CASE STUDY OF THE PAVEMENT DISTRESS AT A SERVICE STATION

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ABSTRACT

Parking lot pavement and driveway distress were observed in a service station underlain the expansive clays in the Metropolitan Houston Area. A systematic forensic study was carried out which included: (1) conducting site reconnaissance, (2) performing a traffic study, (3) performing non-destructive rebar location evaluation, (4) coring and testing of the concrete pavement, (5) drilling, sampling and testing of the subgrade in the parking lot area, (6) reviewing existing data and reports by others, and (7) analyzing this and previous data to develop causation and repair recommendations.

The primary causes of the pavement distress at the project site include: (1) Misuse of the pavement structures (18-wheeler traffic loading) at the 5- and 6-inch concrete areas, (2) Subsurface drainage inadequacies, high perched water table at several areas, (3) Excessive amount of expansion joints and poor joint sealant conditions, (4) The presence of sand and clay mix in the fill soils, and (5) Insufficient pavement thickness.

INTRODUCTION

The Texaco Service Station located in the Metropolitan Houston Area has experienced pavement distress problems. These pavement distress problems have resulted in joint spalling and cracking within the concrete paving. The Texaco Service Station consists of one main building, one RV pump station and two canopies. A site plan is shown on Figure 1.

The project site was divided into eight segments, Areas I through VIII, for the convenience of our study. Among these area segments, Areas I and II have 6-inch pavement (driveways), and Areas III through VI are 7-inch concrete paving (for heavy trucks) while Areas VII and VIII are 5-inch concrete (for light-weight passenger vehicles).

The purpose of this study is to (a) evaluate the possible cause(s) of pavement distress, and (b) recommend repair techniques that would minimize distress of the pavement. These objectives were accomplished by conducting site visits, performing a traffic study, performing non-destructive tests (rebar location evaluation) and destructive tests, coring, drilling, sampling and testing of the concrete and subgrade soils in the paving area. Furthermore, existing data and

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reports by others were review and analyzed, together with the information obtained in this study to develop engineering recommendations.

SITE VISIT

The information gathered during the site visit includes three categories: (a) Observations of the Problematic Areas, (b) Pavement Condition Evaluating and (c) Concrete Pavement Joint Survey. Details of these categories are presented in the following sections.

Observations of the Problematic Areas

The major findings at the subject area during our site reconnaissance are as follows:

- The property is about 2- to 4-ft above the surrounding area. Fills have been placed on this property.

- Some steel poles were added to the site, at the passenger vehicle parking lot located to the east of the food mart building, to prevent 18-wheelers from crossing to the passenger vehicle parking lot. A picture taken at this location is presented in Figure 2.

- The observations of both driveways (leading to the state highway, with 6-inch thick concrete paving, Areas I and II) indicate significant concrete cracking and spalling all over these areas.

- The observations of the concrete paving at Area III (7-inch thick concrete) indicate an expansion joint with missing joint sealant and deteriorated wooden insert located to the southeast of the RV service islands. Subgrade fines mixing with water were pumped out when heavy trucks passed by. A picture taken at this location is shown in Figure 3. The similar failure was observed at a control joint located to the southeast of the food mart at Area V, and an expansion joint located at the service station exit to the country road at Area VI. This type of failure suggests that the pavement is losing the subgrade support underneath the concrete.

- The 5-inch thick concrete pavement at Areas VII and VIII was observed with extensive cracking and spalling.

- The observations of the concrete joint located to the east of the northern driveway at Area VIII, indicate the presence of joint faulting (stepping) as shown in Figure 4. This type of failure suggests that the subgrade materials do not provide adequate support for the concrete paving.

- In general, the concrete paving at Areas IV, V and VI (with 7-inch thick concrete) has a better condition.

- The observations of the expansion joint wood (premolded expansion joint material) at various locations throughout the paving area, indicate that the wood material has deteriorated and voids exist at the joints at this time. No maintenance of the joints has been taking place.

- The observations of the patch concrete located to the south of the food mart building at Area IV, indicate the replacement patch is cracking and spalling, and aggregates are falling apart, as shown in Figure 5. Concrete patches were also observed at Area I, II, III and VIII. Concrete cracking and spalling were found at these patches as well.

- More detailed pavement distress types and observed areas are presented in the following section.

<u>Pavement Condition Evaluating</u>

The pavement condition was evaluated using the *Guide for Making a Condition Survey of Concrete Pavements* (Ref. 1) by American Concrete Institute Committee 201 (ACI 201.3R-86). This condition survey is an examination of the exposed concrete for the purpose of identifying and defining areas of distress. The pavement condition rating data is used to evaluate the ability of the pavement to continue to provide required service, as well as the guidance for the planning of a repair program. A Pavement Condition Checklist from ACI including the type, severity, and extent or frequency of occurrence of distress present, was adopted in our field evaluation process.

In general, concrete pavements are expected to show some cracking during their design life. Cracking of concrete can never be totally eliminated. The pavement condition survey identifies the distress type, severity and extent. The following pavement distress types (Ref. 1) were observed during our site visit:

- Crazing (moderate, Area VIII)
- Settling (moderate, Areas I, II, III, IV, VII and VIII)
- Faulting Joint Crack (Moderate, Area VIII)
- Pumping (moderate, Areas III, V and VI)
- Joint Seal Loss (moderate, Areas I, II, III, IV, V, VI, VII and VIII)
- Joint Sealant Bond Loss (moderate, Areas I, II, III, IV, V, VI, VII and VIII)
- Joint Sealant Cohesion Failure (moderate, Areas I, II, III, VI, V, VI, VII and VIII)
- Joint Sealant Extruded (moderate, Areas I, II, III, IV, VI and VIII)
- Joint Sealant Impregnated with Debris (severe, Area I; moderate, Areas II, III, IV, V, VI, VII and VIII)
- Joint Separation (severe, Area I; moderate, Areas III, IV, V, VI, VII and VIII)
- Joint or Cracking Spalling (severe, Area I; moderate, Areas II, III, IV and VIII; very slight, Areas V and VI; slight, Area VII)
- Joint or Crack Failure (severe, Area I)
- Longitudinal Cracks (moderate, Areas I, II, III, IV and VIII; very slight, Areas V and VI; slight, Area VII)
- Corner Cracks (moderate, Areas I, II, III, IV and VIII; slight, Area VII)

- Transverse Cracks, including Single, Multiple and Faulting Cracks (moderate, Areas I, II, III, IV and VIII; very slight, Areas V and VI; slight, Area VII)
- Edge Cracks (moderate, Area IV; very slight, Area V)
- Concrete Patching (few, Areas I, II and IV; intermittent, Areas III and VIII)

The severity of pavement distress is shown in the parentheses following the distress type, if available.

Concrete Pavement Joint Survey

Two different concrete joints at the project site were identified. They were expansion and control joints. Our site reconnaissance indicates that there are a lot of expansion joints being used in the project area. The designer should be cautioned that expansion joints within the pavements are difficult to construct and maintain. Their use should be kept to the absolute minimum necessary to prevent excessive stress in, or distortion of, the pavement (Ref. 2). Furthermore, deteriorate joint inserts or poor-maintained joint sealing are tend to cause water seeping into the subgrade materials and result in fines loss under the concrete pavement and reduce the subsoil bearing capacity for the paving. The general spacing conditions between adjacent joints at the project site are presented on Figure 1.

