Moisture Induced Damages to Building Foundations

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SYNOPSIS The effect of moisture on foundation soils is a very important factor in the design of building foundations especially when the foundation soils are expansive in nature. The variations in subgrade moisture, with corresponding change in volume and strength characteristics of foundation soils may cause severe damage to the building. Two case histories are described where excess moisture in foundation soils caused damages to the building in distinctly different ways. In one case, moisture increase in the expansive foundation soils caused considerable swelling of the clays resulting in severe damage to the building. In the other case, excess moisture caused wash out of filter material causing considerable settlement of a sidewalk adjacent to a building. In both cases, excess moisture was related to a break in the underground water lines.

INTRODUCTION

Volume changes in soil caused by changes in water content are of great interest in soil and foundation engineering as well as in agricultural engineering. Consequently, the amount of research carried out on this subject is very extensive and covers many aspects of the problem.

In clay soils, changes in moisture content result in changes in volume and consequently any foundation located in the affected soil will experience some movement, certainly vertical and possibly also in a horizontal direction. Damage to the structure can be considerable and numerous cases occur. In the United States alone, the cost of the damage caused by expansive soils amount to some $2.3 billion annually - more than twice the damage from floods, hurricanes, tornadoes, and earthquakes(Jones and Holtz, 1973).

Expansive clay foundation soils are located in many parts of the world, including much of the western, central and southern areas of the United States. A 1972 survey (Lamb and Hanna, 1973) of the highway departments indicated that 36 states have expansive soils within their geographical jurisdiction. Expansive soils, which swell or shrink substantially due to changes in water content, are characteristically highly plastic clays and clay shales that often contain colloidal clay minerals such as the montmorillonites. Atterberg Limits and the natural soil suction are the most consistent indicators of potential swell. Indentification of potentially expansive soils are discussed, among others, by Snethen, Johnson and Patrick (1977) and Bandyopadhyay (1981). Numerous structures constructed on these soils have experienced and sustained significant damage from differential heave and settlement. Differential movements redistribute loads of the structure on the elements of the foundation and can cause large changes in moments and shears not accounted for in the design. The types of structures most often damaged from heaving soils include foundations and walls of residential and light commercial buildings, sidewalks, highways, canal and reservoir linings, and retaining walls.

Another type of soil which is typically considered to be unstable as a foundation material because of its potential for large settlements when it absorbs free moisture is loess. Terms like "collapse", "hydroconsolidation" or "hydrocompaction" have been used to describe the sudden settlement which is different from classical consolidation since no water is being forced out and in fact, soil may be adsorbing additional water during and progressively losing strength. Since all loessial soils are not susceptible to hydroconsolidation, identification of collapsible soils is of utmost importance to geotechnical engineers. A detailed account of loessial soils, including identification of collapsible soils, foundation design criteria, slope stability analysis and stabilization methods, is given by Bandyopadhyay (1983).

Moisture induced damages to structures founded on expansive soils and collapsing soils are well known and documented in the literature. However, excess moisture,under certain circumstances, can cause wash out of granular and fine materials under the foundation thereby causing damages to the structure. This form of moisture induced damage has not been documented in the literature, yet it happens frequently and therefore should be of real concern to practicing geotechnical engineers.

CASE HISTORIES

The following two case histories offer information on some of the practical problems encountered by the author in dealing with moisture induced damages to building foundations. In the first case, moisture increase in the expansive foundation soils caused considerable swelling of the clays resulting in damages to the building and dessication in the expansive soils due to vegetation caused severe distresses in the parking lot. In the second case, excess moisture caused wash out of filter material resulting in considerable settlement of a sidewalk adjacent to a building. In both cases, the source of moisture was unknown initially. However, after many interviews, it was apparent that excess moisture was related to a break in the underground water lines. Even though excess moisture was responsible for the ensuing damages, the mechanism of damage was distinctly different in each case.

