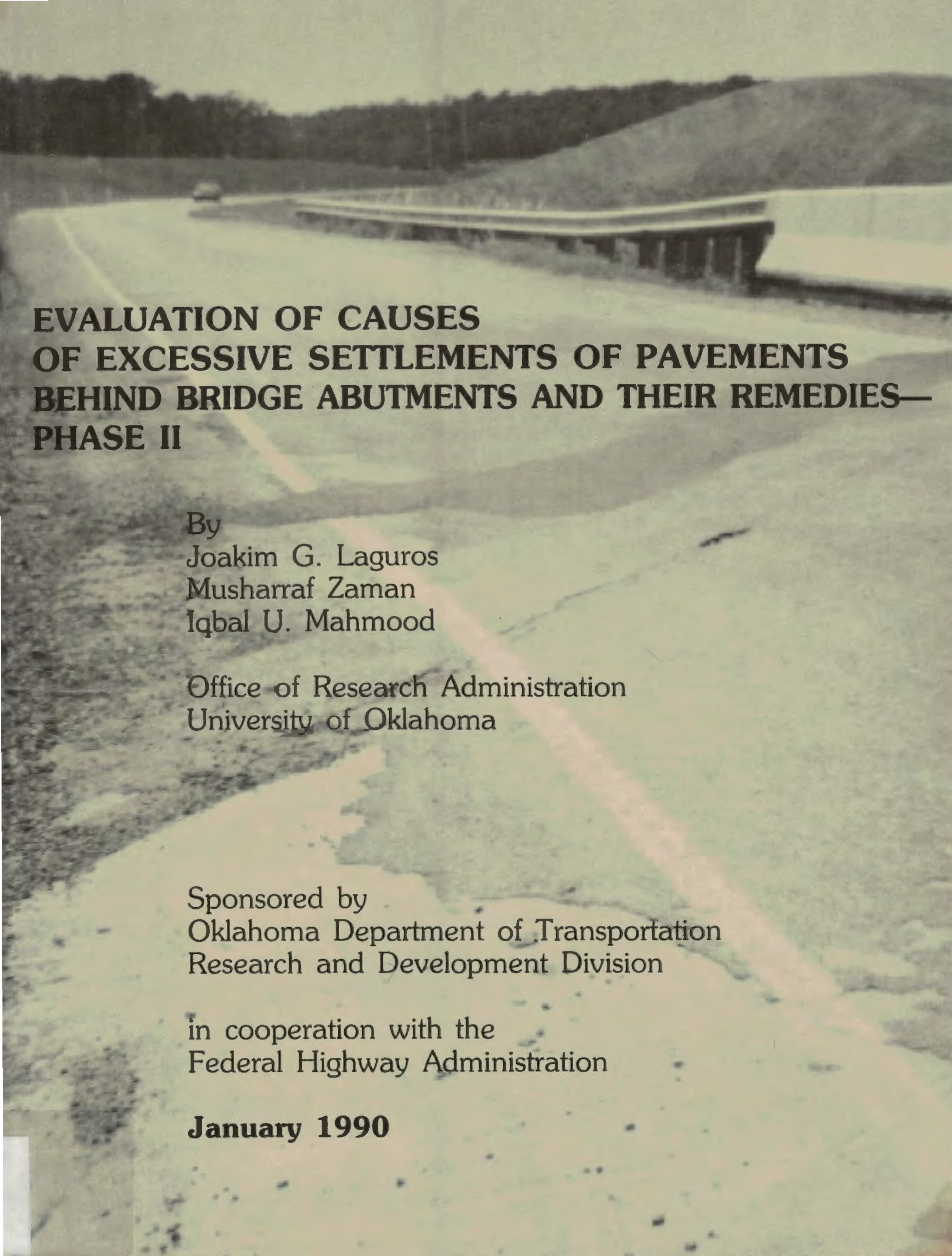

EVALUATION OF CAUSES OF EXCESSIVE SETTLEMENTS OF PAVEMENTS BEHIND BRIDGE ABUTMENTS AND THEIR REMEDIES— PHASE II

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16. ABSTRACT

To evaluate the causes of bridge approach settlement a survey of 758 bridge approaches in seventy-seven counties of Oklahoma was conducted. In this survey, data related to the following items were collected: (i) bridge, abutment, approach, and slope protection structure, (ii) embankment material. Information related to the construction and maintenance for these approaches was collected by interviewing ODOT personnel and searching records maintained at ODOT. The analyses of data show that the settlement problem is extensive in Oklahoma, namely, 83% of the approaches surveyed experienced settlement. It was observed that on the basis of long term performance rigid and flexible approaches are similar, but on a short term basis, rigid approaches experience lower differential settlement. Pile supported abutments as compared to stub type and high embankments with no drainage for the fills appear to be conducive to larger settlements. In general, skewed approaches have a higher settlement than nonskewed approaches. Regression techniques were used to develop an empirical relationship between the approach settlement and the causative parameters such as age of the approach, embankment height, traffic volume, and skewness of the approach. As a preliminary work for the next phase of the study, soil samples were collected from two sites. Comprehensive laboratory testing was conducted with the purpose of determining their site-specific embankment and foundation soil characteristics which may be used in a settlement prediction model.

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SUMMARY

Bridge approach settlement is a wide-spread problem in the U.S.A. While it has been investigated since the early 1960's, no satisfactory solution has been found. With the objective of finding the causes and the remedies to this problem, a comprehensive study, funded by the Oklahoma Department of Transportation (ODOT), was undertaken by the University of Oklahoma.

The study encompasses five phases. In Phase I, a comprehensive literature search and a survey of personnel involved in construction and maintenance of highways were conducted. In Phase II, a total of 758 bridge approaches in seventy-seven counties of Oklahoma were surveyed. These sites were selected in a way that they covered a wide range of parameters/factors that were considered as contributing to the referenced settlement problems. In this survey, data related to (i) bridge, abutment and approach geometry, (ii) existing conditions of the approach, abutment headwall, slope protection structure, drainage, and embankment slope, and (iii) embankment material, were collected. Information regarding the construction and maintenance of these approaches were collected by interviewing ODOT personnel and searching records maintained at ODOT.

