A Full Scale Investigation of the Thermo-osmotic Hypothesis

Etude complète de l'hypothèse thermo-osmotique

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Summary

An opportunity was afforded to investigate the thermo-osmotic hypothesis when one of the older Agricultural and Mechanical College of Texas dormitories was razed in 1951.

The assumption was made that a maximum temperature and moisture differential between the mass of soil beneath this building and that adjacent to it should exist as a result of an unusually hot and dry summer. Nineteen three-inch borings were made to a depth of 20 feet, and undisturbed soil samples were taken at intervals of 2 feet. The temperature was measured and the water content, liquid limit, and plastic limit were determined for each specimen.

An analysis of the data did not indicate any definite relationship between temperature and water content for soil samples taken beneath and adjacent to the building. However, a fairly consistent relationship between liquid limit and water content was indicated for soil samples taken both inside and outside the building area.

Sommaire

La démolition, en 1951, d'un dortoir de l'«Agricultural and Mechanical College of Texas» donna lieu à un examen de l'hypothèse thermo-osmotique.

A la suite d'un été particulièrement chaud et sec, on comptait trouver, entre le sol directement sous le bâtiment et le sol adjacent, un différentiel maximum de température et d'humidité. On pratiqua donc dix-neuf sondages jusqu'à la profondeur de vingt pieds, tout en extrayant des échantillons de sol non remanié tous les deux pieds. La température fut déterminée, aussi bien que la teneur en eau, la limite de liquidité, et la limite de plasticité.

Une analyse des données n'indiqua aucun rapport définitif entre la température et la teneur en eau des échantillons pris sous le bâtiment et à côté; par contre, elle indiqua un rapport assez maintenu entre la limite de liquidité et la teneur en eau.

Many of the older masonry buildings on the Agricultural and Mechanical College of Texas campus and in the nearby city of Bryan are disfigured by cracks. In addition to representing a continuing maintenance problem, these cracks make the use of many of the buildings hazardous for the occupants. The importance of a solution for this problem becomes apparent when the number of new buildings is compared with the number of old buildings presently condemned for razing.

It is unfortunate that more observations have not been made on the behavior of A. & M. College buildings. Had this been done, many questions concerning the most suitable type of footing, proper depth of footing, and allowable bearing capacity of the soil could probably be answered from empirical data. A portion of the problem was studied by *Glenn* (1931), and his observations of seasonal moisture and elevation changes added valuable information. This study was only for a nine-month period, and little information has been recorded since.

A project was initiated by the Texas Engineering Experiment Station in 1949 to study the relationship of temperature and depth beneath and adjacent to a building. The project was actually an attempt to investigate the thermo-osmotic hypo-

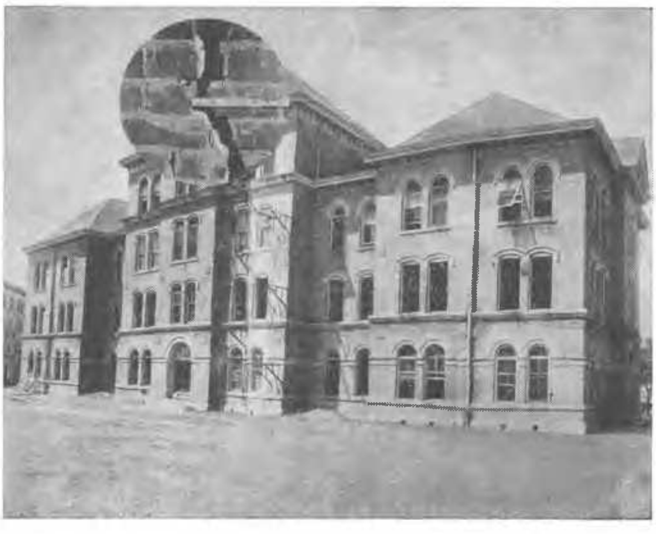

Fig. 1 An Example of a Partition Wall Crack for Foster Hall
Fissure dans un mur de refend à Foster Hall

thesis which has been so well discussed by *Jennings* (1950) and others. Three 30-inch borings were made to a depth of 30 feet and fourteen thermocouples were installed at various depths in each boring. Two of the installations were beneath and one adjacent to the site of the New Science Building which was constructed the following year. Heating coils were installed in a circular pattern around the inside installation to provide a heat source to drive away moisture in the event the building began to heave. Unfortunately, the heating coils were cut during the construction of the building. Observations of the thermocouples, while giving valuable temperature data for depths up to 30 feet, had not justified any definite conclusions relative to the thermo-osmotic hypothesis by 1951.