Case One: Building and Parking Lot Distress, Clear Lake City, Houston, Texas

Damage occurred to a two-story building constructed approx-

FIG. 1. Typical Damage to the Building Wall

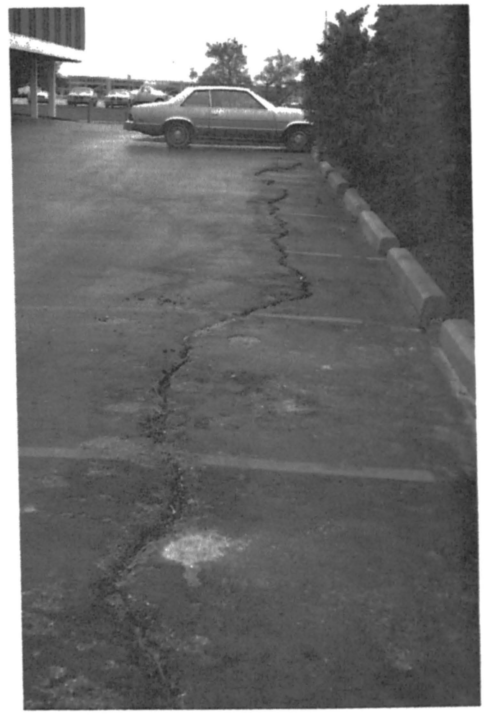


FIG. 2. Typical Pavement Distress in the Parking Lot

imately in 1970 in Clear Lake City, Houston, Texas. The asphalt surfaced parking lots on the north and south sides of the building for quite some time exhibited considerable distress in the form of longitudinal and transverse cracking and local depressions. However, distress in the building was observed within the last few months. Typically, cracks have occurred in the walls and the floors exhibit differential movement and heave. Typical distresses in the building and the parking lot are shown in Figs. 1 and 2.

Site Inspection: The pavement and building were inspected several times during the course of the study and plans of the building were examined. Pertinent features revealed by the inspection are summarized as follows:

1. Deformation of the pavements has occured during the life of the structure or for approximately 13 years.

2. Deformation of floors and cracking of walls to a significant degree occurred within the last six months during the time of this study.

3. The areas of pavement distress appear to be exclusively related to the presence of vegetation with areas of maximum movement generally adjacent to areas with oak trees.

4. No sewers or water lines are present beneath the structure. However, a 1-1/2 inch water line and a concrete sewer line are located within 6± feet of the north wall as shown on Fig. 3.

5. It was reported that a break in the water line occurred within the last six months; a patch in the pavement is believed indicative of the location of the break.

6. Significant cracks in the north wall of the building and an area of maximum floor heave in the offices along the north side are adjacent to the area of the water line break.

7. Exterior and interior wall cracks are also evident the south exterior wall and an east interior wall.

8. Concrete pavement in a parking area south of the si and concrete pavement of adjacent streets do not sh significant deformation.

9. Asphaltic concrete pavement in the area of the wate line break appears to have heaved slightly.

10. Structural loads are supported on underream footing founded at eight feet and the floors are connected to grade beams between the footings.

11. Several moisture entry channels beneath the grade beams were noted along the south wall in the flower bed area.

Field Investigation: Subsurface conditions in the buil ing and parking lot area were defined by seven borings drilled to a depth of 10 feet. Locations of the boring are shown on Fig. 3. Two of the borings, B-3 and B-4, were inside the building; borings B-2 and B-5 were in t flower beds on the north and south sides of the buildin and the remainder of the borings were located in the pa ing lot. Borings B-2, B-3, B-4 and B-5 were hand auger and jar samples were obtained at regular intervals. Undisturbed samples were obtained continuously at other locations to a depth of 10 feet.

Laboratory Tests: Liquid and plastic limits, and natur moisture content determinations were peformed to evalua general uniformity of soil conditions, verify field cla sifications, and define shrink-swell potential of the soils. Swell potential of the foundation soils was eva uated by conducting swell tests.

Site Stratigraphy: Stratigraphy defined by the study i shown in profile form in Fig. 4 together with the moisture content and plasticity data. Deposits at this sit consist of stiff dark gray to gray clay underlain by ta clay. The clays are slickensided and deeper zones con-