The specifications called for 20-and 40-ft maximum spacings for the control joints and expansion joints respectively. Our observations during our site visit indicate that most of the joint spacings are larger than the specifications requirements of 20- or 40-ft around the project site, for example, control joint spacing required less than 20-ft and measured up to 25-ft in Area VII, and expansion joint spacing required less than 40-ft and measured up to 90-ft in Area V.

American Concrete Institute (Committee 330) suggested that internal expansion joints should be omitted, that is, the main body of the pavement should not contain expansion joints since expansion joints often contribute to premature pavement failures (Ref. 2). The extensive application of the expansion joints at the project site actually increases the possibilities of premature pavement failures. The contractor used large expansion joint spacings are, in fact, helping to reduce the pavement cracking. On the other hand, the control (contraction) joints are a necessity to the parking lot concrete pavements since these joints are designed to control the cracking caused by shrinkage of the concrete and by the effects of loads and warping. More saw-cut control joints are therefore recommended in the areas with large joint spacings.

FIELD EXPLORATIONS

General

Our field exploration programs consisted of conducting concrete coring in the pavement area as well as soil sampling under the concrete paving. Non-destructive test method was adopted to identify the rebar locations in the concrete pavement. Furthermore, slug tests to examine the water condition at the project site were performed at Borings B-1 and B-2 locations.

Concrete Corings and Soil Borings.

Subsoil conditions at the project site were explored by seventeen (17) soil borings. Approximate boring locations are shown on Figure 6, Borings B-1 through B-15 were drilled around the food mart building, and B-16 and B-17 were drilled at the driveways (approaches) connecting to the adjacent highway. Among the seventeen (17) borings, Borings B-1, B-2, B-10 through B-12 and B-14 through B-17 were cored and drilled at the areas that had apparent cracks and damages on the pavements (bad areas). Borings B-3, B-4 and B-6 through B-9 were located at the areas with better pavement conditions. Furthermore, Borings B-5 and B-13 were sampled at the replaced concrete patch areas.

The concrete pavement was cored prior to drilling and sampling. A void was observed at Boring B-11 under the concrete paving but not in the remaining borings. Undisturbed samples were obtained continuously every foot in the borings from the ground surface to the termination depths ranging from 1-to 5-ft.

In general, the subgrade soils consist of soft to very stiff, non- to moderately expansive fill lean clays, or mixture of lean clay and sand fill materials from the surface to the depth of 3- to 4-ft. Silty sand fill soils were observed only in Boring B-17 from the ground surface to the depth of 1-ft, underlain the fat clay fill soils to the depth of 2-ft. Followed the fill soils are soft to very stiff, gray, dark gray or olive gray lean clay soils or firm to very stiff, dark gray, olive green or brown fat clay soils to the completion depth of the soil borings of 5-ft. Clayey sand materials was found only in BoringB-17 from the depth of 4- to 5-ft.

Rebar Locating

Non-destructive tests were engaged in detecting the rebar locations in the concrete paving. The instrument adopted to determine the rebar spacings and depths was Profometer 4 Rebar Locator manufactured by PROCEQ Testing Instrument. The accuracy of the rebar locator was ± 5 mm with the setup used in this study, i.e. #3 or #4 rebars and 5- to 7-in measuring range. Rebars in two different directions (x- and y- directions) were examined.

Eight 10-ft by 10-ft square blocks at different locations were checked for the rebar locations and are shown on Figure 7. In general, 59% of the rebars in the concrete pavement were placed at inappropriate depths and 31% of the rebar spacings did not comply with the specifications, according to our field test results.

Field Slug Tests

Groundwater fluctuation has substantial influence on the subgrade materials. An instantaneous head test (Slug Test) was used to monitor the water level reaction at the project site. The Slug Test method based on ASTM D 4044, involves causing a sudden change in head in a control well (i.e. a borehole in our case) and measuring the water level response within that control well. In the field practice, a known quantity amount of water was withdrawn from a specific borehole and the reaction time for the water level to resume to its original location was measured. This method is known as the "*Water Slug*" procedure. The water level response in a borehole is a function of the mass of water in the well and the transmissivity and coefficient of storage of the perched water.

The purpose of the field slug tests in this section is not to calculate the transmissivity (T) and storage coefficient (S) for the field hydrogeologic conditions, such as the procedures described in ASTM D 4104, since there is no indication of any aquifer system existing at the project area. The purpose of this analysis is to use a quantified method to describe the quick recovery of the depth of the perched water table after an instantaneous change in head, and display the perched water under the pavement tend to accumulate at certain locations.

The field slug tests were carried out at two boreholes, Borings B-1 and B-2 which are located next to each other at Area III. Subgrade fines and water pump-out are observed at the expansion joints in this area. Our tests indicated that after the removal of certain amount of water in Borings B-1 and B-2, the hydraulic heads in these two holes resumed to the original heights shortly. The water inflow rates (back to the boreholes) are between 55.4- to 62.4-cm^3 /second. Furthermore, high perched water tables also observed at Borings B-5, B-7, B-11, B-12 and B-14. Our field slug test results and water level observations indicate that the presence of perched water at portion of the project site.

LABORATORY TESTING

General

The laboratory testing program was directed primarily towards evaluation of the physical properties and engineering characteristics of the subsurface soils. The tests were conducted in general accordance with the ASTM Standards as described in the following sections.

Classification Tests and Strength Tests

As an aid to visual soil classifications, physical properties of the soils were evaluated by ASTM test method D2487 which is used for classification of soils for engineering purposes. 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. In addition, undrained shear strengths of the cohesive soils were further measured with laboratory hand penetrometer and laboratory hand operated Torvane. These test results are summarized in Table 1. Furthermore, the moisture profile and liquidity index profile of the subsoils are presented in Figures 8 and 9 respectively. In accordance with the moisture profile, the moisture contents from the original soil report done in 1997 are generally less than 15% (CB-1 and CB-2), while the soil borings performed recently (B-1M, B-2M and B-4M) and from this study (B-1 through B-17) shows a higher moisture contents (up to 33% in the top 5-ft subgrade). In addition, the liquidity index profile indicates that in general, more than half of the soil borings performed in this study have liquidity index values more than 1.0 which suggest that the subgrade was wetter at the time of our study than it originally was.

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Table 1. Soils Stratigraphy and Related Properties at the Project Site

Stratum No.	Average Depth	Soil Type (or Paving)	PI*	Soil Expansivity	Soil Strength, tsf
	0 – 16”	Concrete Paving & Sand Bedding	-	-	-
I	5½” – 3’	Fill: Lean Clay (CL)	16-23	Non- to Moderately Expansive	0.15 – 1.5
II	6½” – 4’	Fill: Lean Clay/Silty Sand (CL/SM)	13-22	Non-Expansive**	0.15 – 1.5
III	6¾” – 1’	Fill: Silty Sand (SM)	-	Non-Expansive**	-
IV	1’ – 2’	Fill: Fat Clay (CH)	38	Expansive	0.31
V	1’ – 5’	Lean Clay (CL)	17-30	Non- to Moderately Expansive	0.15 – 1.5
VI	2’ – 5’	Fat Clay (CH)	30-34	Expansive	0.46 – 1.5
VII	4’ – 5’	Clayey Sand (SC)	-	Non-Expansive**	-

Note: *PI - Plasticity Index **Moisture Sensitive

Compaction Tests

Two standard proctor tests (ASTM D 698) were performed on the representative bulk samples of the on-site fill soils. The results of these tests were used to evaluate the “percentage of compaction” of the existing on-site fill soils. In addition, the dry density data are presented on the boring logs at the respective sample depths.