An opportunity to extend the moisture and temperature study was afforded when Foster Hall was razed during the summer of 1951. Foster Hall was erected in 1898, and while its design was impractical for present day use, the building had not been considered structurally sound for a number of years. An example of the severly cracked condition of this brick building is illustrated by Fig. 1. The footings for this building were continuous for both exterior and interior walls and were formed by offsetting several courses of bricks to give a total bearing width of approximately three and one-half feet. The footings were founded to a depth of over three feet. Arched openings between the interior walls permitted free circulation of air below the ground floor.

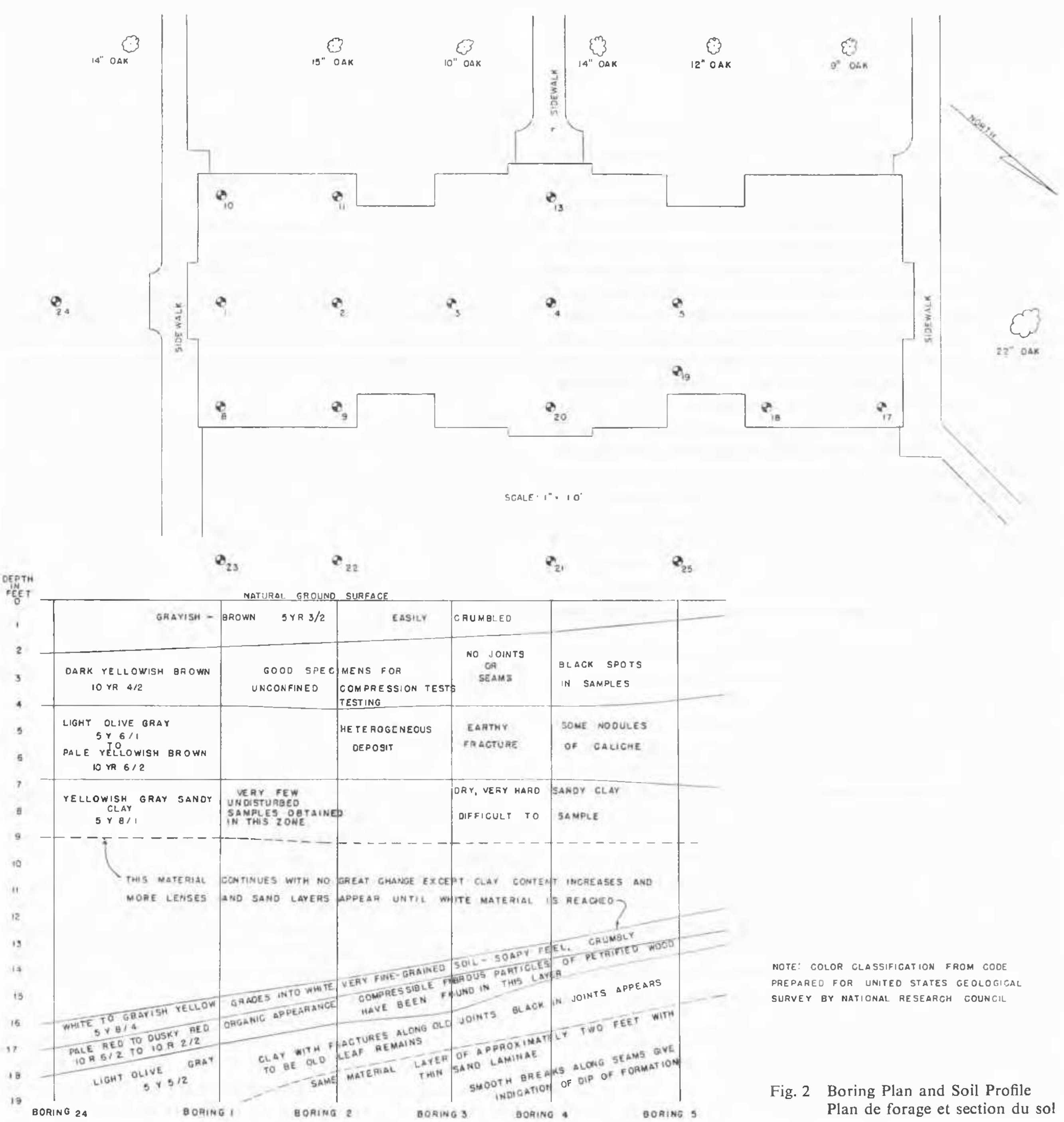

Fig. 2 Boring Plan and Soil Profile
Plan de forage et section du sol

Fig. 3 Soil Temperature Observations
Observations de la température du sol

Strength tests performed on representative wood and brick specimens from Foster Hall indicated that little deterioration had occurred and the damaged condition of the building could not be attributed to defective materials.

It was reasoned that if there was an accumulation of moisture benath the building as a result of the thermo-osmotic movement, then since this was not a seasonal but a long term phenomenon, there should exist a definite relationship between moisture content and temperature for the mass of soil beneath and adjacent to Foster Hall. It was further reasoned that since the summer of 1951 had been unusually hot and dry, the differences between the temperature and moisture content for soil beneath and outside the building area should show a maximum differential. A project to measure temperature and moisture content for undisturbed soil samples beneath and adjacent to the building was proposed in anticipation that the data would establish the validity of the thermo-osmotic hypothesis. At this time it seemed questionable that the data from the Science Building thermocouple installations would be sufficient in scope to permit such a conclusion to be made, especially since no provision for observing moisture content changes had been made.

The project was sponsored by the Texas Engineering Experiment Station and the drilling program performed between October 14 and 18, 1951. Nineteen three-inch borings were made to a depth of 20 feet with truck mounted rotary drilling equipment. Soil cuttings were removed with water and undisturbed soil samples taken with a three-inch Shelby tube. Fourteen borings were made inside the building area and five outside as shown in Fig. 2. Undisturbed samples were taken at two-foot intervals for each boring.

