



CASE STUDIES OF RESIDENTIAL FOUNDATION MOVEMENTS IN SOUTHERN HOUSTON AREA

By H. Stephen Tien, Ph.D., P.E.¹ and David A. Eastwood, P.E.²

ABSTRACT

Residential structures in the southern Metropolitan Houston area commonly experience slab movements due to highly expansive subsoil. These slab distress phenomena were caused by one primary factor or a combination of different factors, which can be divided into five major categories: design, construction, materials, maintenance, and wear and tear. Cases of various residential slab foundation movements evaluated through complete Level C forensic study, are analyzed and presented systematically in this paper. In addition, subgrade soil moisture variations as well as the tree effects, and their related influences towards the foundations are further discussed.

INTRODUCTION

Foundation distress is commonly observed in the areas where expansive soils are present. The changes of moisture content in the expansive soils are the major cause of swelling and shrinking, which result in foundation differential movements. Positive drainage is therefore especially important in minimizing the soil-related foundation problems. Three Level C forensic case studies are presented in the following sections with extensive information obtained through various approaches including site reconnaissance, interviewing the residents, performing micro-elevation survey, conducting geotechnical exploration/ geophysical investigation, executing laboratory testing programs, as well as reviewing existing data and expert reports.

Major factors that possibly caused the foundation movements were evaluated and presented systematically in the following sections. The moisture content and liquidity index profiles of the subgrade soils in these cases are further studied and used to suffice the causation of the foundation distress problems.

¹ Engineering Manager and Chief Engineer, Geotech Engineering and Testing Co., 800 Victoria Drive, Houston, Texas 77022, TEL: 713-699-4000

² President and Principal Engineer, Geotech Engineering and Testing Co., 800 Victoria Drive, Houston, Texas 77022, TEL: 713-699-4000



CASE I: THE RESIDENCE IN CLEAR LAKE AREA, HOUSTON, TEXAS

Overview

The first residential foundation case study is a residence in the Clear Lake area of Houston, Texas. This two-story, wood-frame residence was constructed in 1996, using a post-tensioned slab foundation. A swimming pool was built at the backyard of this residence in 1998. Furthermore, this residential lot was heavily wooded prior to construction. A site plan of this residence is presented in Figure 1.

Review of the Existing Documents

Our review of the available documents and expert reports is summarized as follows:

1. The original soil report recommended that fill materials within the building area be a silty or sandy clay with a plasticity index (PI) of 10 to 20 and a liquid limit (LL) of 28 or more. Fill materials should be placed in 6- to 8-inches loose lifts and compacted at optimum moisture content to 95% of their maximum dry density as determined by the Standard Proctor Compaction Test.
2. The original soil report indicated that the subsurface soils consisted of stiff to very stiff; dark gray, gray and tan, light gray and tan fat clay soils (CH) from the ground surface to the end of borings of 15-ft. Groundwater was not found in the soil borings. Furthermore, the soil report suggested that the on-site soils had an effective Plasticity Index (PI) of 39. The recommended Edge Moisture Variation Distances (e_m) were 3.8-ft for center lift and 5.0-ft for edge lift, and Estimated Differential Swells (y_m) were given 0.61-inches for center lift and 0.54-inches for edge lift. The depth to constant suction (i.e. the depth of Active Zone) was suggested to be 7-ft.
3. A structural inspection was performed at the project site in July, 2001 and suggested that poor site drainage has caused edge lift of the post-tensioned slab foundation at the project site.
4. A forensic study was conducted in September 2001. The forensic report suggested that excess moisture was due to the excessive usage of the irrigation system in the yard and lack of maintenance of the system. The engineer then recommended that the yard irrigation system be improved to perform its irrigation function with introducing excess moisture into the soils at the perimeter of the foundation. After the soils supporting the foundation reach moisture equilibrium and foundation is stable, the superficial damage to the structure should be repaired.

Field Explorations

Our field exploration program consisted of conducting four (4) test pit excavations, concrete coring (four cores in total) inside the residence and garage, and three (3) exterior soil borings to



20-ft deep and three (3) interior soil borings to 10-ft deep. The locations of the test pits and borings are presented in Figure 1.

Our test pit excavations indicated a significant amount of root fibers under the grade beams, such as the large tree root found in Test Pit #3, as shown in Figure 2(a). Furthermore, perch water was observed behind/under the grade beam while digging the test pits. Figure 2(b) shows the perched water condition in Test Pit #4. Soil samples obtained from the interior borings showed that sands were mixed with clays and used as fill materials (see Figure 2(c) and 2(d)).

The soil borings were dry augered to evaluate the presence of perched or free-water conditions. The level where free water was encountered in the open boreholes during the time of our field exploration and 24 hours later ranged from 5- to 16-ft. Moreover, perch water was found at 3-ft deep in Boring B-3 and no free water was encountered in Boring C-2.

Laboratory Testing

The laboratory testing program was directed primarily towards evaluation of the physical properties and engineering characteristics of the subsurface soils. These tests consisted of natural moisture content tests (ASTM D4643), Atterberg limits determinations and plasticity tests on clay soils (ASTM D4318), percent passing No. 200 sieve (ASTM D1140) and dry unit density test (ASTM D2166). Similarity of these properties is indicative of uniform strength and compressibility characteristics for soils of essentially the same geological origin. Variations of the average moisture contents and standard deviation versus depth are shown in Figure 3. Test results from previous studies are also presented in this figure for comparison. The induced liquidity indice versus depth are shown in Figure 4.

Undrained shear strengths of the cohesive soils were further measured with laboratory hand penetrometer and laboratory hand operated Torvane. Furthermore, two standard proctor tests (ASTM D698) were performed on the representative bulk samples of the on-site fill and natural soils. The results of this test were used to evaluate the "percentage of compaction" of the existing on-site fill soils.

On-site soil particle sizes were studied based on ASTM D422, the Standard Method for Particle-Size Analysis of Soils. The soil samples were first separated to two portions using the No. 10 (2.00-mm) sieve. A sieve analysis was performed on the soil samples retained on the No. 10 sieve, if any obtained. The portion of soil samples passed the No. 10 sieve then went into the hydrometer tests followed by another sieve analysis to complete the particle size distribution curve. Our soil particle size analyses indicated that the fill soils at the project site were a mixture of fat clay (CH) soils and silty sands (SM), such as the curve shown in Figure 5. This result confirmed our observations in the field explorations.

Soils Stratigraphy

Subsurface soils interpreted from the exterior Borings B-1 through B-3 and the interior Borings C-1 through C-3 indicate that the soils appear to be relatively variable across the site and can be



grouped into five (5) major strata with approximate average depth limits and characteristics as follows: (concrete slab thickness ranging from 4.2" to 6.0" was found in the interior borings)

Range of Depth, ft.	Soil Type	PI(s)*	Soil Expansivity	Soil Strength, tsf	Remarks
0 - 2	Fill: Fat Clay/Silty Sand (CH/SM)	14 - 30	Moderately Expansive	0.31 - 0.85	Moisture Sensitive
0 - 13	Fat Clay (CH)	33 - 48	Expansive	0.23 - 1.01	Root Fibers to 10'
2 - 3	Lean Clay (CL)	26	Non-Expansive	0.31	Root Fibers
4 - 20	Lean Clay (CL)	26 - 30	Moderately Expansive	0.15 - 1.50	Root Fibers to 14'
14 - 16	Clayey Sand (SC)	-	Non-Expansive	-	Moisture Sensitive

*Note: PI = Plasticity Index

Moisture Profile Study

Moisture content testing was performed on all soil samples collected during the geotechnical exploration. Average values of the moisture contents from soil borings in the same field exploration were calculated for projects with more than two borings. In addition, standard deviations of the moisture contents were calculated for projects that had more than three borings. These results are presented in Figure 3.

It is seen from Figure 3 that in general the moisture contents obtained after the residence was built are higher than those measured before the construction, since the project site was heavily wooded. In the other words, the moisture contents in the subsoils increase after the trees at the project area were removed.

Liquidity Index Profile

The liquidity index relates the subsoil moisture to the liquid and plastic limits. The liquidity index profile for all the borings is shown in Figure 4. In addition, the liquidity index profiles generated from the data of previous field explorations are also presented in the chart. A review of these data indicates that the subsoils had mostly positive (wet) liquidity index values after the residence was built (i.e., trees were removed), and subsoils had negative (dry) liquidity index values prior to the construction of the residence (heavily wooded condition).