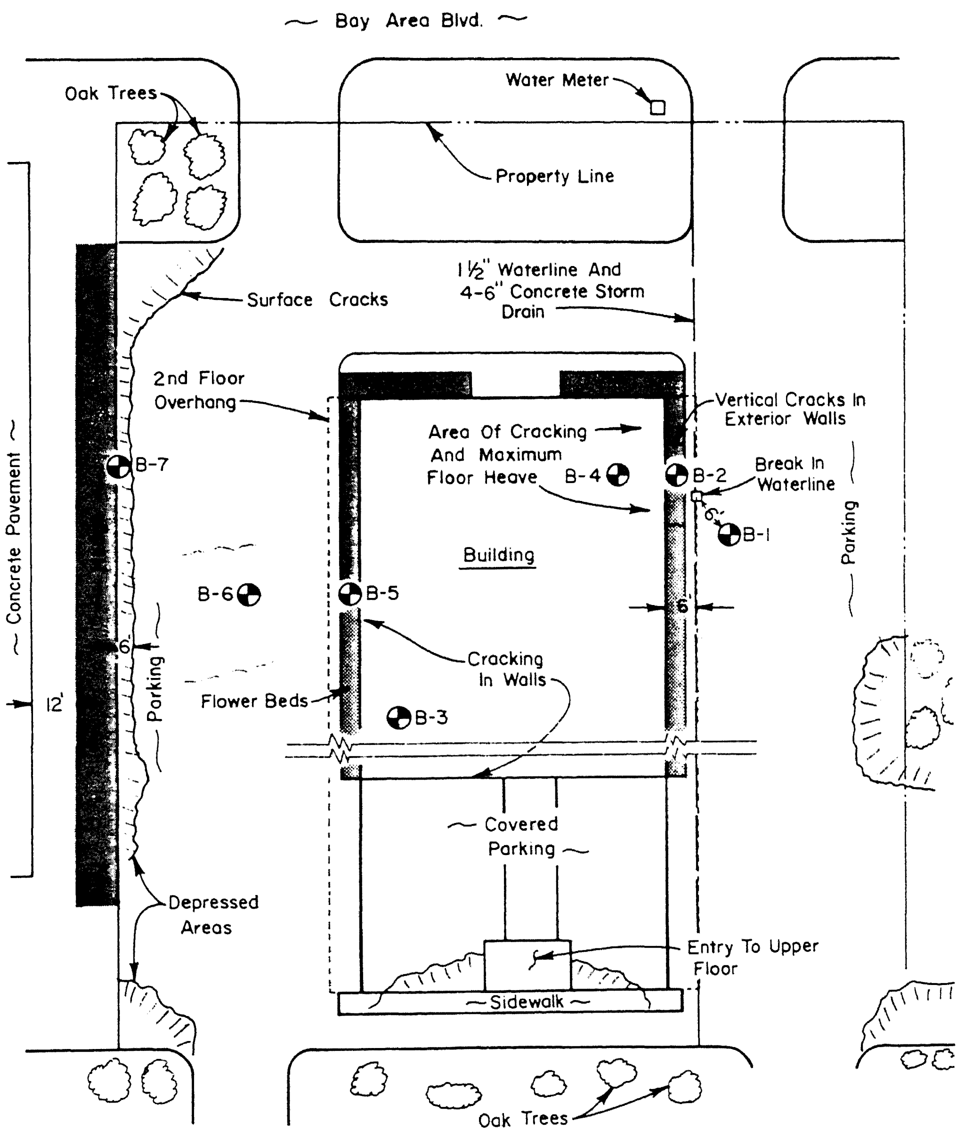


FIG. 3. Building Layout and Plan of Borings

tain calcareous nodules. The classification data show that the clays are high plasticity soils and typical of clays in this region that are susceptible to maximum volume expansion or contraction (shrink/swell potential) with changes in moisture content. The pressure swell test also confirmed this volume change susceptibility.

Soil Moisture Conditions: Moisture content data are tabulated on the profile and grouped by areas in the lower data plots in Fig. 4. Comparison of the data shows that moisture contents are presently above the plastic limit. Moisture contents for soils underlying the parking lots show that a substantial range in values exists in these areas as compared to data for soils below the building and flower beds adjacent to the building. Pertinent moisture data are summarized as follows:

1. Moisture contents beneath parking areas vary from an average of 30 percent to an average of 37 percent. Maximum average values were measured in B-1 near the area of the water line break. Boring B-7 near a crack in the pavement also exhibited maximum moisture contents. Boring B-6 in the central area of the parking lot that is not cracked exhibited an average moisture content of 30 percent which is probably the moisture content at the time of construction.

2. Average moisture content in soils below the building is on the order of 35 percent in B-4 nearest the water line break and 33 percent in B-3 in the southeast corner of the building.

