equilibrium soil suction occurs at a shallower depth of approximately 3.5 ft (1.1 m) at that location.] The month-by-month changes in the elevations of the deep bench marks also suggest the depth of the active zone to be greater than 9 ft. Thus, it is not surprising that the monthly psychrometer readings do not show a point at which equilibrium suction is

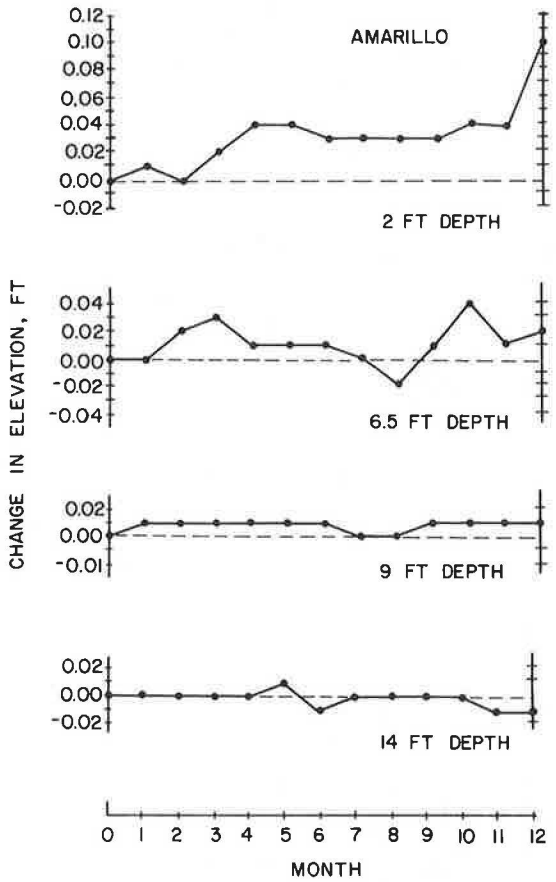


**FIGURE 10 Month-by-month changes in elevation of the deep bench marks.**

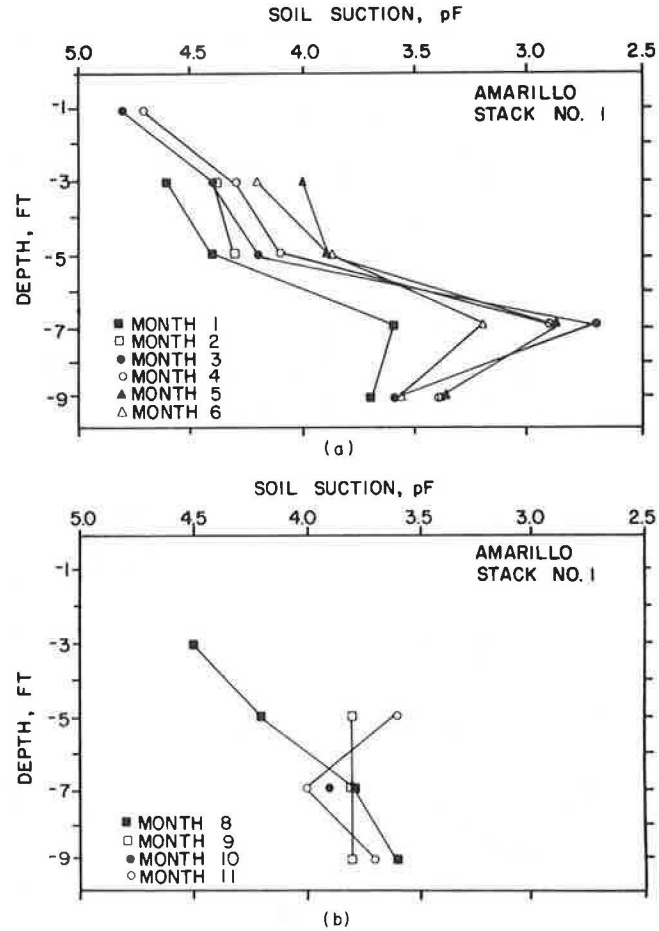


**FIGURE 11 Monthly changes in soil suction with depth for instrument stack No. 1, located 3 ft outside the covered area.**

present. However, plotting the monthly soil suction measurements versus depth presents some interesting trends.