Micro-Elevation Data

Our review of the previous micro-elevation data indicates an elevation differential of about 2.3- to 2.6-inches in the subject residence. The data indicates floor elevations are high at the edge and low at the center (edge lift). The high areas are at the western portion of the residence (west wall of the study and the west wall of the dining room). The low area is at the northeast corner of the house (inside the master bedroom). Our micro-elevation data are presented in Figure 6, and show an elevation differential of 2.6-inches. Our measurements and previous micro-



elevation data indicate the elevation measurements from different engineering companies are consistent and all lead to an edge-lift case at the subject residence.

Foundation Distress Causation

Inadequate Design. Our review of the original soil report indicated that the foundation design values given at this report are incorrect. In accordance with GET's field explorations, the depth of the Active Zone at the project site should be 12-ft instead of 7-ft. The original soil report recommended Edge Moisture Variation Distance (e_m) to be 3.8-ft for center lift and 5.0-ft for edge lift, and Estimated Differential Swells (y_m) were given 0.61-inches for center lift and 0.54-inches for edge lift. These recommended parameters are low, and would have resulted in the design of a flexible slab foundation. Based on our review of the average moisture content and liquidity index profiles at the project site (shown in Figures 3 and 4), as well as the micro-elevation data (shown in Figure 6), heaving occurs as a result of the presence of underlying expansive soils. Nevertheless, evidences showed that the project was heavily wooded prior to construction, as shown in Figure 7(a). The foundation heaving has been caused due to not considering the effects of tree removal in the initial design, and a flexible slab foundation was designed and constructed. Because of the existence of highly expansive soils and tree removal prior to construction, we recommend Edge Moisture Variation Distance (e_m) to be 4.5-ft for center lift and 5.5-ft for edge lift, and Estimated Differential Swells (y_m) to be 1.4-inches for center lift and 1.2-inches for edge lift.

Construction Problems. Standing water was observed around the construction pad in the project site pictures taken during construction (see Figure 7(b)). In accordance with our review of the rainfall data for the Year of 1996 in Houston, Texas, published by NCDC, Asheville, NC, the total rainfall during the month of August in 1996 was about 10.58-inches (the month with the most rainfall amount during that year). Since the foundation was constructed in August, 1996, a lot of rainwater could have infiltrated the building pad prior to floor slab pour.

Poor Materials. Our review of the construction photo shown in Figure 7(b) indicated that significant amount of sandy soils were used for the construction pad. Our examination of the interior borings, C-1 through C-3, showed that silty sands and fat clay soils were mixed and used as fill materials on the site (see Figures 2(c) and 2(d)). In addition, the original soil report for the subject residence indicated that fill material within the building area should be lean clay having a plasticity index (PI) of 10 to 20 and a liquid limit of 28 or more. Among the three interior borings, Borings C-1 and C-3 have fill materials with plasticity indices (PIs) of 27 and 30 respectively, both over the required range. These sandy fill soils found in the interior borings, as well as in the test pit excavation next to the grade beams do not resist water to seep through these materials and travel under the foundation causing the expansive soils to swell and result in distress.



CASE II: THE RESIDENCE IN FRIENDSWOOD, TEXAS

Overview

The second case study is a residence in Friendswood, Texas. This one-story, stucco veneer, ranch style residential structure was constructed in 2001, using a foundation of floor slabs supported on drilled footings. A swimming pool located to the west of the residence was built at the same time. In addition, the pool shell had cracks before and has been repaired a few times. A site plan of this residence is presented in Figure 8.

Review of the Existing Documents

Our review of the original soil report is summarized as follows:

1. The subsoils generally consist of firm to very stiff; gray, light gray, tan and reddish brown fat clay soils (CH) from the ground surface to the end of the borings at 15-ft. Groundwater was not encountered during drilling. Trees have been removed from the proposed building area.
2. The original soil report recommended the underreamed footings be placed at a depth of 9- to 10-ft below the existing grade. A void space of 4-inches can be provided beneath the grade beam. In addition, the concrete slab of the structure was recommended to be placed on a minimum of 36-inches of non-expansive select fill materials. The select fills should consist of a lean sandy clay with a liquid limit less than 35, and a plasticity index (PI) between 10 and 20.

Field Explorations

Our field exploration program consisted of conducting four (4) drilled footing exposures, concrete coring inside the residence as well as four (4) exterior soil borings to 20-ft deep and four (4) interior soil borings to 10-ft deep. The location of the drilled footing exposures and borings are presented in Figure 8. Our observations during the field explorations indicated that planter areas were constructed around the residence except the front porch and the pool area. Figure 9(a) shows the planter area located to the south of the residence. Furthermore, several cracks were observed all over the pool deck area, as shown in Figure 9(b).

Our pier exposure indicated perched water under the grade beam (see Figure 9(c)). The perched water drained away as the excavation continued. No free water was encountered thereafter to the end of the excavation. Furthermore, a substantial amount of root fibers (up to 3/8-inch in diameter) were observed in our pier exposures, such as shown in Figure 9(d).

The soil borings were dry augered to evaluate the presence of perched or free-water conditions. The level where free water was encountered in the open boreholes during our field exploration and 24 hours later ranged from 10- to 18-ft in the exterior borings. No free water was encountered in the interior borings.



Laboratory Testing

The laboratory testing program was directed primarily towards evaluation of the physical properties and engineering characteristics of the subsurface soils. These tests consisted of natural moisture content tests (ASTM D4643), Atterberg limits determinations and plasticity tests on clay soils (ASTM D4318), percent passing No. 200 sieve (ASTM D1140) and dry unit density test (ASTM D2166). Similarity of these properties is indicative of uniform strength and compressibility characteristics for soils of essentially the same geological origin. Variations of the average moisture contents and standard deviation versus depth are shown in Figure 10. Test results from previous studies are also presented in this figure for comparison. The induced liquidity indice versus depth are shown in Figure 11.

Undrained shear strengths of the cohesive soils were further measured with laboratory hand penetrometer and laboratory hand operated Torvane. Furthermore, two standard proctor tests (ASTM D698) were performed on the representative bulk samples of the on-site fill and natural soils. The results of this test were used to evaluate the "percentage of compaction" of the existing on-site fill soils. On-site soil particle sizes were also studied based on ASTM D422, the Standard Method for Particle-Size Analysis of Soils.

Soil suction in accordance with ASTM D5298 is a measure of the free energy of the pore-water in the soil. Soil suction in practical terms is a measure of the affinity of soil to retain water and can provide information on soil parameters that are influenced by the soils water, such as, volume change, deformation, and strength characteristics of the soil. The soil suction was measured using laboratory filter papers method. The results of these tests are shown in Figure 12. In general, the soil suction values showed that subsoils were wetter (i.e., closer to the "wet" profile", 2.5 pF) at the depth of about 5-ft.

Soil Stratigraphy

Subsurface soils interpreted from the exterior borings and the interior borings indicate that the soils appear to be relatively variable across the site and can be grouped into five (5) major strata with approximate average depth limits and characteristics as follows: concrete slab thickness ranging from 4.7" to 8.5" was found in the interior borings)

<u>Range of Depth, ft.</u>	<u>Soil Type</u>	<u>PI(s)</u>	<u>Soil Expansivity</u>	<u>Soil Strength, tsf</u>	<u>Remarks</u>
0 - 2	Fill: Silty Sand (SM)	-	Non-Expansive	-	Moisture Sensitive
0 - 5	Fill: Lean Clay (CL)	17 - 24	Non- to Moderately Expansive	0.15 - 1.08	Root Fibers to 4'
0 - 6	Fill: Fat Clay (CH)	37 - 66	Expansive	0.23 - 0.46	Root Fibers to 6'
2 - 20	Fat Clay (CH)	43 - 81	Expansive	0.23 - 1.50	Root Fibers to 10'
15 - 20	Lean Clay (CL)	-	Moderately Expansive	0.31 - 0.39	-



Legend: PI = Plasticity Index

Moisture Profile Study. Moisture content testing was performed on all soil samples collected during the geotechnical exploration. Average values of the moisture contents from soil borings in the same field exploration were calculated, and compared to each other. Furthermore, standard deviations of the moisture contents were calculated for our soil borings. These results are presented in Figure 10.