A database was developed for storing and sorting the information. Both exploratory and statistical analyses were performed on these data. The analyses show that the settlement problem is extensive in Oklahoma. 83% of the approaches surveyed experienced settlement. It was observed that on the basis of long term performance, rigid and flexible approaches behave similarly but on a short term basis, rigid approaches experience lower differential settlement. Pile supported abutments are associated with higher approach settlement than the stub type. High embankments and the absence of drainage in the fills

appear to be conducive to larger settlements. In general, skewed approaches have a higher settlement than nonskewed approaches.

Regression analyses of the database were conducted to develop an empirical relationship between the approach settlement and the causative parameters such as age of the approach, embankment height, traffic volume, foundation soil type and thickness, and skewness of the approach.

In Phase II, and only as a preliminary work for Phase III, soil samples were collected from two selected sites. Comprehensive laboratory testing was conducted with the purpose of determining their site-specific embankment and foundation soil characteristics which may be used in a settlement prediction model. Detailed boring and testing of soil samples for many other sites are being pursued in Phase III of the project.

The details of the survey, data analyses, regression models, as well as comprehensive study of the two selected sites are presented in this report. At the end, a discussion of the findings and recommendations for further research are made.

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CHAPTER I

INTRODUCTION

1.1 Background

Differential settlement between the approach pavement and the bridge deck (Fig. 1-1) has been a nationally recognized problem for a long time. A large number of abutments and approach embankments founded on oxbow lakes in Oklahoma have made this settlement problem particularly critical. Differential approach settlements or, as some engineers call it a "bump" at the end of the bridge, have manifold influence on the function and maintenance of the roads and highways. Differential settlement leads to an unsafe and uncomfortable riding surface and creates excessive impact loads on the bridge structures. The usual remedy is periodic maintenance involving patching (concrete or bituminous concrete approaches) or mudjacking (concrete approaches) the approach pavement which is costly and inconvenient. Where a heavy traffic flow exists, the maintenance operation may tend to impede the normal flow of traffic. Mudjacking provides temporary relief and it often aggravates the problem due to cracking of the approach slab.

Cognizant of the extensiveness of this problem in Oklahoma, the Department of Transportation (ODOT) commissioned the University of Oklahoma (OU) to undertake a systematic study of this problem with the main objectives being:

1. To identify various causes which contribute to such settlements and assess their relative contribution;
2. To develop guidelines for the design, material selection, construction and maintenance of approach pavement and embankment to substantially reduce this settlement.