Instrument stack No. 1 (Figure 1) is located 3 ft (0.9 m) outside the edge of the covered surface and is, therefore, measuring changes in the uncovered soil. The monthly psychrometer readings for this stack are depicted in Figure 11. The figure shows that a general wetting of the soil (a reduction in the soil suction) was measured from Month 1 through Month 5. However, beginning with Month 6, a gradual drying of the soil was noted through Month 8. Month 9 showed a rewetting occurring, but Months 10–12 suggest a new drying, at least at the lower depths of 7 to 9 ft (2.1 to 2.7 m). In reviewing the psychrometer results, it should be kept in mind that psychrometers are not reliable—and may not even produce a reading—in very wet soils. They are considered effective measuring devices for soil suction only if the water potential is at least 3.0 pF *(12)*. They also will not give results if the psychrometer tip becomes corroded; in these instances, the instrument essentially becomes dormant and will no longer respond. Thus, there are a number of months in the figures showing psychrometric measurements where there were no data to record. This condition is suggested in Figure 11, although it appears that the psychrometer at the 1-ft depth ceased functioning after Month 4. Figure 4 shows that an increase in precipitation occurred during the months of May and June 1986 (Months 10 and 11). Thus, the upper few feet of the soil may have still been wet enough from these rains to cause the soil suction to decrease to the point where infinity readings were measured for these instruments during the monthly readings. (Infinity readings imply that the soil conditions are too wet for a reading.) As can be noted from the figure, only one instrument provided a reading for Month 10 (May 1986) but the deeper instruments again gave readings during the Month 11 (June 1986) measurement visit. No psychrometric readings were obtained during the Month 7 measurement visit because of an equipment malfunction.

Figure 12 is representative of the west-end interior psychrometer readings. Instrument stack No. 20 is located 2 ft (0.6 m) inside the covered area. As was observed from the readings taken in the instrument stack outside the covered area (Figure 11), there is a general wetting of the soil from Month 1 through Month 5. At Month 5 this wetting trend is reversed, the soil begins to dry out, and the drying continues through Month 9. Month 10 shows a wetting of the soil had occurred but this reversed in Month 11 as Months 11 and 12 show a continued drying trend. However, the loss of instrumentation readings that occurred at Stack No. 1 due to the rains in Months 10 and 11 did not affect the covered instrumentation to the point that readings could not be made.

Instrument stack No. 26, located at the center of the covered area, has the same general shape as the other covered area stacks located beneath the west end of the slab model (Figure

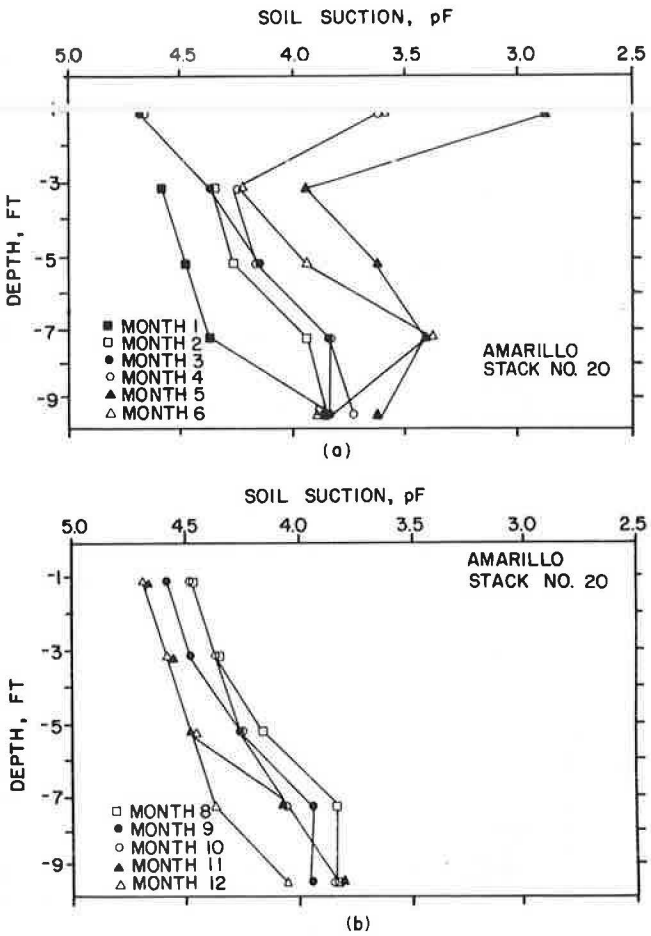


**FIGURE 12 Monthly changes in soil suction with depth for instrument stack No. 20, located 2 ft inside the covered surface.**