It is seen in Figure 10 that in general the moisture contents obtained after the residence and swimming pool were built are lower than those measured before the construction, above the depths of 5-ft, but higher below the depth of 5-ft. Namely, the moisture contents in the subsoils below the depth of 5-ft increased after the pool and house were constructed.

Liquidity Index Profile. The liquidity index relates the subsoil moisture to the liquid and plastic limits. The liquidity index profile for all the borings is shown in Figure 11. Furthermore, the liquidity index profiles generated from the data of previous field explorations are also presented in the chart. A review of these data indicates that the subsoils had mostly positive (wet) liquidity index values. In addition, the subsoils from the interior soil borings had lower liquidity index values than those from the exterior borings in our field explorations.

Geophysical Exploration and Analysis. Our geophysical information for the subject residence indicate that the majority of extremely low resistivity zones (resistivity values on the order of 3.0 ohm-m or less) were measured underneath or in the vicinity of the pool deck area. As shown in Figure 13, these extremely low resistivity zones distribute at the depth of around 2- to 8-ft in those profiles. The extremely low resistivity areas were summarized on the map shown Figure 14. Among the three resistivity profiles, the high moisture content soils (extremely low resistivity zones) were found under the pool deck, under a portion of the master bedroom and outside of the master bedroom, in the planter area (located to the east of the master bedroom). Two other spots of the extremely low resistivity zones were also documented in the planter areas next to the home office and front porch.

Based on the geophysical information, the most probable sources of water at the project area are from the pool leak and the planter irrigation water. To further identify the major water source, it is our opinion that analytical chemistry tests should be performed to verify the chloride content in the water sample retrieved from the ground.

Micro-Elevation Data. Our review of the micro-elevation data performed on April 30, 2003 indicated that an elevation differential of about 2-inches in the subject residence, as shown in Figure 15. The high areas were at the walk-in closet of the master bedroom and the west wall of Bedroom #3. The low areas were at the dining room and Bedroom #1. Our review of this micro-elevation data suggested that the slab elevations were generally higher at the west side of the house which was the area close to the swimming pool.



Foundation Distress Causation

Inadequate Design. Our review of the original soil report indicated that the recommended underreamed footing depth was too shallow. Based on our field exploration observation and laboratory testing results, the active zone depth at the project site is estimated to be about 12-ft. However, The original soil report recommended to place the pier underreams at a depth of 10-ft. The active zone is defined as the region of soil near the surface in which the water content varies due to precipitation, irrigation and evapotranspiration. The deeper the active zone is, the longer the region over which soil expansion can occur and thus the longer the potential for heave/soil movement due to soil expansion. It is our opinion that the piers at the project site were placed too shallow to prevent them from possible vertical movement. An appropriate installation depth for the piers should be at least 18-ft in the specific case here.

The original soil report also suggested using a minimum of 36-inches of non-expansive select fill materials which have a liquid limit less than 35, and a plasticity index (PI) between 10 and 20. Due to the highly expansive soils and tree removal at the project site, a stiffened slab with at least 48-inches of select fill materials underneath should be used for the foundation at the project site.

Construction Problems. Our interview with the homeowner and our observations during our field exploration indicate that the swimming pool unit and pool deck have been repaired several times. Our soil explorations as well as the geophysical investigation conclude that subsoils at the depth between 2- to 8-ft have been affected by excess moisture which was not present prior to the pool construction. All of the above information showed that the pool unit was not constructed adequately, and the pool water leakage from the pool unit has increased the water content in the subgrade soils under the house foundation in the vicinity of the pool. The fluctuation of moisture in the subsoils then resulted in the movement of the expansive soils underneath and caused foundation distress.

Poor Materials. Our evaluation of the exterior borings (Borings B-1 and B-2) indicated that sandy soils were used as fill soils at the project site. Furthermore, our examination of the interior boring logs C-1 through C-4 showed that some moderately expansive clay soils were used as fill materials under the foundation. In accordance to the original soil report for the subject residence, fill materials within the building area should be lean sandy clay having a plasticity index (PI) of 10 to 20 and a liquid limit less than 35.

As to sandy fill soils, found in the exterior borings (Borings B-1 and B-2) as well as the pier exposure locations in the planter areas next to the grade beams, do not resist water to seep through these materials and travel under the foundation causing the expansive soils to swell and result in distress. The perched water found under the grade beams during our pier exposure indicated such water infiltration. Furthermore, the geophysical investigation also showed that sandy soils distribute on the ground surface to the depth of about 3-ft across the project site (see Figure 13, for soils with resistivity values 7.5 ohm-m and up).



CASE III: THE RESIDENCE NEAR LEAGUE CITY, TEXAS

Overview

The last residential foundation case study is a one-story, wood-frame, brick veneer structure located close to League City, Texas. This residence was constructed in 1966, using a slab-on-grade foundation. The add-on behind the garage was built in 1974. On-going foundation movements have been observed after the construction of the house. Several piers have been installed underneath the slab to ease further foundation movements.

Site Reconnaissance

Our site reconnaissance indicated the following issues at the subject residence:

1. The drainage conditions at the north and east sides of the residence were poor. The south side of the residence had an average drainage condition. The west side (front) of the residence had French drain installed and water was in general drain away from the residence at this area.
2. Planter areas with sprinkler systems were found all around the garage and add-on area (see Figures 17(a) and 17(c)). Planter areas were also found in front of the house and at the west side of the house (see Figure 17(b)).
3. Our observations of the guttering system indicated that the north and south sides of the residence did not have a guttering system.
4. Our observations indicated that some gutters did not have downspout and discharged rainwater directly to the subsoils next to the foundation, as shown in Figure 17(a). Furthermore, most of the downspout discharged water to the subgrade next to the foundation, as shown in Figure 17(b). No extension pipe was connected to the downspout to drain the water away from the foundation.
5. Our interview with the homeowner indicated that a large post oak tree at the back of the add-on (about 10-ft away) died in 1998.
6. Our observations of the soil conditions next to the foundation at the south side of the residence, Figure 17(d), indicated a separation between the grade beam and the soils. This separation was about 1-inch in width.

Field Explorations

The soil conditions were explored by two (2) soil borings to 20-ft deep located at approximately as shown in Figure 16.



The borings were drilled dry, without the aid of drilling fluids, to more accurately estimate the depth to groundwater. Water level observations made at the completion of drilling indicated that groundwater levels ranged from 14- to 17-ft.

Laboratory Tests

Soil classification and shear strengths were further evaluated by laboratory tests on representative samples of the major Strata. Specifically, strengths determined by field tests were verified by calibrated hand penetrometer shear strength tests and by laboratory Torvane tests. Uniformity of soils stratigraphy, strength, and compressibility characteristics was determined by moisture content tests (ASTM D 4643) and Atterberg limits determinations (ASTM D 4318).

Soil Stratigraphy

Base on our field and laboratory data, subsurface soils appear to be variable across the site. In general, the soils can be grouped into three (3) major strata with depth limits and characteristics as follows:

Range of Depth, ft.	Soil Type	PI(s)	SPT	Soil Expansivity	Soil Strength, tsf	Remarks
0-1/3	Fill: Silty Sand (SM)	-	-	Non-Expansive	-	Moisture Sensitive
0-17	Fat Clay (CH)	46 - 58	-	Highly Expansive	0.39 - 0.78	Root Fibers to 10'
13-20	Silty Sand (SM)	-	17	Non-Expansive	-	Moisture Sensitive

Legend: PI = Plasticity Index
SPT = Standard Penetration Test

Foundation Distress Causation

Improper Maintenance. Drainage away from the structure and vegetation can play an important role in how the foundation system performs. Negative drainage next to the grade beams or ponding of the surface water can cause excessive moisture of the underlying expansive soils, causing foundation distress.

Our site visit indicated poor drainage condition existed at several locations of the residence, especially around the back of add-on structure. Planter areas were observed all around the residence except a portion of the southern wall and at the rear patio and driveway. Furthermore, sprinkler systems were found in all of the planter areas.

Roof water drainage should properly discharged away from the foundation. Our site visit indicated the presence of guttering and downspout systems at various locations around the residence. However, there is no guttering system installed at the north and east sides of the add-on and the south side of the original structure. In addition, missing downspouts (Figure 17(a)) or



downspouts without extension pipes and draining water into the planter areas right next to the foundation (Figure 17(b)) were observed around the residence.