3. Average moisture content in soils below the flower beds averages 34 percent.

Cause Of Cracking And Deformation: The pattern of deformation and presence of high plasticity clays warrants the conclusion that observed movements were caused by moisture variations in the high plasticity clays underlying the site. However, it appears that two separate conditions of moisture change occurred as follows:

1. Moisture decrease due to withdrawal of moisture by trees and vegetation caused shrinkage and cracking of soils beneath pavement areas.
2. Moisture increase, due primarily to the water line break and possibly from watering of flower beds, caused swell of soils beneath the building.

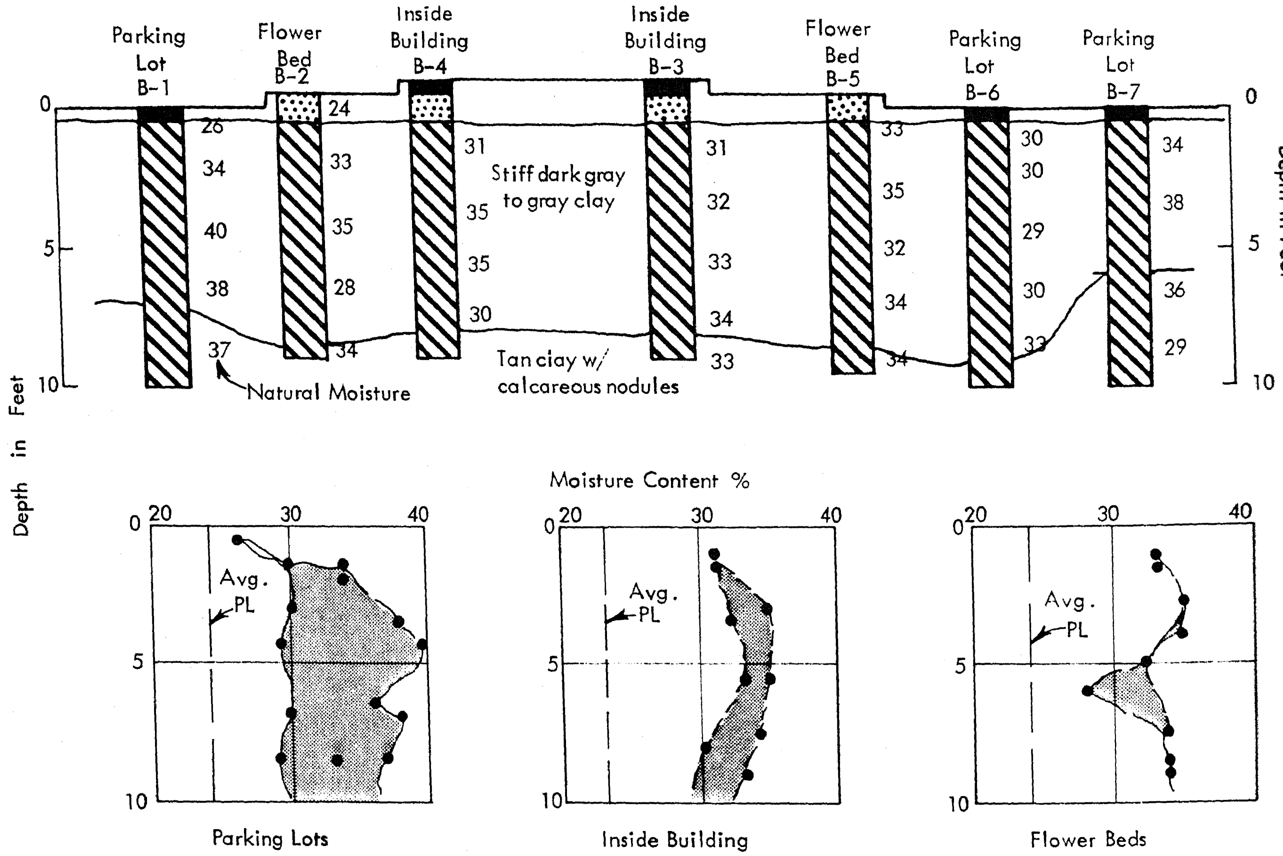


FIG. 4. Generalized Stratigraphy and Summary of Test Results

Location of hedges and particularly oak trees with respect to destressed pavement areas is believed conclusive evidence of the cause for pavement failure. Similarly, occurrence of significant wall cracks and floor heave immediately adjacent to the area of the water line break, and more significantly, occurrence of structural movement within the last six months following the water line break and a period of 12.5 years without structural movement, is believed conclusive evidence that movements were caused by excess moisture supplied by the water line break. Structural movement in the east wall, a considerable distance from the water line break, must also be related to the excess moisture supplied by the break since movement in this area also occurred within the last six months. The presence of slickensides and fissures in the clays resulted in rapid flow of water from the break to the south side of the building or other areas beneath the building, depending on the frequency and continuity of the fissures. However, excessive watering of flower beds due to day weather conditions may also represent another source of excess moisture that would induce heave of the supporting soils.