As soon as the soil sample was extruded from the thin-walled sampling tube, a three-inch section was cut and a hole large enough to accommodate the bulb of a thermometer was made at one end of the sample. The soil and the thermometer were than placed in a cork insulated box with the thermometer stem projecting out as shown in Fig. 3 to permit reading. Temperature readings were made at either one or two minute intervals for ten to fifteen minutes.

As a check on temperature data, maximum and minimum recording thermometers were lowered to the bottom of several borings and left for time intervals varying from one hour to over seventeen hours. The data presented in Table 1 show there is little variation between the boring temperature and the soil sample temperature, except when the air temperature was lower than the soil temperature. This condition occurred only for the first borings made each morning. The effect of the air temperature being higher than the soil temperature appeared to be negligible.

After the temperature had been measured, the soil samples were placed in containers to prevent evaporation and taken to the laboratory for water content determination. The soil was kept in these containers until liquid limit and plastic limit tests had been performed on all samples. Shrinkage limit tests were performed for Borings 21 and 22 and unconfined compression tests were performed on all suitable specimens. In order to eliminate the variations in individual technique, all tests were performed by the same operator, and the same liquid limit device was used for all liquid limit determinations.

The laminated nature of the soil resulted in a wide range of moisture content values for some strata. In cases where these variations occurred, a sufficient number of water content determinations were made to give a representative average value.

The soil profile shown in Fig. 2 was established after a detailed study of the samples. Profiles for other sections were not included in this paper as essentially the same strata would be repeated.

A fill material was encountered in each boring to a depth of one to three feet. This material was considered of no importance in the study. Underlying the fill material was a stratum of dark yellowish brown clay. Excellent undisturbed samples were obtained from this horizon and most of the unconfined compression test results were as high as six tons per square foot. The natural water content for this stratum varied between fifteen and thirty per cent with corresponding liquid limit values between fifty and one hundred per cent. This clay underwent a negligible amount of disintegration when placed in water.