Tree roots tend to desiccate the soils. During the useful life of the structure, if a tree dies, subsoil swelling may occur in the expansive soil areas for several years. Studies have shown that this process can take several years in the area where highly expansive clays are present. In our case, a large oak tree in the proximity of the add-on died a few years ago. This has caused the subsoil to swell at the back of add-on structure.

CONCLUSIONS

The lessons learned from our case studies are summarized as follows:

1. The differential movement values (e_m and y_m) in the geotechnical reports are proposed based on climate controlled soil conditions and are generally not valid when influenced by significant other conditions, such as trees, poor drainage, slope, cut and fill sections, etc. Due to presence of expansive soils and trees on the site, we recommend the floating slabs be stiffened (rigid) such that minimum differential movements occur once a portion of the slab is lifted as a result of tree removal and presence of expansive soils. The foundation system may experience tilt if designed as a rigid slab. Foundation tilt can be minimized if several feet of on-site expansive soils are removed and replaced with structural fill.
2. Tree roots tend to desiccate the soils. In the event that the tree has been removed prior to building construction, during the useful life of the structure, or if a tree dies, subsoil swelling may occur in the expansive soil areas for several years. Studies have shown that this process can take several years in the area where highly expansive clays are present. In this case, the foundation for the structure should be designed for the anticipated maximum heave. Furthermore, the drilled footings, if used, must be placed below the zone of influence of tree roots. In the event that a floating slab foundation is used, we recommend the slab be stiffened to resist the subsoil movements due to the presence of trees. In addition, the area within the tree root zone may have to be chemically stabilized to reduce the potential movements. Alternatively, the site should be left alone for several years so that the moisture regime in the desiccated areas of the soils (where tree roots used to be) become equal/stabilize to the surrounding subsoil moisture conditions.

It should be noted that the upheaval in the expansive clays (where trees have been removed or trees have died) occurs predominantly in the areas that poor drainage, excessive irrigation or plumbing/sewer leak is occurring.

3. In the areas where expansive soils are present, rough grade the site with structural fill soils to insure positive drainage. Due to their high permeability of sands, sands should not be used for site grading where expansive soils are present. Furthermore, structural fill beneath the building area may consist of off-site inorganic lean clays with a liquid limit of less than 40 and a plasticity index between 12 and 20.

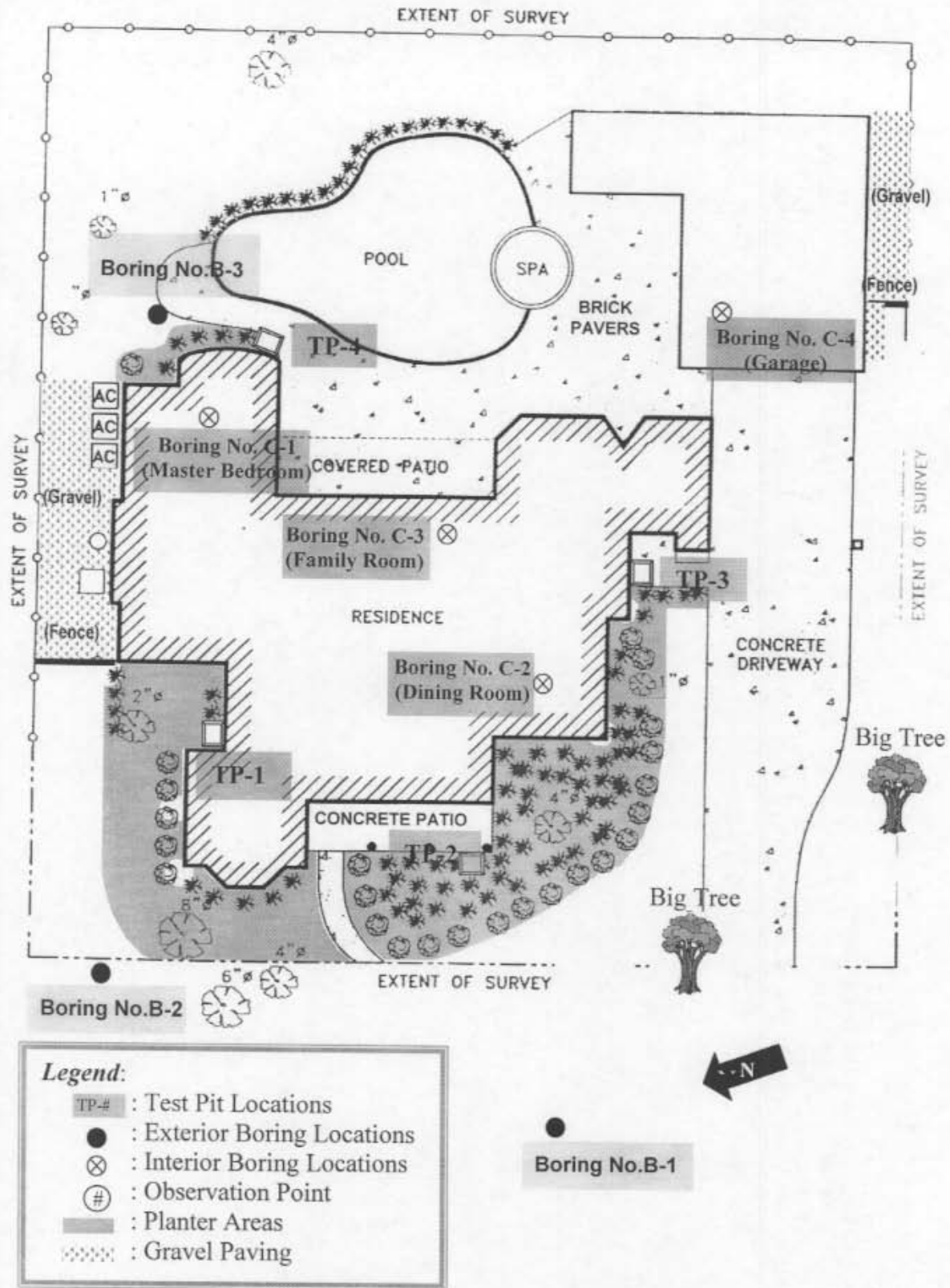


Figure 1. Site Plan of the Clear Lake Residence

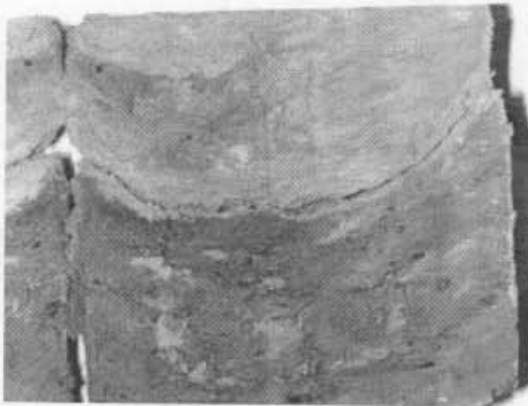


(a)

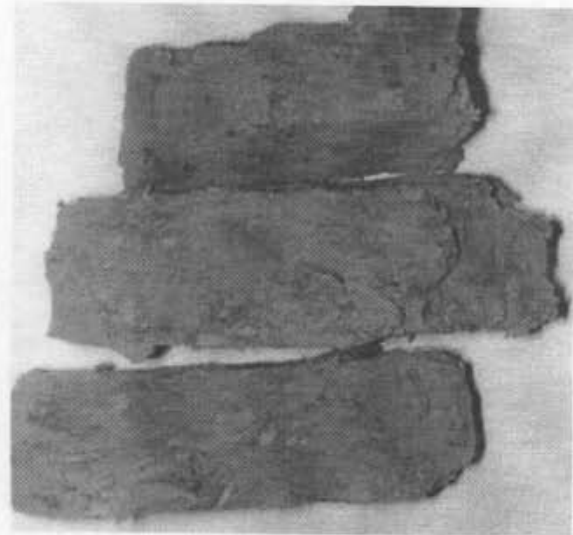
4



(b)



(c)



(d)

Figure 2. Test Pit Excavations and Soil Sampling at the Clear Lake Residence:
(a) Large Tree Root Found in Test Pit No.3, (b) Perched Water Observed Under the Grade Beam at Test Pit No. 4 Location, (c) Clay and Sand Mixture Soils Found at the Depth of 1- to 2-ft in Boring C-1, and (d) Clay and Sand Mixture Soils Found at the Depth of 0- to 1-ft in Boring C-2