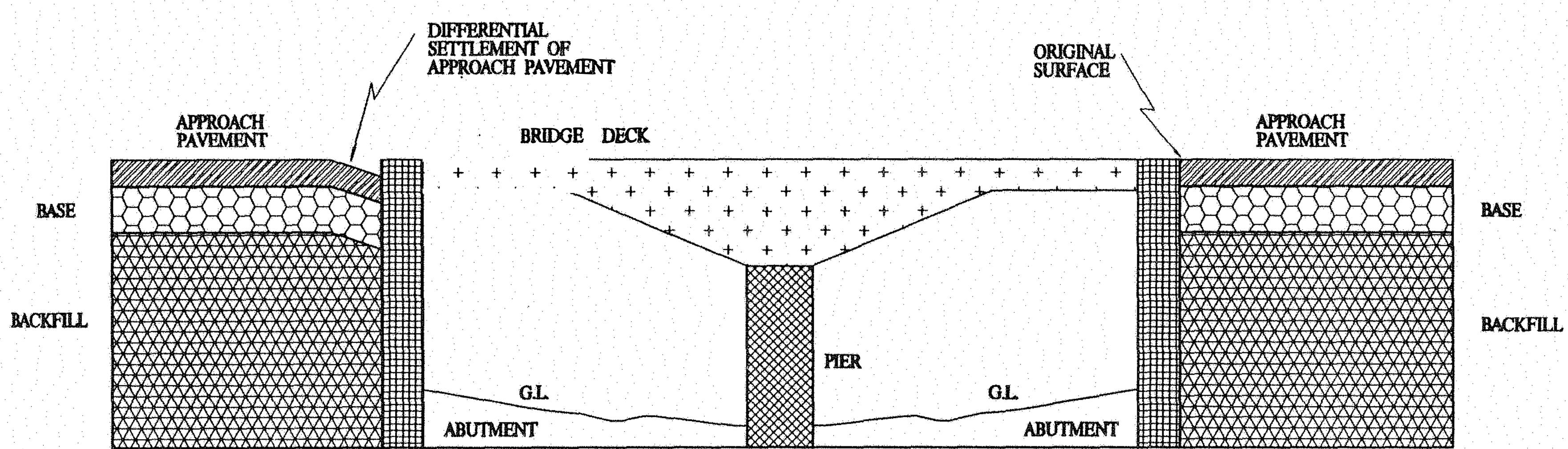

Fig. 1-1 Schematic of excessive differential settlement of approach pavement

To accomplish its intended goals, the study was proposed to be conducted in five different phases as depicted schematically in Fig. 1-2.

1.2 Overview of Phase I

The research work for Phase I, which started in May 1985 and was completed in February 1986, consisted of three major tasks: (a) comprehensive search of available literature, (b) survey of various state, federal and private agencies involved in construction and/or maintenance of pavements and bridges, and (c) analysis of survey responses. The computer search facilities of the Highway Research Information Service (HRIS) as well as the search facilities at the University of Oklahoma (namely, DIALOG, ORBIT and BRS) were used to accomplish the intended goals of Task (a). All of these systems have broad databases which are updated at two weeks to two months intervals. In addition to computer search, manual searches were conducted to locate pertinent literature.

Based on the knowledge gained through the literature review, a survey questionnaire was designed in coordination with ODOT, and sent to 52 state DOTs and 36 Corps of Engineers Districts as well as to some other agencies and professionals. Of the 61 responding agencies, 42 considered the problem to be significant or very significant in their states. The Idaho and Maryland DOTs considered the bridge approach settlements as a severe problem. Of the 42 responding organizations who considered the approach settlements a significant or very significant problem, only 6 (California, Iowa, Kentucky, Louisiana, Ohio and Texas) have undertaken some research work to investigate this problem. Recently, several other states (Colorado, North Carolina and Washington) have been involved in investigations pertaining to some specific aspects of approach settlements.