Table 1 A Comparison of Air Temperature and Soil Temperature

Boring Number	*Temperature of Soil Samples*	*Temperature at Bottom of Boring*	*Air Temperature*
2	24.7	24.4	28.9
8	23.1	25.0	21.1
9	24.7	24.4	28.6
10	24.4	24.4	28.4
11	24.4	24.4	30.2
17	22.3	24.4	21.1
21	23.9	24.4	23.9
22	24.3	25.1	28.8
24	25.5	25.4	28.4
25	24.6	25.0	28.6

Below the stratum of clay was found a laminated deposit with alternating layers of fine sand, silt, and clay; the individual laminations varying considerably in thickness. This material was extremely difficult to sample. The water content for this stratum was less than twenty per cent and the liquid limit values varied between forty and sixty per cent.

Below depths of 12 to 16 feet (see Fig. 2) the strata dipped sharply. The first formation encountered with a definite dip was a dusky red to pink colored soil. Directly beneath this material was a stratum of white or sometimes yellow clay. The two strata while appearing to be quite different had approximately the same liquid limit. A grey clay containing both vertical joints and thin sand seams (which were inclined at the dip angle) were found beneath white or yellow clay to the bottom of all borings.

The first attempt at correlating data consisted of plotting temperature, water content, and liquid limit versus depth for each boring. Fig. 4 shows these data for Boring 5 (inside the building area) and Boring 23 (outside the building area). It may be noted here that although there was a marked difference between the temperature versus depth curves for depths up to sixteen feet, the temperatures for the two borings at a depth of twenty feet were approximately the same. A study of these curves for the nineteen borings did not disclose any consistent relationship between moisture content and temperature for either the inside or outside borings. The small differential to be measured was recognized, but it was felt that the cumulative results of all data should indicate a general trend. Although the temperature data indicated a cooler area beneath the building, this reflected a seasonal condition subject to change during winter months. The data did not establish the existence of a wetter area beneath the building area.

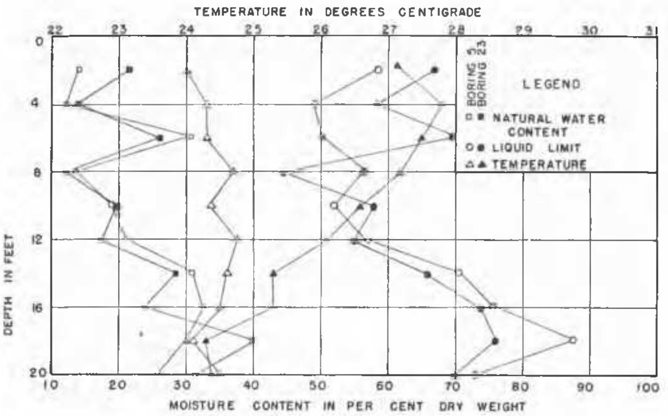

Fig. 4 Variation of Temperature, Moisture Content and Liquid Limit for Inside and Outside Building Area
Variation de température, teneur en eau et limite de liquidité à l'intérieur et au dehors du bâtiment

The data were next expressed by plotting contours of temperature, moisture content, and liquid limit for elevation intervals of two feet. Fig. 5 and 6 show these data for depths of 12 and 18 feet, respectively. These contours did not suggest any significant changes in the moisture content, temperature, and liquid limit relationships as the depth increased.

The final analysis of the data consisted of determining the average moisture content and liquid limit for a column of soil at each boring. The assumption was made that the liquid limit represented a measure of the soil's ability to attract and hold moisture. If moisture had migrated beneath Foster Hall in measurable quantity, then the soil beneath the building should be nearer an equilibrium condition and have a lower liquid limit versus moisture content ratio than soil outside the building area (*Croney*, 1952). Approximately four hundred moisture content values and two hundred liquid limit determinations were used to establish these ratios. Using all data, the ratio of liquid limit to moisture content for the fourteen inside borings was 2.74 as compared to 2.79 for the outside borings. Using only the data between depths of six and sixteen feet, the ratios for inside and outside the building area were 2.66 and