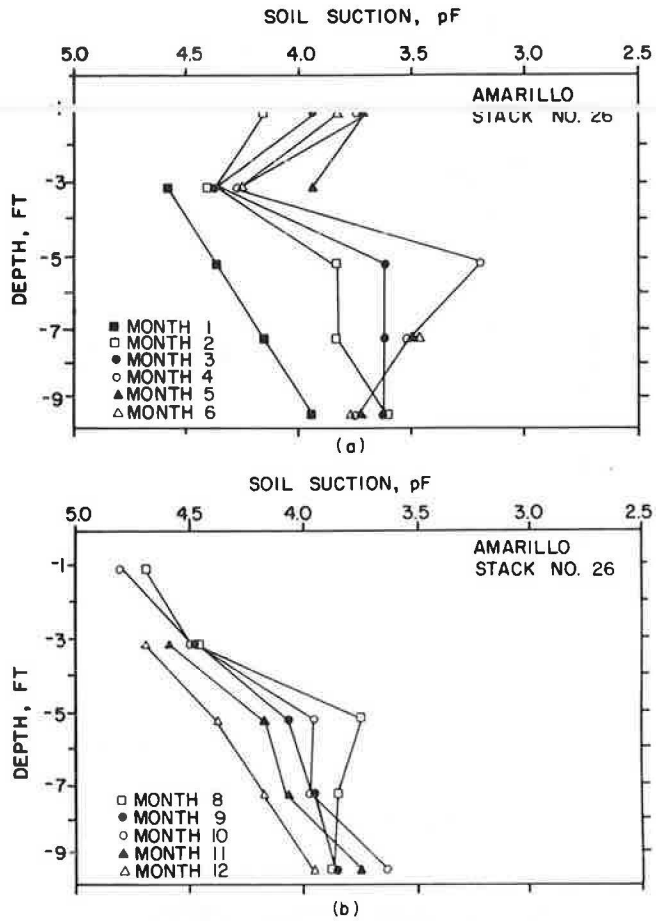


**FIGURE 13 Monthly changes in soil suction with depth for instrument stack No. 26, located at the center of the covered surface.**

13). It exhibits the same initial wetting followed by a general drying trend previously noted for the other instrument stacks. However, one observation to be made about each figure (Figures 11, 12, and 13) is that the slopes of the suction curves for Months 8–12 are all quite similar and all are within a fairly tight band, particularly for the covered instruments.

Similar soil suction versus depth curves could be plotted for each instrument stack as a function of time and analyzed in a similar fashion. Soil moisture content measurements could also be discussed similarly. However, such discussions would exceed the limits of this presentation and will be included in a future publication.

## CONCLUSION

Twelve months of data are insufficient to form any definite conclusions from the measurements made and the trends developing from this field investigation. However, there are some observations that can be made at this time that may be of assistance to design professionals who must construct an on-grade structure over expansive soils in a dry climate.

1. The filter paper method of determining in situ soil suction is a simple and reasonably reliable method of determining the subsurface conditions with respect to potential for shrink or heave. It can apparently also provide an estimate of the depth to constant soil suction. The test is actually no more difficult to perform than the standard soil moisture content test, only requiring good laboratory technique.

2. The distance measured inward from the edge of a covered surface over which the soil moisture conditions change sufficiently to cause differential soil movement appears to be between 3 and 6 ft (0.9 to 1.8 m) for a location with a climate of about –22 in./yr (–56 cm/yr) as measured by the Thornthwaite Moisture Index.

3. An impervious surface, such as a structure or pavement slab, placed over an expansive soil when the soil is in a dry condition, can be expected to be subjected to edge heaving, at least initially.

4. Changes in the soil moisture conditions due only to changes in climate can apparently occur beneath a covered surface as far as 12 ft (3.7 m) inward from the edge of the surface. However, these induced changes may not result in significant amounts of shrink or swell in the supporting soil.

## ACKNOWLEDGMENTS

The results reported in this paper were obtained under a National Science Foundation Grant. The field measurements and

laboratory testing were accomplished by Sydney Austin, Boon Lim, Jimmy Hawkins, C. H. Tsai, William Escajeda, and Norman McLeod. Wes Bratton and Dee Hardin prepared and drafted the figures.

The author is particularly indebted to the Family Hospital Center for providing the experimental site; Amarillo Engineering & Testing, Inc., Dyess Testing Laboratories, and KGNC radio, all of Amarillo, Texas; and N. L. Baroid Co., Lovington, New Mexico, which donated services and materials to the project.

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*Publication of this paper sponsored by Committee on Environmental Factors Except Frost.*