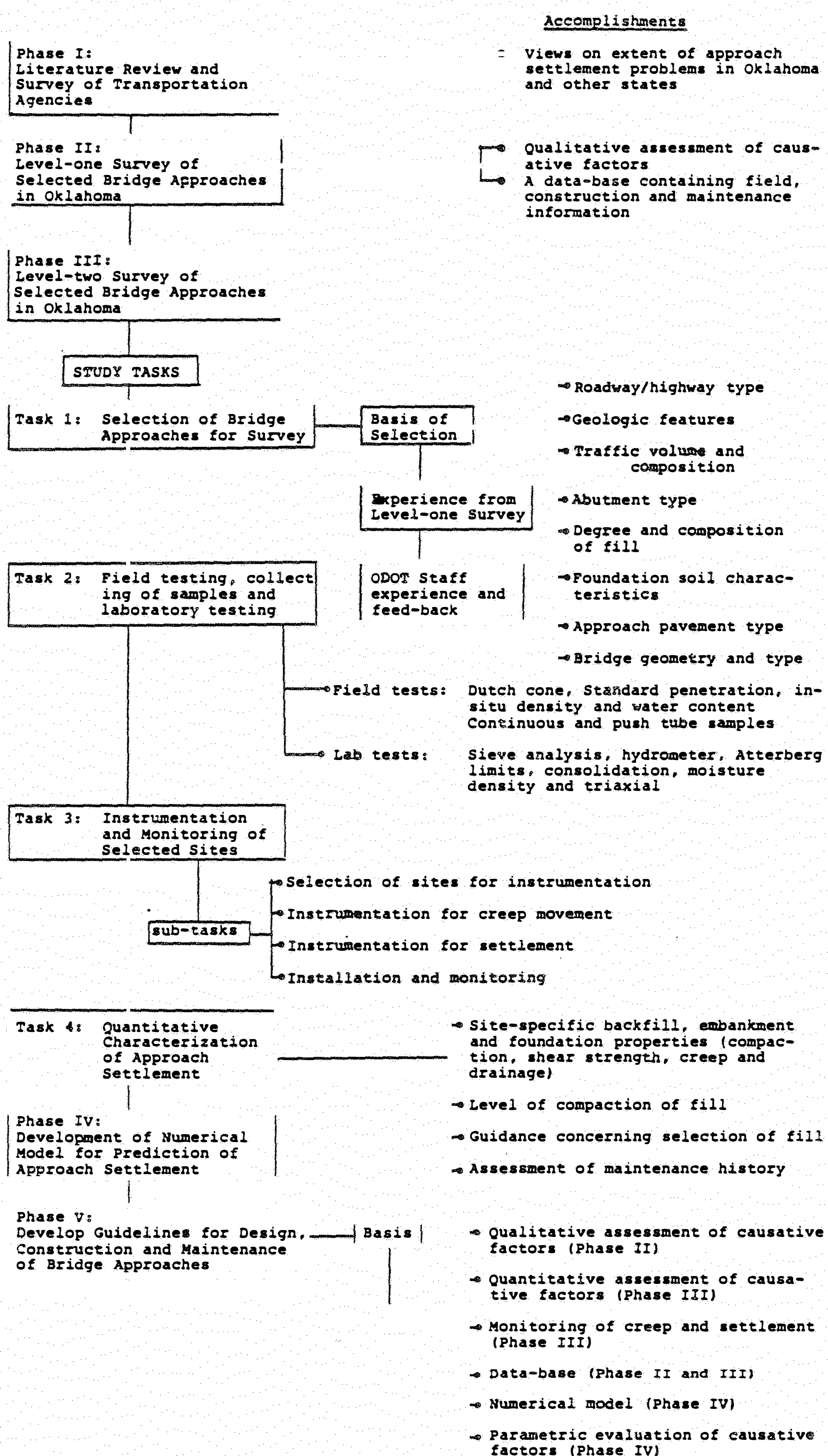

Fig. 1-2 Flow chart of the study tasks for five different phases

The Phase I survey indicated that the bridge approach settlement problems are quite extensive in Oklahoma. It was realized that finding feasible remedies of these problems will require a structured solution approach of which an indepth understanding of the settlement process and its causative factors constitute an important step. Toward this end, it was proposed to conduct a two-level survey of selected bridge approaches in the State. The first part of the two-level survey (referred to here as the level-one survey), which was conducted as a part of Phase II involved collection of information from visual observations and some measurements in the field. This report is concerned with the findings of the level-one survey. The following section describes the specific objectives and scopes of Phase II.

1.3 Objectives and Scopes

In Phase II it was proposed to conduct a level-one survey of selected bridge approaches to obtain information pertinent to the following general questions:

1. What is the extent of approach pavement settlement problems in Oklahoma?
2. Could these problems be characterized in qualitative and quantitative terms?
3. What type of data, pertinent to the referenced settlement problems, are currently available at ODOT?
4. What additional data might be required to develop specific remedial measures for the referenced settlement problems?

The main purpose of the level-one survey was to obtain first-hand information on the referenced settlement problem in the state by visual inspection of some selected Oklahoma bridge approaches and by obtaining detailed information pertaining to their design, construction and maintenance. It was envisioned that appropriate analysis of the collected data would provide information concerning (a) the extent of the referenced settlement problem in the state, (b) the possible site specific causes for such settlements, and (c) the relative significance of various causative factors.