Our Proctor test results indicate maximum dry densities of lean clay fill soils (with sands) obtained from the west and south sides of the project site (along the curb) to be 118 and 119.2 pcf, and optimum moisture contents of 12.9% and 12.5% respectively.

Since the on-site fill soils are mostly the mixture of clay and sand materials, and the proportions of different fill soils mixed vary from location to location, the degree of fill soil compaction cannot be evaluated based on one single procedure or soil index correlation. For the lean clay fills with available dry density values (Borings B-1, B-2, and B-14 through B-16), the lean clay fills at Borings B-1 (from 1- to 2-ft), B-2 and B-14 passed the dry density requirements and those at Boring B-1 (from 0.58- to 1-ft), B-15 and B-16 failed.

Concrete Thickness Measurements and Compressive Strength Tests

The measuring of the concrete core thickness is based on the test method ASTM C174/C174M-97. Nine (9) measurements of the length on each concrete specimen are taken. One at the central position and one each at eight additional positions spaced at equal intervals along the circumference of the circle of measurement. The average of the nine measurements is reported as the thickness of the concrete core. Our concrete coring information indicates the concrete pavement thickness ranges from 4.75- to 8-inches.

The concrete pavement was cored at seventeen locations (Borings B-1 to B-17). The concrete core samples were tested in accordance with ASTM C42 to estimate the compressive strength of the concrete paving and to locate the reinforcements, if exists. The results of compressive strength tests for the three concrete samples taken from 5-inch pavement area (Borings B-10 through B-15) ranged from 3,445 psi to 3,763 psi, and for the six concrete cores obtained on the 7-inch pavement area ranged from 3,107 psi to 4,338 psi. In addition, the concrete sample obtained on the southern driveway (Boring B-16) was tested with a compressive strength of 3,163 psi. In general, all ten concrete samples fulfilled the specification's 3,000 psi minimum compressive strength requirement.

Concrete Petrographic Analysis

The purposes of the examination of concrete is to provide information that can be used to evaluate the condition of the concrete and to corroborate observed satisfactory performance, or to document and explain distress or failure. Petrographic analysis is used to evaluate: (1) detailed condition of concrete in construction, such as water-cement ratio (W/C), amount of unhydrated cement particles (UCP) and Portland cement content, (2) the cause of inferior quality, distress, or deterioration of concrete in a construction, and (3) the probable future performance of the concrete. Petrographic analysis was carried out according to ASTM C 856 method.

The concrete petrographic study was performed on the two concrete cores obtained at the locations of Borings B-4 and B-12 (shown as Cores B-4 and B-12 in the following text). Core B-4 was taken from Area IV and Core B-12 was from Area VII.

The petrographic examination of Core B-4 shows that the amounts of the microcracks and entrapped air voids were limited and were not the causes of any major concern. In addition, the water-cement ratio (W/C) and Portland cement content were estimated to be in the range of 0.55 to 0.60, and 450 ± 25 lb/yd^3 respectively for Core B-4. In general, Core B-4 appeared to be of satisfactory quality and in a serviceable state.

The petrographic analysis of Core B-12 indicates only a few vertical microcracks observed, however, excessive amount of voids were present in the upper part of the core (see Figure 10) due to improper mixture of water and concrete, or delayed placement of concrete mixture. Furthermore, unhydrated cement particles and marginally hydrated cement grains were found in Core B-12 which showed incomplete hydration of the concrete. Core B-12 showed the concrete at its adjacent area may not be in a fully serviceable condition.

TRAFFIC STUDY

The types of vehicles and frequency of traffic loading on the subject pavement are significant to the structural design and life expectancy of the concrete paving. Appropriate usages of the concrete pavement can prolong its service span and reduce the expense for maintenance and regular replacement.

The traffic study was designed to evaluate the vehicle loading applied on the pavement at the project site. The study was specifically set up to monitor the 18-wheelers (or other heavy equipments) traveling on the pavement areas designed for light-weight passenger vehicles (Areas I, VII & VIII), such as the photos shown in Figures 11 and 12.

Our traffic study has two different stages. The first stage is observing the traveling routes of the 18-wheelers in the Texaco Food Mart site. In general, the five-inch concrete areas (i.e. Areas VII & VIII) are set up for light-weight passenger vehicles. However, 18-wheelers were often observed traveling and parking at these areas. Our two-day Phase I traffic study indicates that more than 40% of 18-wheelers took the routes through the five-inch concrete areas, and resulted in premature failure of the five-inch concrete pavements.

The second stage is monitoring all the traffics through the project site, classifying vehicles by types and weights, and calculating the life expectancy of the pavement based on the traffic loads coming from the 18-wheelers. With the observed traffic pattern, concrete properties and subgrade conditions, the procedures for concrete pavement design in Appendix A of ACI Code 330R-92 (Ref. 2) were used to evaluate the 18-wheelers repetitions of the 100% fatigue consumption towards three different thickness pavements, i.e. 5-, 6- and 7- inch pavings. The analyses indicate that the 5-inch pavements at the project site would have lasted for approximately two months before the 100% pavement fatigue consumption has reached, and the 6-inch pavements would have lasted for less than four and half years, under present daily truck traffic. As to the 7-inch pavement, a service life span more than twenty years was found with current traffic conditions. Study results from the second stage are summarized on Figure 13.

REASONS FOR PAVEMENT DISTRESS

General

The pavement movements observed at the project site can generally occur as a result of one, or a combination of, structure misuse, inadequate design, poor construction, poor materials, inadequate pavement maintenance program, and wear and tear. These items are described in the following report sections.

Structure Misuse (Overloading)

Wrongful use of the pavement structure, such as excessive weight on concrete with insufficient thickness, can cause paving distress problems and result in early termination of the pavement usage.

- o During various site visits, 18-wheelers were observed running through the areas designed for light-weighted passenger vehicles and RVs (*Areas VII and VIII*). Heavy trucks traveling on thin pavements usually lead to extensive cracking and significant shorten the service span of the concrete paving.

- o According to the traffic studies, the existing pavement thickness of 5- and 6-inches at *Areas I, II, VII and VIII* is not appropriate for the current traffic load. This results in a shorter pavement life expectancy. Instead of the 20-year life span described in the contractor's warrantee, the 5- and 6-inch pavement structures would have lasted for only 56 days and 4.3 years respectively, after the service station started to operate.

<u>Inadequate Design</u>

Pavement distress can occur if the pavement or the structure is poorly designed. For example, if an inadequate geotechnical exploration was done to come up with the faulty pavement design parameters, the paving was designed using underestimated traffic loads, the recommendation procedures were not followed or inappropriate pavement design procedures were followed, etc. The observation with respect to pavement design is as follows:

- o The original geotechnical report was conducted on January 14, 1998. Our field exploration and laboratory testing indicate the presence of silty sands and sand pockets ranging from 0- to 4-ft in the fill soils. The original geotechnical report has recommended that the soils under the pavement could be 6-inches of lime-stabilized subgrade, or 12-inches of low plasticity clay fills. The clay fills should have a plasticity index between 8 and 20, and compact to at least 95 percent of the maximum dry density determined by ASTM D-698. However, the fill soil type and requirement were not clearly defined in the architecture drawings. In the architect drawings, two different versions of fill soils were provided (a conflict).
  The subcontractor used silty sands, or the mixture of sand and clay materials as fills. Although these fill soils were free of objectionable foreign objects and fulfilled the maximum particle size, liquid limit and plastic limit requirements provided in the drawings, this surficial silty sand/silty clay/sandy clay fill soils may act as a pathway for water to travel under a pavement system. This condition resulted in an increase in subsoil moisture contents and decreasing dry density and subsequent settlement and softening of the underlying soils.