Corrective Methods: The potential for continued movement in the foundation soils under the building at a decreased rate until equilibrium is established necessitated that no corrective action be undertaken until movement was complete. Several measurement points were therefore established at crack locations on the walls to determine if movement was continuing or was complete. Given below are the results of the crack monitoring program;

Date	Crack 1	Crack 2	Crack 3	Crack 4
2-15-83	25 mm	23 mm	30 mm	25 mm
3-02-83	25 mm	23 mm	30 mm	25 mm
3-25-83	25 mm	23.5 mm	30 mm	25 mm
7-01-83	25.5 mm	24 mm	30 mm	25 mm

As can be seen, no appreciable movement was noted durin the next five months and the client was advised to make necessary repairs.

The cause of movement in the parking area, namely veget tion and trees adjacent to distressed areas, clearly indicates that prevention of future pavement failure woul necessitate replacement of vegetation and in particular the trees with foliage that has a shallow root system a can be watered effectively from the surface. It can be anticipated that pavement movements may encompass a lar area as existing root systems expand with tree size. Accoringly, the following programs were recommended.

1. Replace existing trees and vegetation with foliage that has a shallow root system and minimum water re quirement.

2. Relevel and pave distressed areas.

Case Two: Basement Floor and Sidewalk Settlement, Down-Town, Houston, Texas.

The basement floor and the sidewalk adjacent to a multistory office building in downtown Houston had settlement problems in late 1981. Even though the sidewalk was leve led before, recurrence of sidewalk settlement has been o served in the recent past.

Field Investigation: Subsurface conditions in the sidewa area were defined by five borings drilled to a depth of 20 feet below sidewalk elevation. Locations of the borings are shown in Fig. 5. Undisturbed samples were obtained continuously from the surface to a depth of 12 feet and then at depths of 15 and 20 feet.

Consistency variations of the clay strata were estimated in the field with a hand penetrometer. Groundwater leve