The following tasks were identified to achieve the objectives of Phase II:

1. Selection of bridge approaches for survey
2. Survey of those selected bridge sites
3. Characterization of approach pavement settlements in the state
4. Preparation of a report including findings of Phase II and a detailed proposal for Phase III.

With ODOT's approval the original (Phase II) proposal was modified to include complete sampling at two selected sites in order to develop a somewhat detailed understanding of the approach pavement settlement process and to prepare the desired background for the Phase III. A total of six borings were drilled by the ODOT sampling crew and laboratory tests of the samples recovered were conducted to determine the soil type, field moisture content, field density (as a possible correlation with the level of compaction), Atterberg limits, consolidation and maximum dry density. Findings of this study are also included in this report.

1.4 Overview of Study Tasks

In selecting appropriate sites, which was considered to be a key element in the proposed level-one survey, considerations were given to ensure that the sites covered a wide range of parameters/factors that contribute to the referenced settlement problems in the state. The bridges were selected randomly using county maps and bridge subsection summary published by ODOT. In consultation with ODOT it was decided that the number of bridges to be surveyed in each county would be more extensive in three divisions. Details of the site selection procedure and other relevant information are presented in Chapter II. The field survey of selected bridge sites was conducted by the OU research team. A survey form, prepared in consultation with ODOT research, construction, maintenance and material divisions, was filled out for each bridge approach. The survey form consisted of three parts (i) field survey, (ii) information relating to construction and (iii) information relating to maintenance (see Chapter III). For each bridge approach, construction related information were also collected using the bridge files maintained at the ODOT headquarter in Oklahoma City (see Chapter IV). The maintenance supervisor for each ODOT district, as well as interstate units, were interviewed to obtain information pertaining to maintenance of the selected bridge approaches (see Chapter III). The information was computerized using a database and the database was used to identify the influence of various causative factors and to characterize the settlement problem. The details of the results obtained from this synthesis process are discussed in Chapter V. Results of the field and laboratory tests pertaining to two selected sites are presented in Chapter VI and the conclusions of Phase II are presented in Chapter VII.

CHAPTER II

FIELD SURVEY OF BRIDGE APPROACHES

2.1 Introduction

As a part of Phase II of the project, it was decided to conduct a level-one survey of some selected bridge approaches in Oklahoma. This survey consisted of the following tasks:

(i) Field visits for visual inspection of 758 selected bridge approaches all over the state, including 78 county bridge approaches;

(ii) Collection of information related to maintenance of these bridge approaches; and

(iii) Collection of information related to construction and materials of these approaches.

In order to accomplish the field visits for visual inspection of the sites, also referred to herein as "field survey", the following tasks were identified:

(a) Preparation of a "field survey form" which were filled out at the bridge approach sites.

(b) Preparation of a "field survey manual" which was used as a guideline to fill out the field survey form.

(c) Selection of the bridge approaches for survey in all seventy-seven counties of Oklahoma.

(d) Field survey of the selected sites.

A detail discussion of the above tasks are presented in this chapter.

2.2 Review of Bridge Approach Surveys Conducted by Other Agencies

Similar surveys to determine the causes of bridge approach faults have been conducted previously by several states. Hopkins (1969) conducted a survey of 782 bridge approaches in Kentucky in the summer of 1964. It was observed that there was a general relationship between development of the approach fault and such possible causative factors as the type of abutment, embankment height, and geological and foundation soil characteristics. From the survey it was evident that the lowest percentage of defective approaches were located in a dissected plateau with rolling hills and moderately wide valleys. A large number of defective approaches were located in areas where the subsoil consisted primarily of recent alluvial deposits, shale and plastic clays. Another area with a high percentage of approach settlement had a rough, hilly terrain with narrow and winding valleys, having entered by numerous streams. The soil was highly plastic and was considered to provide poor pavement support at normal moisture content. Subsequently, Hopkins and Deen (1970) and Hopkins (1985) reported the results of a study involving monitoring of long-term movements at a number of bridge approach sites in Kentucky.

In a similar survey by the California Department of Transportation (Caltrans) in 1973 the fill height, age, drainage, abutment skewness, settlement period and traffic count were considered as suspected contributors to approach settlements (Stewart, 1985; Zeiler and Kleiman, 1972). The data consisted of 410 bridges along an 1800-mile loop of California highways. Seventy-four percent of the asphalt concrete approaches surveyed exhibited patching or a need for patching. Only 43 percent of the rigid approaches surveyed exhibited an evidence of corrective maintenance. In contrast to the observations made by Hopkins, et al. (1969, 1970, 1985), the Caltrans study indicated that abutment skewness, fill height, traffic volume, and approach length do not have any significant effect on the need for at least one time maintenance of bridge approaches. Also, due to lack of correlations between the approach settlement and foundation soil types, this study (Zeiler and Kleiman, 1972) was unable to provide a general solution to the bump problem.