- o The other contradictions of the pavement design in the construction drawings include: (1) the required concrete compressive strength, (2) the maximum distance (spacing) between the expansion joints, (3) the spacings between rebars and (4) application of leveling sands under the concrete paving.

- According to ACI Code 330R-92 (Ref. 3), the internal expansion joints should be omitted in the main body of the concrete pavements, in order to avoid premature pavement failures. The architect recommended placing expansion joints at a maximum spacing of 40-ft in between. This recommendation resulted in the large amount of expansion joints adopted at the project site and increased the chances of premature concrete pavement failures.

Construction

Improper construction practices can result in pavement distress. The opinions with regard to construction are as follows:

- According to the field exploration, the on-site rebars were placed at a depth deeper than the specification requirements of one-third of the pavement thickness plus 0.5-inches. There are 59% of the total measured rebar depths falling at the bottom one-half of the concrete pavement thickness. Furthermore, there are 31% of the measured rebar spacings did not comply with the specifications. The surface cracks of concrete paving can be effectively controlled if the rebars are installed at adequate locations. However, the use of distributed rebars will not add to the load-carrying capacity of the pavement, nor compensate for poor subgrade preparation. Because many areas of the project site sustain higher than designed loads and have problematic fill materials which are more significant to the pavement distress, inappropriate rebar location is not the major cause of the concrete cracking at the project site.

- The joint spacings measured at the project site are found to be larger than the specification requirements. The specifications called for 20-and 40-ft maximum spacings for the control joints and expansion joints respectively. Since expansion joints often contribute to premature pavement failures, the application of the expansion joints at the project site should be avoided. The contractor used large expansion joint spacings actually reduced the possibility of pavement premature failures. However, the control (contraction) joints are required to be installed at the parking lot concrete pavements because these joints are designed to control the cracking caused by shrinkage of the concrete and by the effects of loads and warping. The control joint spacings at the project site therefore may not be optimum.

- The measurement of the concrete pavement thickness indicates that six cores (Borings B-2, B-3, B-4, B-7, B-9 and B-17) were marginally short with one core (Boring B-2) within the tolerances for concrete construction, a passing rate of 71%. Insufficient concrete thickness can result in pavement distress. In addition, undersized rebars were found in the cores taken from Borings B-2, B-8 and B-16. The use of distributed rebars are to control the opening of intermediate cracks and these steel reinforcements will not add to the load-carrying capacity of the pavement, nor compensate for poor subgrade preparation. Since many areas of the project site sustain higher than designed loads and have problematic fill materials which are more significant to the pavement distress, using undersize rebars is not the major cause of the concrete cracking at the project site.

Materials

Using the wrong or inappropriate materials in construction can result in poor pavement performance.

- The examination of Borings B-1 through B-16 indicates that lean clay soils and different amount of silty sands were mixed and used as fill materials on the site. The fill soils in these borings exhibit plasticity indices ranging from 13 to 23. Furthermore, silty sands and fat clays with a plasticity index of 38 were found at Boring B-17. The structural fills under the pavement should have had a PI between 12 and 20. Although only four borings have PI values higher than 20 (Borings B-2, B-5, B-11and B-17), sands and expansive soils should not be used as fill soils. Lime stabilization was an option in the original soil report for the top (6-inch) soils when constructing the parking pavements. Lime stabilization is not necessary to be performed when proper fill soils are placed under the paving (12-inch fills recommended in the original soil report).

- One of the concrete cores obtained at the bad concrete area of the project site (Core No. B12) was examined using the petrographic analysis. The analysis results indicate that this concrete core contains an exceptionally high amount of voids which can result from either that the concrete mixture was not mixed properly before it was placed or an attempt was made to place the concrete that had already began to harden. The testing results of this concrete core show that some of the pavement concrete may not be in a fully serviceable condition. Furthermore, its strength is likely to be affected.

Maintenance

Drainage away from the pavement can play an important role in how the paving system performs. Negative drainage under the pavement or ponding of the surface water can result in excessive moisture of the underlying compacted soils, causing loss of subgrade support and pavement distress. Poor drainage at some locations around the parking lot and driveways were observed during the site visits. These locations include *Areas II, III, IV, VI, VII and VIII*. High perch water table was observed at the soil borings drilled at these areas. Furthermore, planter areas with sprinkler systems were observed around the food mart building. Water seeped through the planter areas and went into the subsoils under the pavement. The subsoils once wet lose load carrying capacity and result in loss of support for the above concrete paving.

REPAIR TECHNIQUES

In general, pavement experiencing the above problems should be repaired by improving the drainage system, increase the pavement thickness, resealing joints, sealing cracks, repairing spalled joints, and correcting faulted joints. These items are presented below:

- Repair all of the cracks in the concrete pavement, using Flexible Glue. All of the cracks should first be cleaned of debris prior to Glue injections.

- Old, deteriorated sealant in the top of the joint needs to be resealed using liquid field-molded sealants as specified for new construction, such as AASHTO M173 and ASTM D 1190 that include hot-applied thermoplastic asphalt-rubber compounds (Ref. 3). Deteriorated sealants should be repaired immediately to prevent more surface water seeping into the subgrade soils.

- In the areas where significant cracking is occurring, these areas should be removed, using saw-cutting techniques and replaced with new pavement. The subgrade soils in the new pavement area should be lime stabilized to a depth of six-inches with 5% lime by dry weight. Texas Department of Transportation (TxDOT) Specifications, Items 260 and 264, can be used as a procedural guide for placing, mixing, and compacting the stabilizer and the soils. Alternatively, the top six-inches of subgrade soils can be replaced with six-inches of crushed limestone. The limestone base should be compacted to 100% modified proctor density, according to ASTM 1557, with moisture contents within ± 2% of optimum moisture contents. All of the sands should be removed in the area that pavement saw cutting takes place.

- To fix a severe spalling joint, a vertical saw-cut needs to be made 1- to 2-inches deep parallel to and at a sufficient distance from the joint to include all spalled and fractured areas. A bonding grout then should be broomed into the exposed surface to a depth of 1/16- to 1/8-inch. A patch mixture consisting of 1 part Portland cement, 2.5 parts sands, and 2.5 parts 3/8-inch-maximum-size coarse aggregate with an air-entraining agent is suggested (Ref. 3). The joint should be sealed before the patch is reopened to the traffic.

- If the spacings between two concrete joints are larger than the specification requirement, saw-cutting more control joints between these two existing joints will reduce the paving movements and cracking.

- Provide subsurface drainage system at areas where high perched water table exists. Details for the rehabilitation of the subsurface drainage can be found at the AASHTO *Guide for Design of Pavement Structures*, Volume 2, Appendix AA.

- Use structural fills for site grading. All of the fill soils should be compacted to a minimum of 95 percent of maximum dry density (ASTM D 698). This will minimize settlements and surface water ponding near the foundation. The structural fill may consist of lean clays with liquid limit less than 40 and plasticity index between 12 and 20. Do not use sands for site grading.