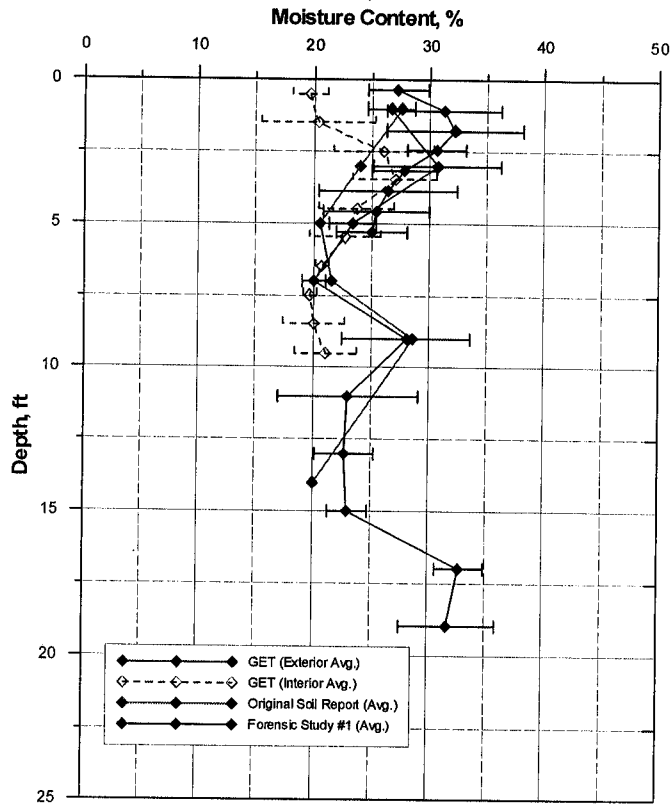
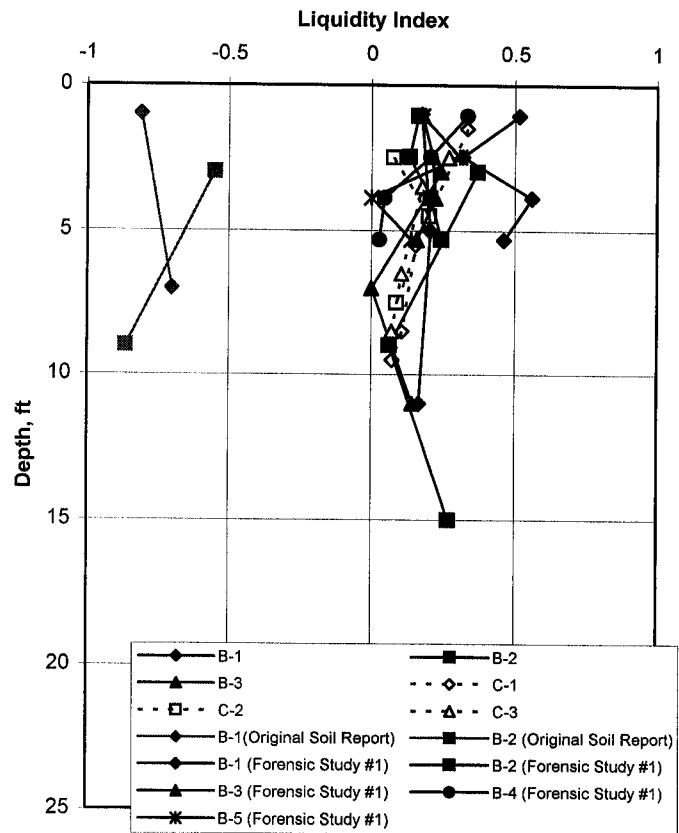


Figure 3. Average Moisture Content and Standard Deviation versus Depth at the Clear Lake Residence

Figure 4. Liquidity Index versus Depth at the Clear Lake Residence



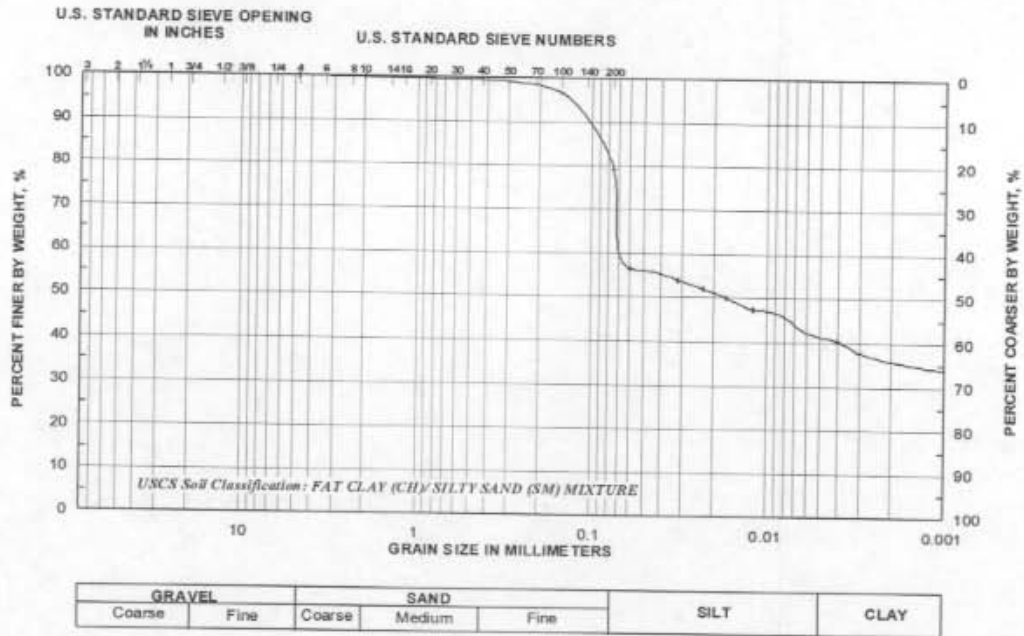


Figure 5. Grain Size Distribution Curve for Boring C-2 (0- to 1-ft) at the Clear Lake Residence

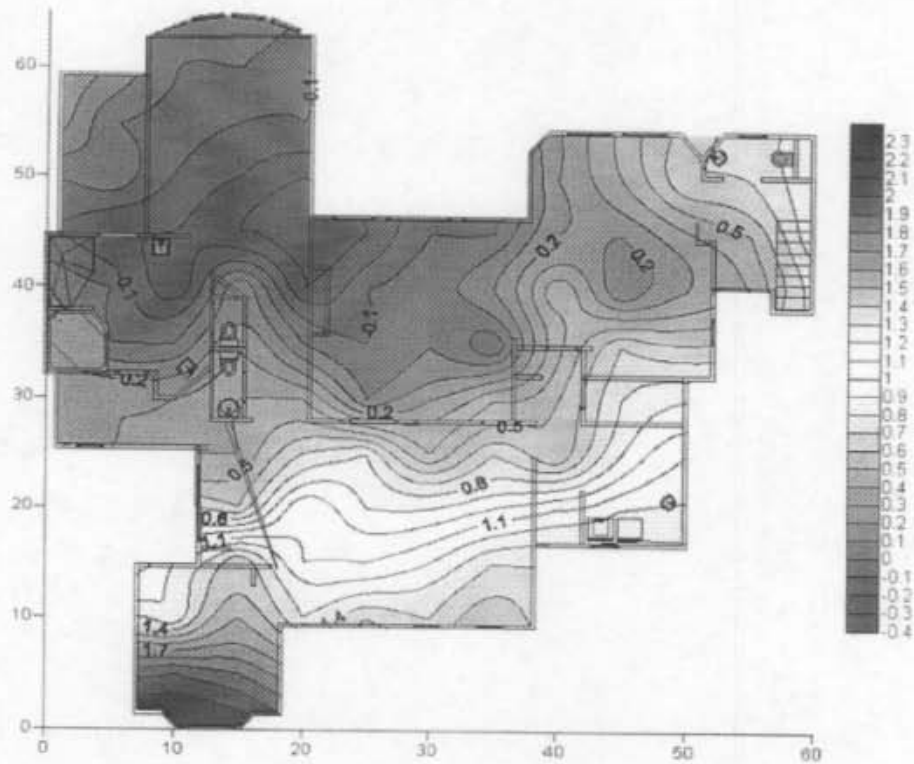


Figure 6. Floor Slab Micro-Elevation Survey at the Clear Lake Residence (performed on December 26, 2002)