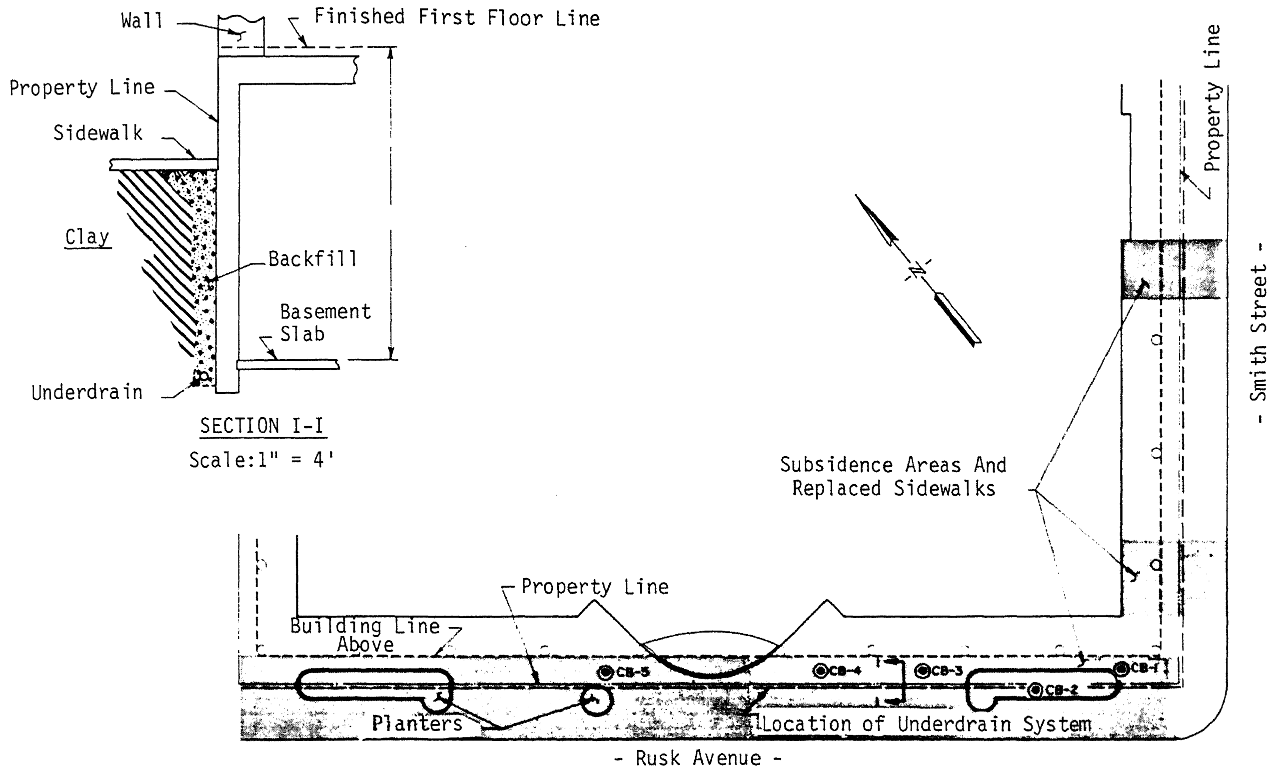


FIG. 5. Plan of Borings and Section

were observed after completion of the borings.

Laboratory Tests: Classification tests, consisting of liquid and plastic limits, and natural moisture content determinations were performed to evaluate general uniformity of soil conditions and shrink-swell potential of these soils. Undrained shear strength properties of cohesive soils were defined by unconfined compression tests. Compressibility characteristics of foundation soils were evaluated by consolidation tests.

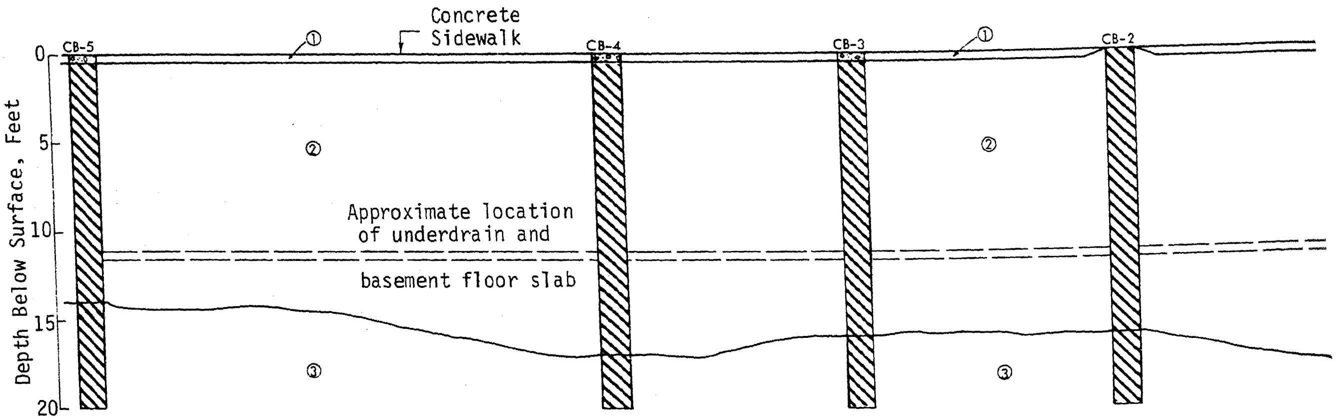
General Soil Conditions: Typical stratigraphy in the sidewalk area is shown by the profile in Fig. 6. Soil conditions are generally uniform. Fill 14 to 18 feet thick was found below the concrete sidewalk. The fill generally consists of firm to stiff brown and gray clay with sand, concrete rubble and gravel inclusions. It also contains organic roots and calcareous nodules. Undrained shear strength of the clay fill generally ranges from 600 to 1800 pounds per square foot, except at some soft spots. The unit dry weight generally ranges from 99 to 105 pounds per cubic foot.