- Construct a designate truck route with 8-inch thick concrete for 18-wheelers to replace the existing truck route, and impede the heavy trucks from entering the thin pavement areas by using barriers or directional signs. For the new constructed truck route, the subgrade soils should be lime-stabilized, or replaced with crushed limestone as discussed above. Concrete flexural strength should be at least 500 psi at seven days and 3,000 psi at 28 days. This paving should be reinforced with No. 4 rebars at 18-inches on-center each way. Suggested longitudinal and transverse joints spacings should be about 20-ft for control joints.

- It should be noted that despite the preliminary recommendations presented here, some pavement cracking may continuously occur. These recommendations will minimize pavement cracks, but will not totally eliminate them. Periodic visual observations of the pavement and structural performance should be made. From these observations, any distress would be noted and a decision made as to the proper remedial measures. It is recommended that the slab elevations be checked every four months for a period of 12 months.

CONCLUSIONS

Based on the review of the expert reports presented and field and laboratory evaluations, the pavement distress occurred as results of combination of the following:

- Wrongful use of the pavement structures (Pavement structure misuse).
- Ambiguous definition of the soil types and properties to be used as structural fills under the pavement provided in the architect drawings, specifically, sands should not be used as fills. (Geotechnical design problem).
- Ineffective drainage system causing surface water ponding under the pavement (Drainage design problem).
- Contradictory pavement design information provided in the architecture drawings (Design problem).
- Application of excessive amount of expansion joints (Design problems).
- Inadequate rebar placements including depths and spacings in the concrete pavement (Construction problem).
- Improper control joint spacing in the paving (Construction problem).
- Insufficient concrete pavement thickness construction (Construction problem).
- Undersize rebars installed in the concrete pavement (Construction problem).
- Use of sand and expansive soil fill materials under the pavement (Materials problem).
- Some of the pavement concrete materials having high amount of voids and not in a fully serviceable condition (Materials problem).
- Missing joint seal/insert and joint spalling (Wear and Tear problem).

GET

REFERENCES

1. Troubleshooting Concrete Problems- and how to prevent them in the future", American Concrete Institute, SCM 17 (87), Committee Report No. 201.3R-86, Detroit, Michigan, 1987.

2. "Guide for Design and Construction of Concrete Parking Lots", American Concrete Institute, ACI Code 330R-92 (Reapproved 1997), Farmington Hills, Michigan, 3rd Printing, Jan. 2000.

3. "Maintenance of Joints and Cracks in Concrete Pavement", Portland Cement Association, Skokie, Illinois, 1976

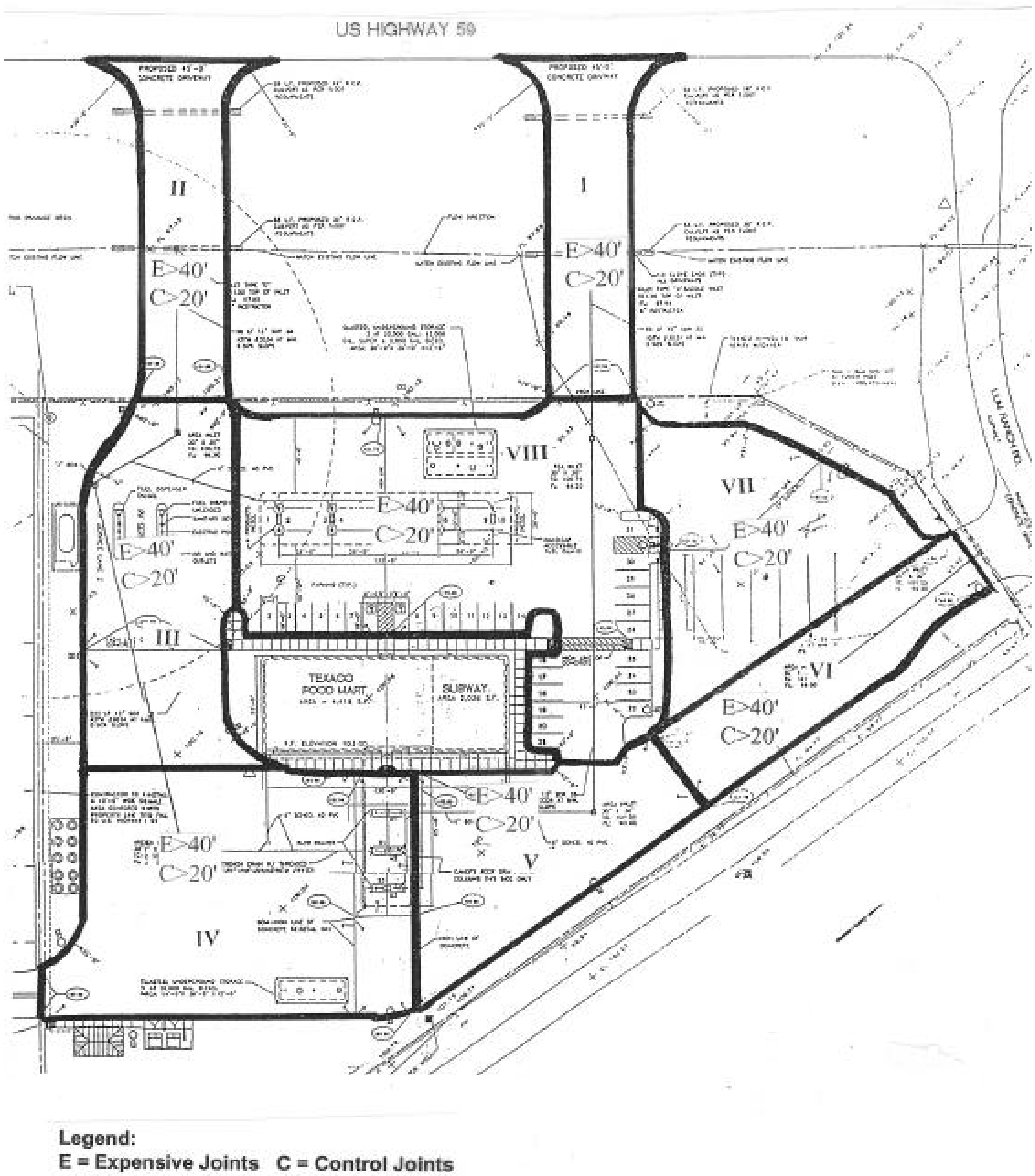


Figure 1. Project Site Plan and Concrete Joint Survey Plan

Figure 2. A View of the Steel Poles Located to the East of the Food Mart (Between Areas V and VIII); These Poles Preventing 18-wheelers from Crossing to the Passenger Vehicle Parking Lot

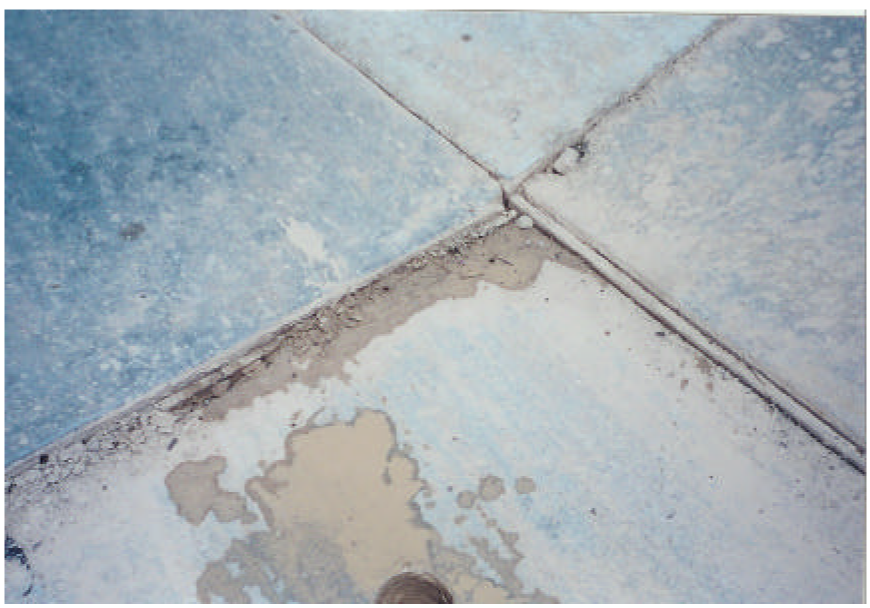


Figure 3. A View of the Expansion Joint with Missing Sealant and Deteriorated Wooden Insert Located to the Southeast of the RV Service Island (Subgrade fines mixing with water were pumped out when heavy trucks passed by.)