(a)



(b)

Figure 7. Project Site Conditions at the Clear Lake Residence: (a) Heavily Wooded prior to Construction and (b) Wet Ground Surface During Construction (prior to Concrete Pour)

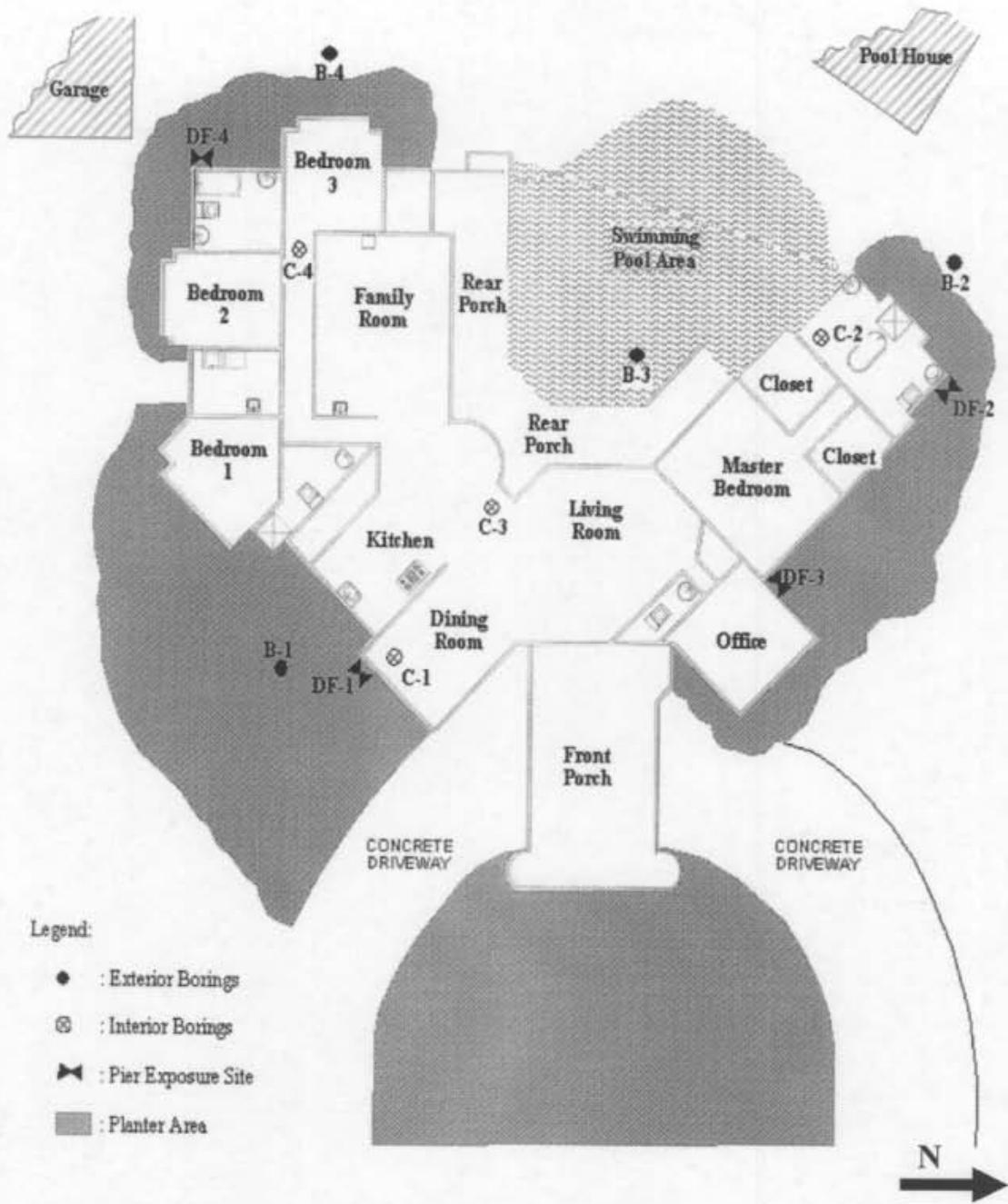
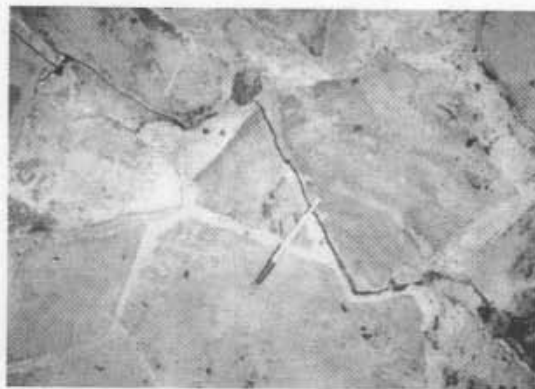


Figure 8. Site Plan of the Friendswood Residence



(a)



(b)



(c)



(d)

**Figure 9. Site Observations and Pier Exposure at the Friendswood Residence:
(a) Planter Area with Trees Adjacent to the South Side of the Residence,
(b) Cracks within the Pool Deck, (c) Perched Water Observed at Pier
Exposure Site No. 4, and (d) the Root System Found at Pier Exposure
Site No. 4**

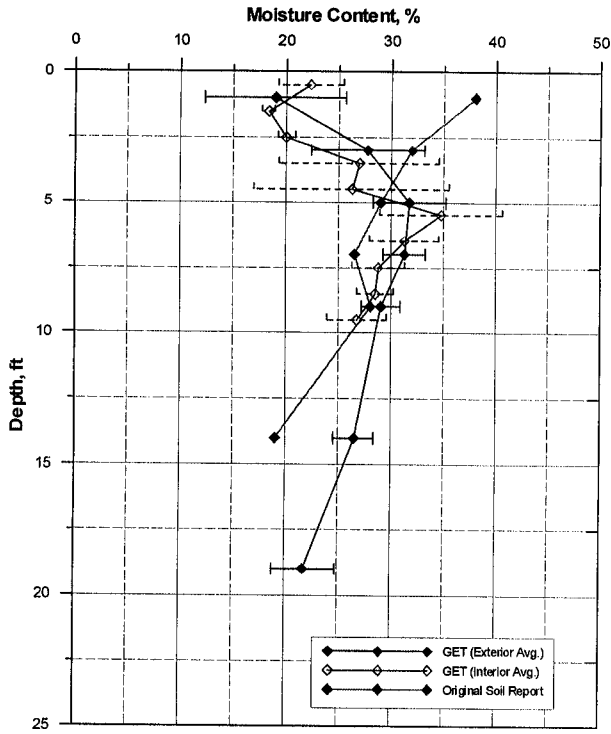
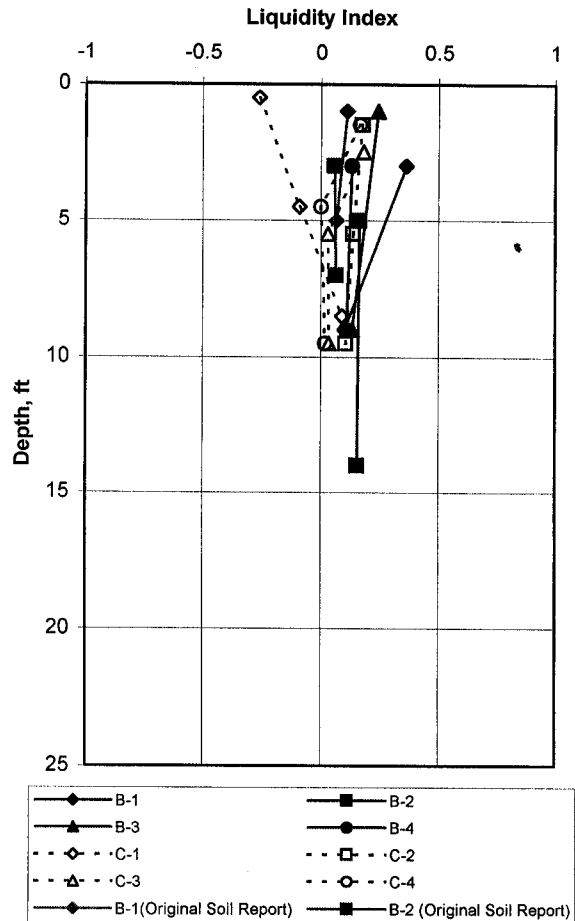