Stiff to very stiff red slickensided clay underlies the fill. This clay is typical of the Beaumont formation and is overconsolidated. The preconsolidation pressure of this clay is on the order of 10,000 pounds per square foot. The plasticity index of this clay ranges from 27 to 34 and the natural moisture content ranges from 27 percent to 33 percent. The unit dry weight is about 100 pounds per cubic foot. Groundwater was found eight to 10 feet below the sidewalk surface elevation.

Cause Of Sidewalk Settlement: It can be concluded at the outset that the overconsolidated red clay below the fill will not consolidate under current overburden pressure, because it has been consolidated before under a much higher load, which is known as "preconsolidation pressure". Preconsolidation pressure is generally estimated from the void ratio-vertical pressure plot obtained from laboratory consolidation tests. The estimated preconsolidation pressure of the red clay, as found from the consolidation test results, is on the order of 10,000 to 12,000 pounds per square foot, which is much higher than the existing overburden pressure, including any ordinary surcharge. Therefore, deformations must have occurred within the fill.

During an interview with the building manager, it was disclosed that, in recent years, a water pipe under the building broke on two different occasions. A considerable quantity of sand and gravel along with fines was removed from two sump pits connected to a drainage pipe located immediately outside the exterior building wall at the elevation of the basement floor level. The sand and gravel removed from the sumps during the water line breaks most probably originated in the filter material around the drainage pipe. Furthermore, the presence of these coarse soils inside the underdrain indicates that this conduit may be broken. Another possible source for the coarse soils found in the sumps is the sand bed under the basement slab. This indicated the development of voids under the floor slab close to the basement wall. Concurrent with this, a void 12 inches deep was recently discovered under the basement floor during grouting operations. Recurrent settlement of the sidewalk can therefore be connected with yielding of the clay fill into the voids created by departure of the sand from around the perimeter drainage pipe. Soft clay zones were found in borings CB-1 and CB-5 at depths within the range of 10 to 14 feet while the - probably broken - drainage pipe runs just outside the perimeter building wall, below the sidewalk, at a depth on the order of 11 to 12 feet.

Recently, the old sidewalk was removed in order to place additional fill needed to raise the grade of the settled sidewalk. Thereafter it was observed that the new sidewalk was again settling. The settlement is greatest near the wall and is evidenced by one inch drop of the sidewalk concrete slab at the construction joint with the basement wall. The sidewalk is most probably still settling because of the



Strata No.	Description
1	Concrete sidewalk
2	Fill - firm to very stiff brown and gray clay w/sand, concrete, rubble and gravel and calcareous nodules
3	Stiff to very stiff red clay, slickensided

Scale: Horizontal 1" = 10'
Vertical 1" = 10'

FIG. 6. Generalized Stratigraphy

voids created in the filter material near the drainage pipe. Only the top one or two feet of fill were properly compacted when the sidewalk was repaired, and therefore subsidence is still possible.

Based on the above discussion, it was concluded that the sidewalk settlement is probably directly related to voids that exist in the filter material around the perimeter drainage pipe located at the basement floor level. The voids in the filter material resulted from water pipe breakdowns and subsequent wash out of sand and gravel material through the pipe. Additional voids may have been created in the backfill behind the basement wall.

Corrective Measures: The field and laboratory tests along with analysis of the sidewalk problem stated above, were taken into consideration to develop the following recommendations regarding possible corrective measures.

1. The most simple alternative would be to allow the sidewalk to settle for some time and then replace it with proper grade elevation and compaction. The disadvantage of this alternative would be the relatively long time and costs involved.
2. Inspect the area of maximum settlement with the aid of a T.V. camera to determine location and extent of damage to the underdrain system. The advantage inherent in this alternative would be the relatively low cost of locating the breaks and the consequent reduced cost of the subsequent repairs.
3. Excavate to the level of the underdrain along the settlement area to check for breaks in the drainage pipe and replace it with a perforated pipe surrounded by filter material and filter fabric, then backfilling under the sidewalk area with properly compacted granular or non-cohesive material.

Grouting techniques were not considered suitable because of the risk of plugging the underdrain.

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