Figure 4. A View of the Faulting (Stepping) Joint Crack Located to the East of the Northern Driveway

Figure 5. A Close-up of the Concrete Patch Located to the South of the Food Mart (The concrete is cracking and spalling, and aggregates are falling apart.)

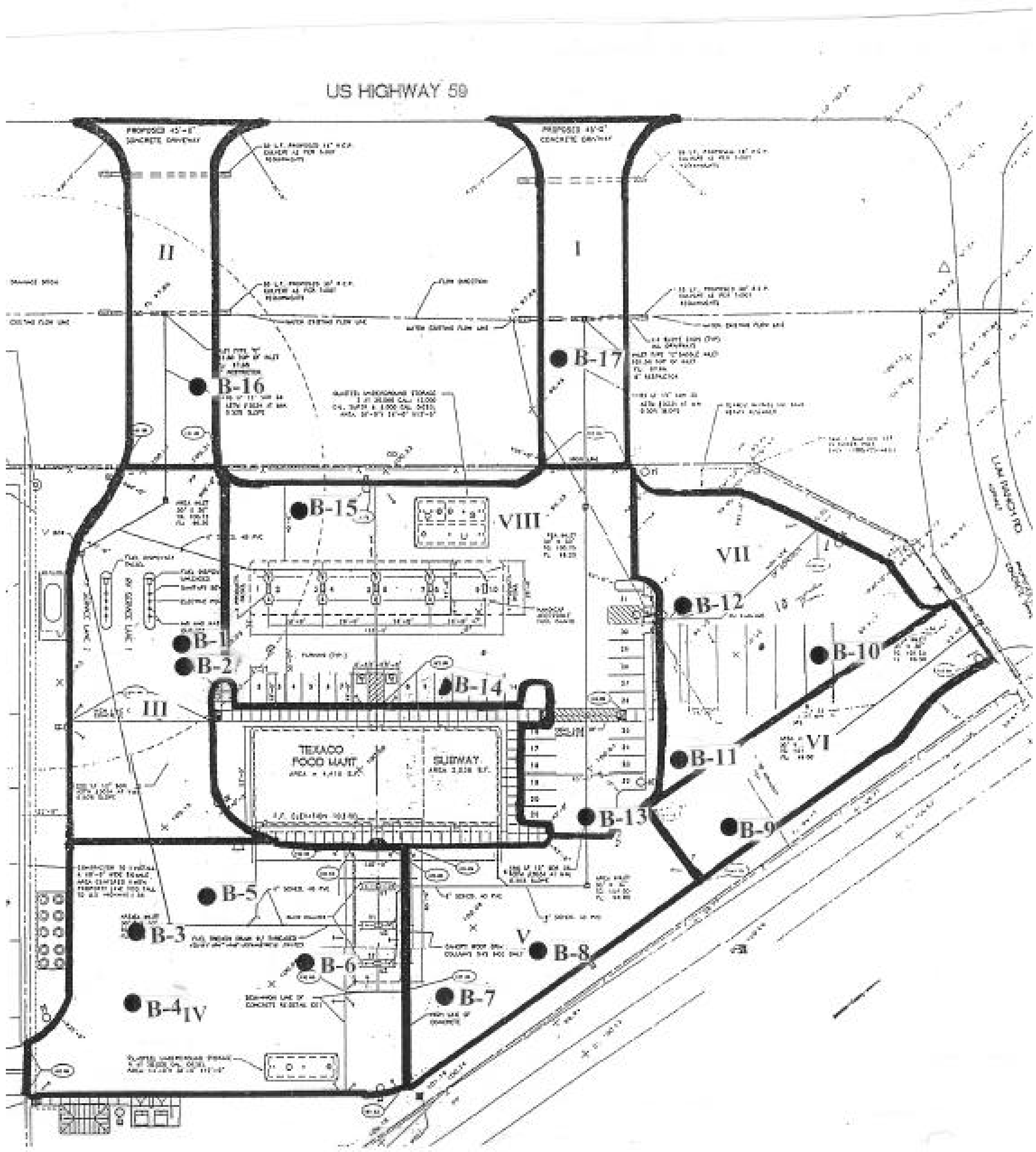


Figure 6. Plan of Borings (Boring locations and dimensions are approximate.)