Figure 10. Average Moisture Content and Standard Deviation versus Depth at the Friendswood Residence

Figure 11. Liquidity Index versus Depth at the Friendswood Residence



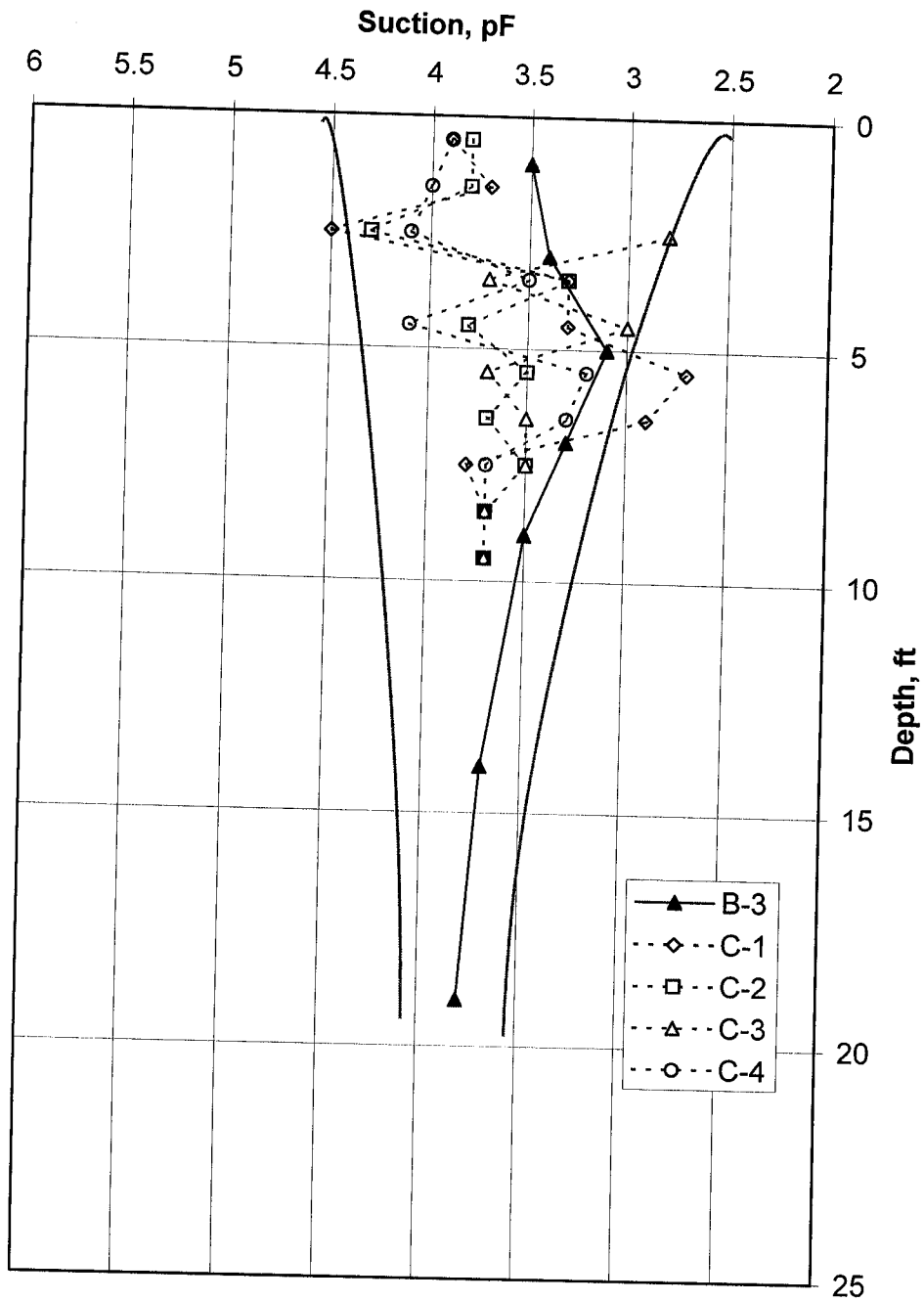
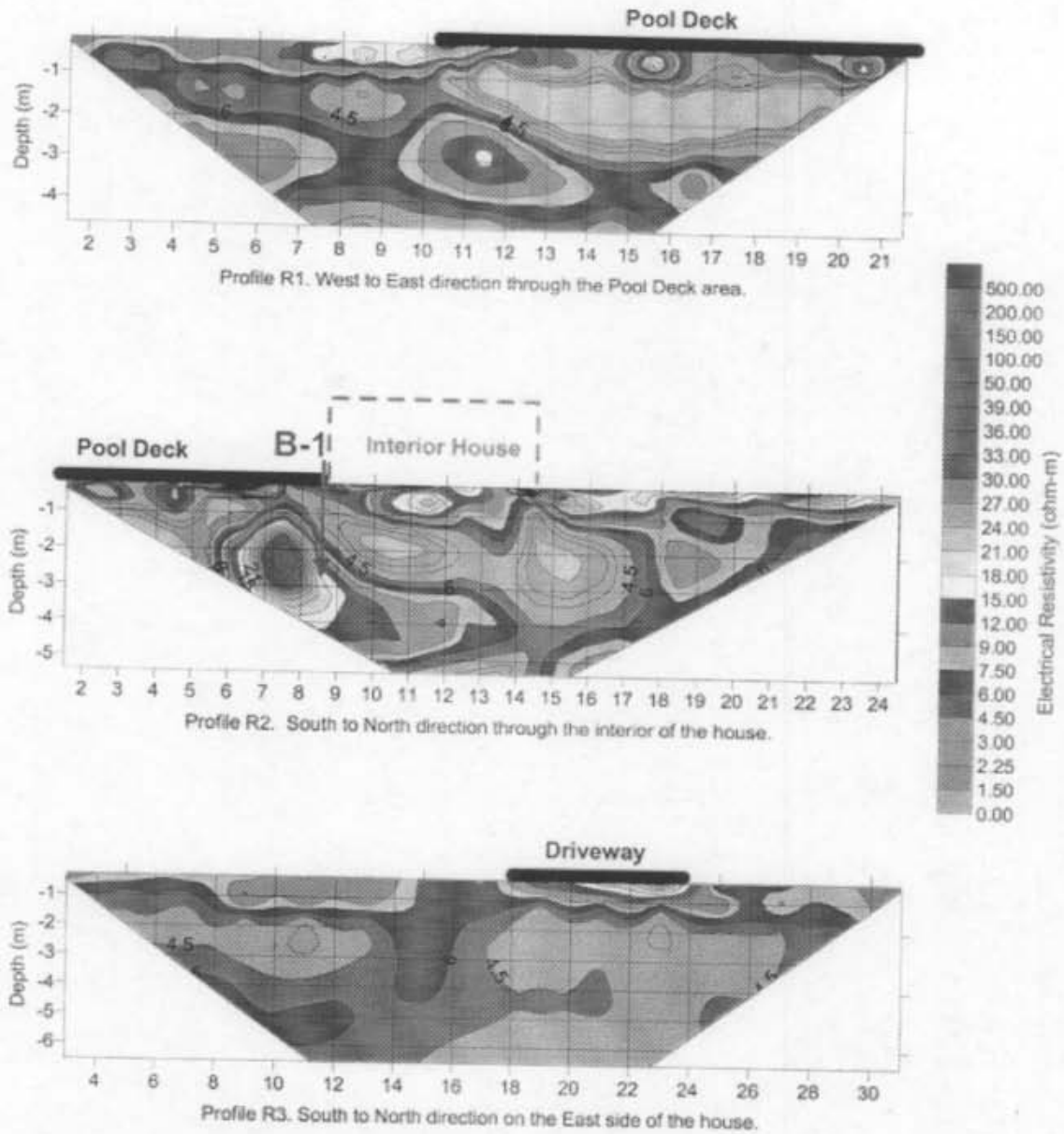