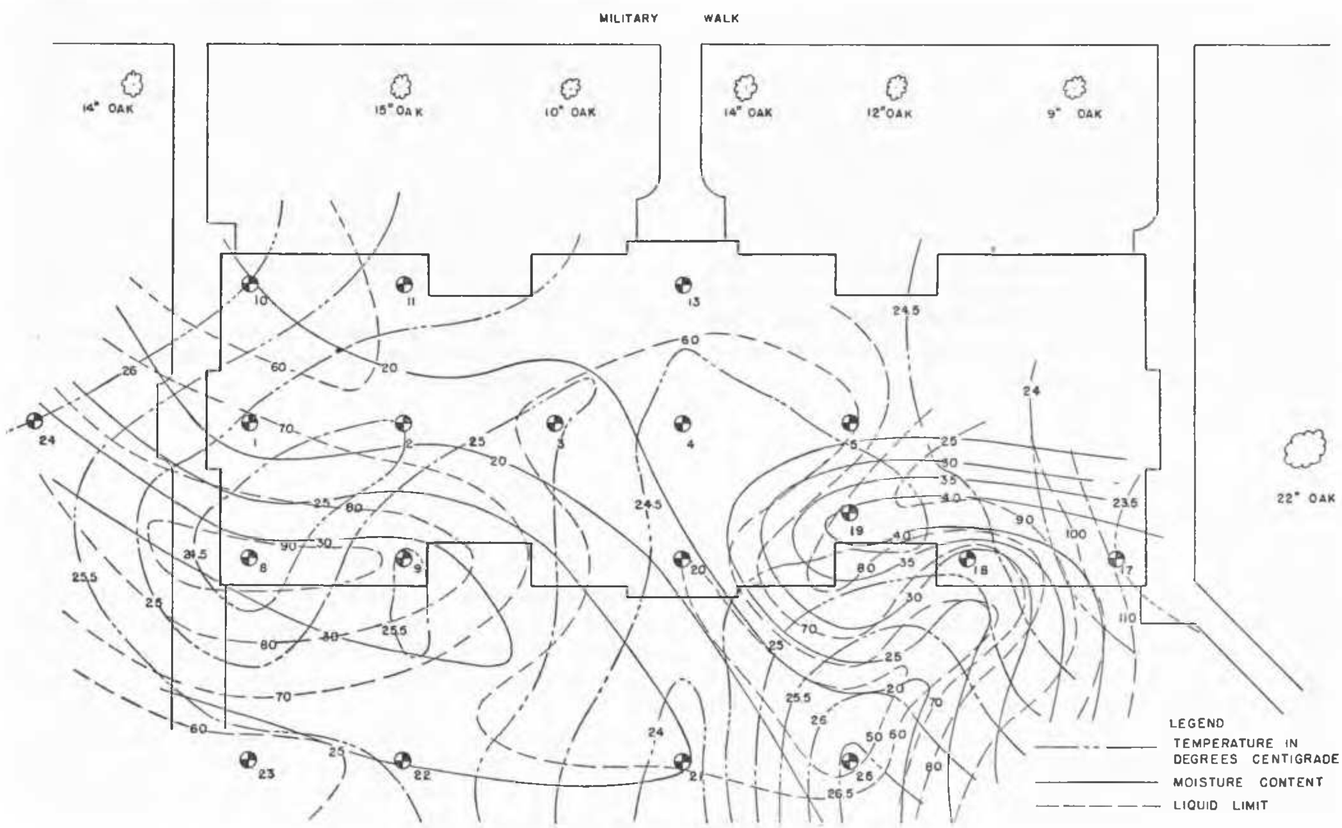

Fig. 5 Temperature, Moisture Content and Liquid Limit Contours for 12 Foot Depth
Température, teneur en eau et contours des limites de liquidité à 12 pieds de profondeur