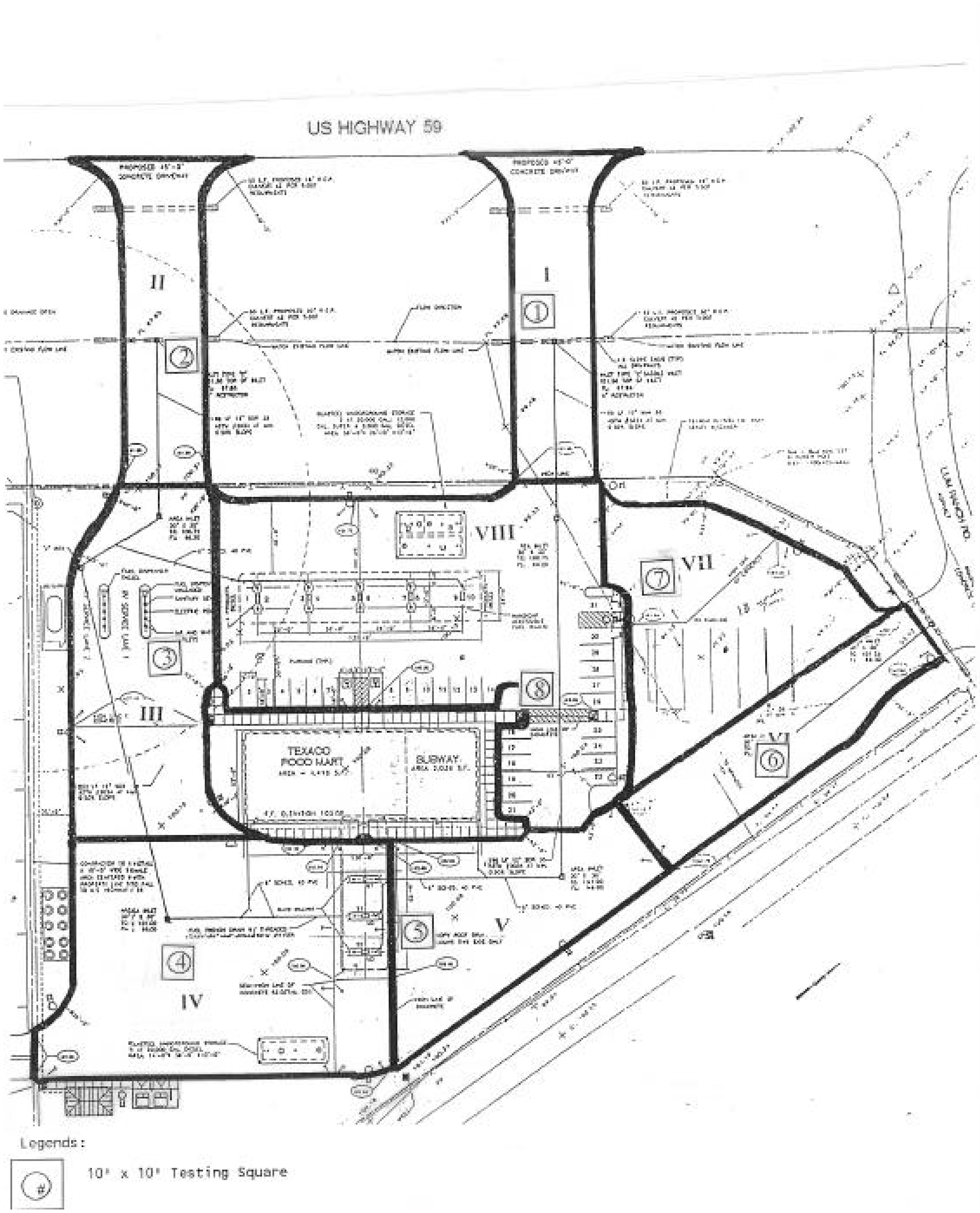
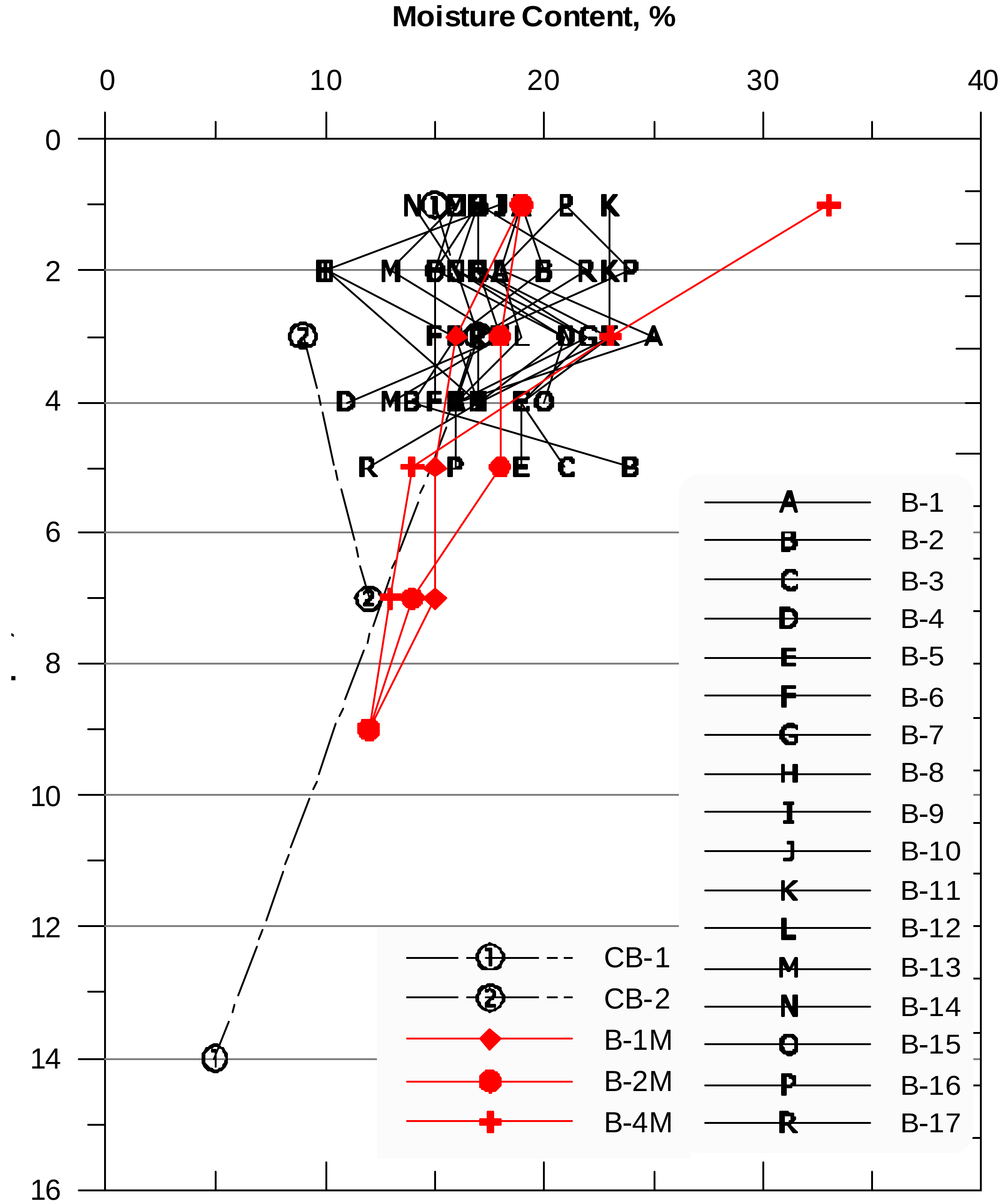


Figure 7. Non-Destructive Tests for Rebar Locations (Testing locations and dimensions are approximate.)



* Note: Borings CB-1 and CB-2, B-1M, B-2M and B-4M are soil borings drilled by two other companies previously.