Figure 12. Soil Suction versus Depth at the Friendswood Residence

Survey Date: 1/22/04



Notes: 1. Data at lower corners is interpolated.
 2. Structure, Boring and Vegetation positions are approximate.
 3. Patent Process. All Rights Reserved.
 US Patent: S/N 6,295,512

Figure 13. Geo-Electrical Moisture/Material Imaging Resistivity (GMMIR) Profiles at the Friendswood Residence

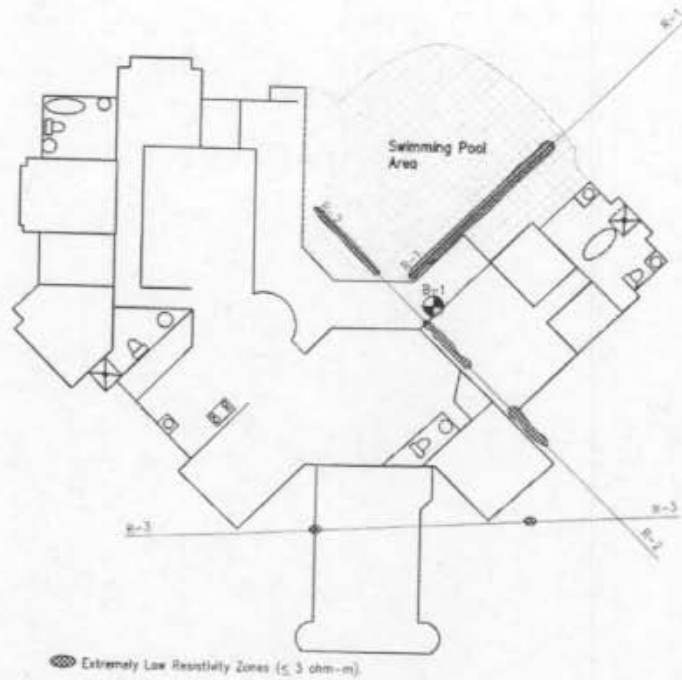


Figure 14. Extremely Low Resistivity Zones (High Moisture Content Soils) Found at the Friendswood Residence

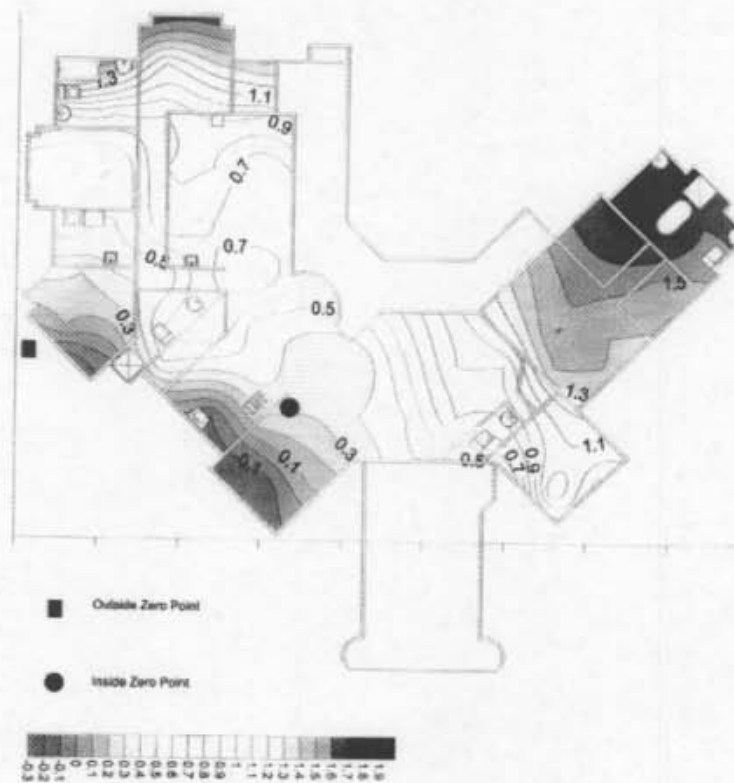


Figure 15. Slab Micro-Elevation Survey at the Friendswood Residence (Performed on April 30, 2003)

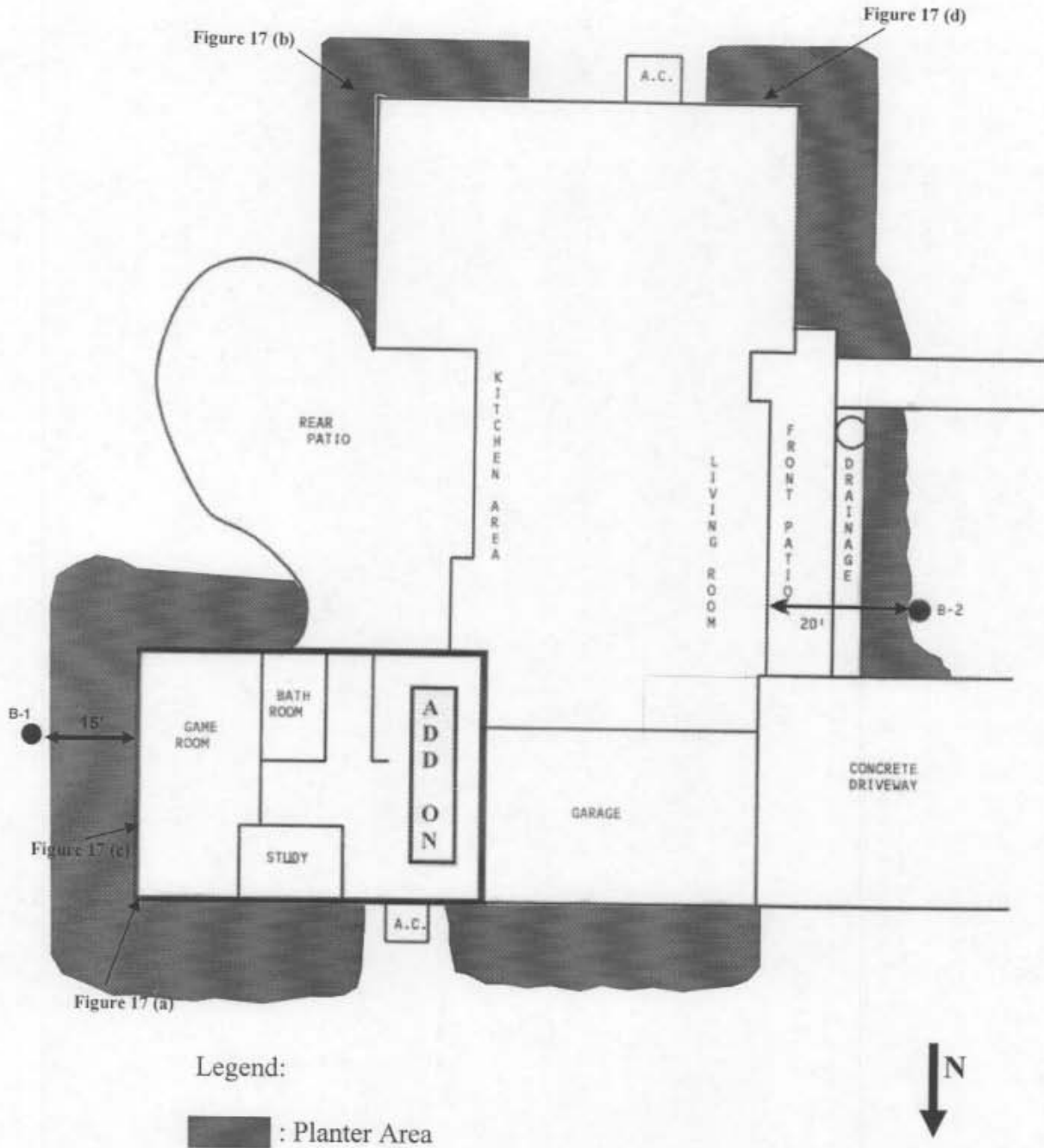


Figure 16. Site Plan of the League City Residence



(a)



(b)



(c)



(d)

Figure 17. Site Observations at the League City Residence: (a) the Gutter System without Downspout located at the Northeast Corner of the Residence, (b) the Downspout Discharging Water next to the Foundation at the Southeast Corner of the Residence, (c) Sprinkler System and Planter Area adjacent to the East Side of the Residence, and (d) the Gap between the Grade Beam and Subgrade Soils due to Subsoil Shrinkage Found at the South Side of the House