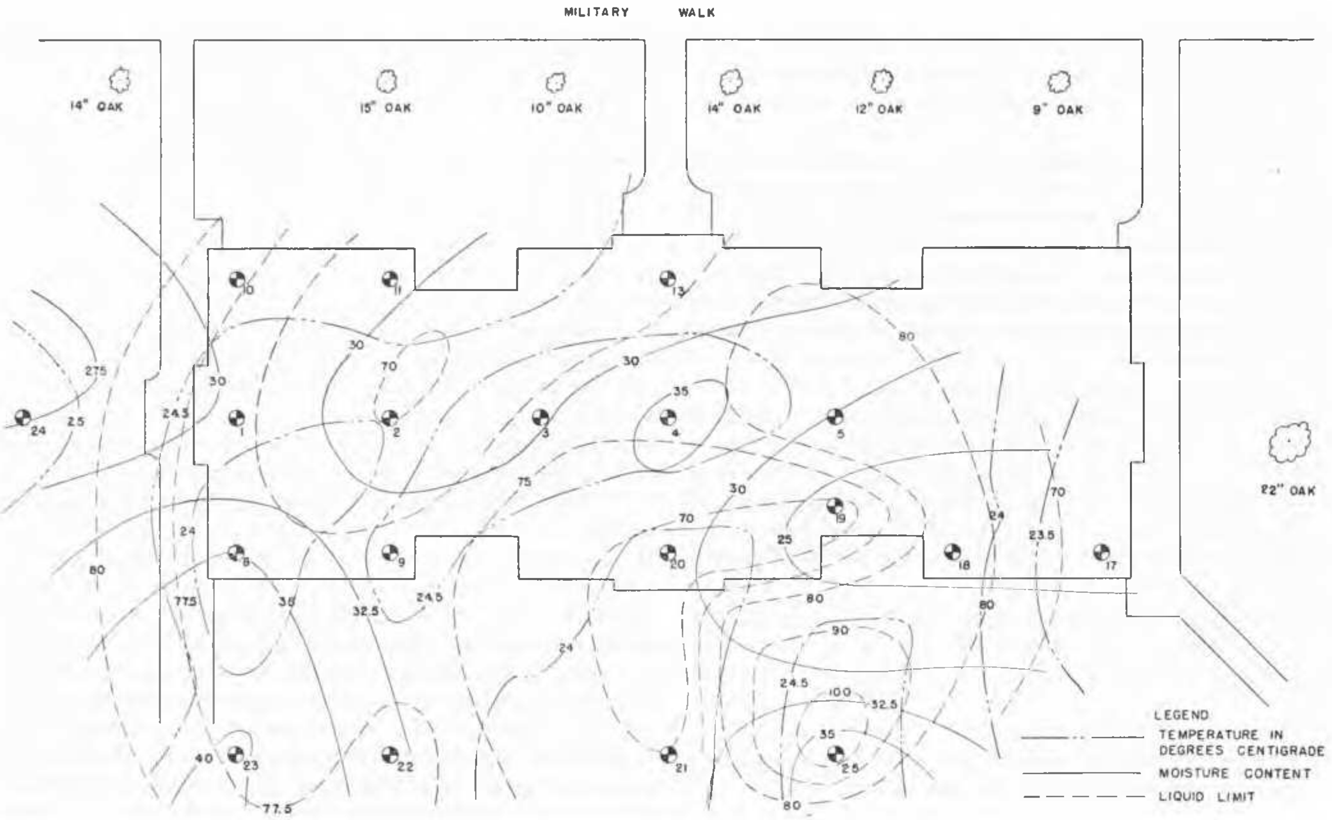

Fig. 6 Temperature, Moisture Content and Liquid Limit Contours for 18 Foot Depth
Température, teneur en eau et contours des limites de liquidité à 18 pieds de profondeur

2.76, respectively. While these ratios do indicate a wetter area beneath the building area, it was found that identical ratios could be obtained by eliminating the "wet boring" from the inside averages.

From the results of this study it was concluded that no definite relationship between moisture content and temperature existed for the mass of soil beneath the building as compared to soil outside the building area. The data also indicated a negligible moisture content differential between inside and outside the building area. Since moisture movement by the thermo-osmotic hypothesis is a long-term phenomenon and the fact that the summer of 1951 had been unusually hot and dry, a maximum moisture content differential between inside and outside the building area should have been shown if the above stated hypothesis was applicable.

In order to more fully appreciate and understand the peculiarities of the foundation soils at College Station, Texas, additional studies employing other tests and more precise temperature measuring methods are currently in progress. It is felt that this paper represents a progress report rather than a completed study.

References

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