Figure 8. The Variation of Soil Moisture Contents versus Depth

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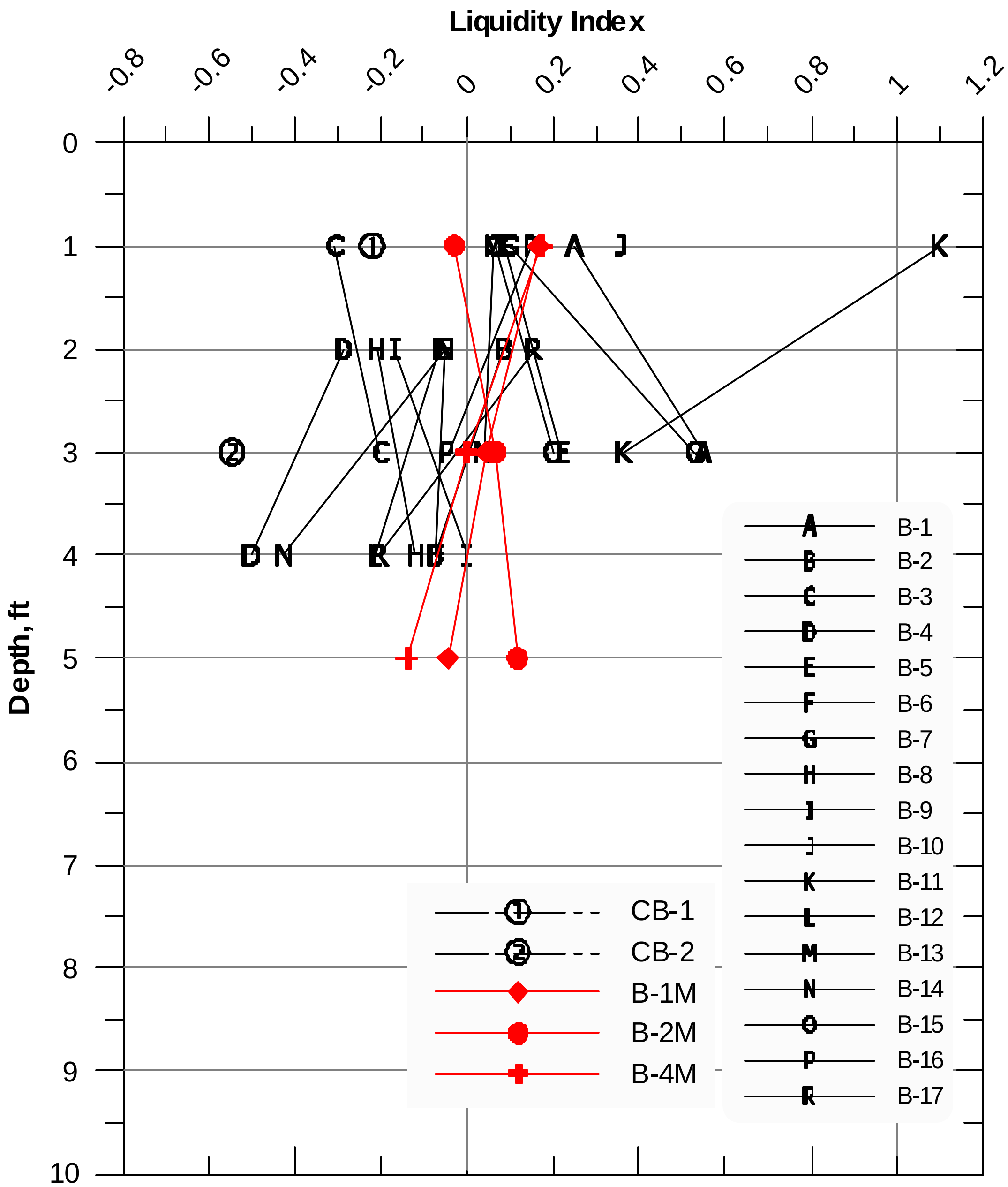

* Note: Borings CB-1 and CB-2, B-1M, B-2M and B-4M are soil borings drilled by two other companies previously.

Figure 9. The Variation of Liquidity Indices versus Depth

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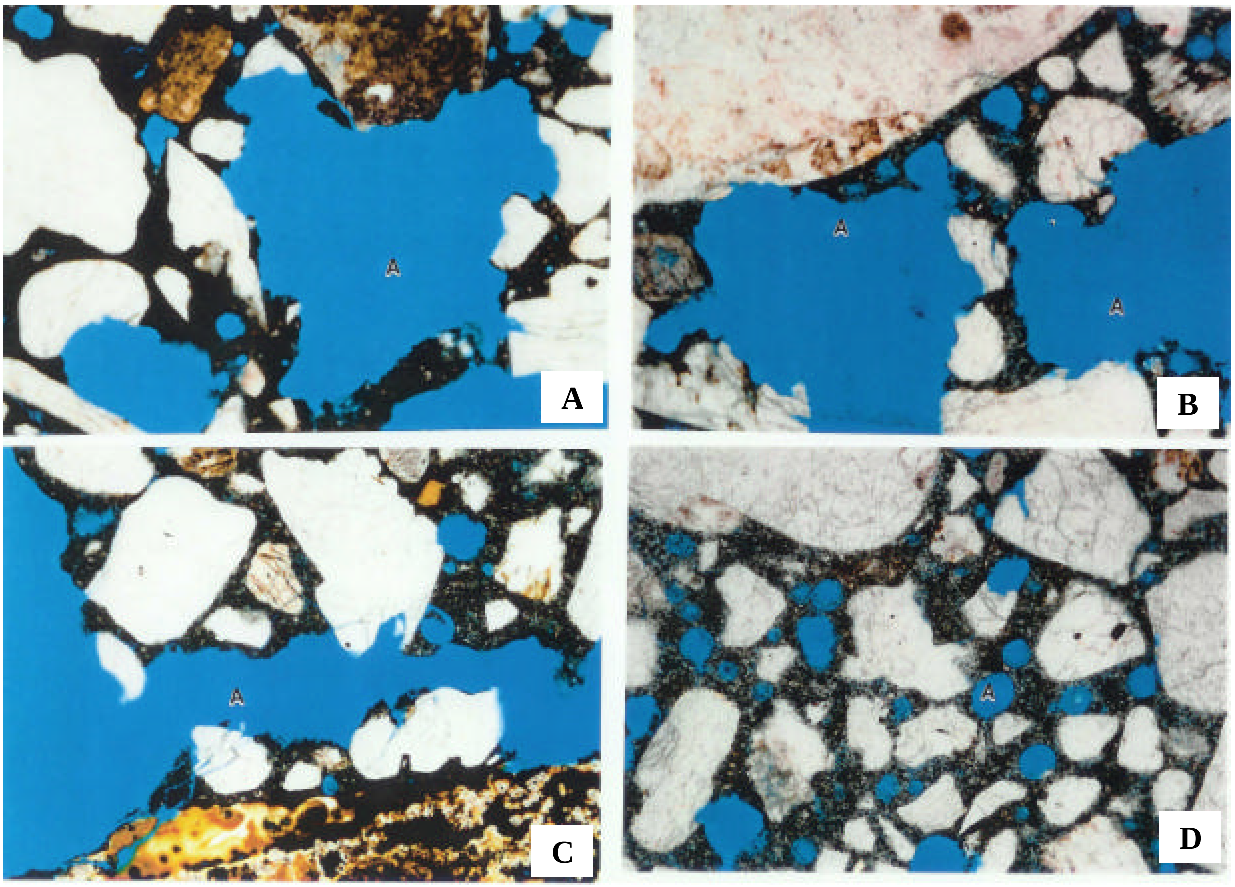

Figure 10. Small to Coarse Air Voids (Blue Areas) Observed in the Concrete Core Obtained at Boring B-12 Location

Figure 11. A View of an 18-wheeler Unloading Merchandise at the Front Entrance of the Food Mart (Area VIII)

Figure 12. A View of an 18-wheeler Travelling Through the Passenger Vehicle Area (Area VIII)

18-wheeler Traffic Pattern (Based on the results of the traffic watch):

Average Daily Amount of 18-wheelers Entering the Texaco Food Mart site:	180	trucks
Average Daily Amount of 18-wheelers Entering the 5-inch Concrete Areas:	71	trucks

18-wheeler Axle Weight:

Front Wheel Axle:	12	Kips
1st Tandem Axle:	32	Kips
2nd Tandem Axle:	32	Kips

Concrete Properties:

Required Compressive Strength:	3,000	psi
Calculated Flexural Strength:	478.4	psi

Subgrade Informations:

California Bearing Ratio (CBR):	3	
Modulus of Subgrade Reaction (k):	100	pci

Life Expectancy Calculation Summary:

Pavement Thickness (inches)	Allowable Load Repetitions		Total Repetitions to Reach 100% Fatigue Consumption	Pavement Life Expectancy
	Single Axle	Tandem Axle		
5	60,000	8,500	3,969	56 days*
6	4,000,000	600,000	280,000	4.3 years
7	10,000,000	10,000,000	3,333,333	more than 20 years

* Based on seventy-one 18-wheelers per day

Figure 13. Summary of the Stage II Traffic Study