More recently, the Colorado Department of Highways (Ardani, 1987) completed a study to identify the contributing factors associated with the settlement of bridge approaches. An analysis of field and laboratory test data from 20 bridge approaches in Colorado revealed that the following factors contribute to bridge approach settlements: (i) consolidation within an approach embankment and foundations; (ii) poor compaction of backfill and embankment material, (iii) poor drainage, and (iv) erosion of soil at abutment face. Other studies conducted in the United States (e.g., Idaho, Wyoming and Texas DOTs) and abroad (e.g., England, India and Thailand) have expressed varied opinions regarding the significance of approach settlement contributing factors.

In summary, the above review indicates that the approach settlement causative factors could vary significantly depending upon the geological characteristics of a region, design, construction and maintenance specifications and standards of the transportation agency involved, as well as the traffic volume and type. Thus, the need for the level-one survey of Oklahoma bridge approaches was clearly evident.

2.3 Preparation of Field Survey Form

To achieve the intended objectives of any survey, it is of utmost importance to prepare a survey form which (i) will include all the inquiries pertinent to the survey, (ii) will have understandable features, and (iii) will be easy to include in a computerized database.

The following steps were followed to design the field survey form:

1. Review of literature and preliminary form design

The purpose of the literature review was to investigate the survey forms used by other researchers for similar surveys. Based on the objectives of our study, the forms used by the Kentucky and the California DOTs were found to be particularly useful. A preliminary survey form was prepared on the basis of the literature review and the response of a questionnaire received in Phase I of this project (Laguros, et al., 1986). Design of the form emphasized the data which can be collected primarily from visual observations and minimal measurements. The following items were included: (i) bridge, abutment and approach geometry, (ii) existing conditions of the approach, abutment headwall, slope protection structure, drainage, and embankment slope, (iii) maintenance history, (iv) embankment material and (v) geology.

2. Modification of the preliminary survey form

The preliminary survey form was modified to account for the remarks from the Research, Materials and Maintenance Divisions of ODOT. Several field trips were made to different geographical regions of the State to check if the criteria listed in the original survey form were adequate and practical. A copy of the modified survey from is included in Appendix I.

3. Further modification for database development

While the content and features of the modified survey form remained the same, it was redesigned at a later period of Phase II so as to make the data entry more convenient. The redesigned survey form is also included in Appendix II.

2.4 Field Survey Manual

A field survey manual was essential in order to avoid inconsistent evaluation of bridge approaches performed by different surveyors. The need for the field survey manual became evident because most of the features of the field survey of bridge approaches are qualitative. As such, the possibilities of human error and differences in opinion could vary widely. The intent of the field survey manual presented in this section is to provide a broad guidance concerning different items in the form. For consistent evaluation the surveyor needs to apply personal judgement based on the criteria in the manual. The description of various features in the survey form and evaluation procedure are discussed below:

1. Type of bridge approach:

   The bridge approaches are classified into three groups (i) Portland cement concrete approaches are termed rigid, (ii) asphaltic concrete cement approaches are termed flexible, and (iii) Portland cement concrete approaches which have been overlayed completely with asphalt are termed rigid with asphalt overlay.

2. Classification of the approach according to criteria in the survey form:

   (a) If a vehicle does not experience any noticeable bump while approaching or exiting the bridge at normal traffic speed, no significant settlement is evident. In order to qualify for this category, a bridge approach should also be maintenance free since its opening to traffic.

   (b) If the approach shows evidence of some type of maintenance work such as level patching, local patching, asphalt overlay or mudjacking, then the approach is categorized as "settlement occurred and maintenance performed". This category may also include approaches which have some existing settlement as well. Here, the term "maintenance" refers to the measures which were undertaken for correcting approach fault. Maintenance works unrelated to settlement (e.g., overlay of the entire roadway) are not taken into account.

(c) The bridge approaches in this category will show existing settlement with no evidence of prior maintenance.

3. Age of the bridge approach:

The age of the bridge approach may be estimated by the types of approach guardrail, general condition of the bridge or bridge structure type. The guardrail shown in Fig. 2-1 was in use during 1930-1960. Figure 2-2 shows typical guardrails which were in use during 1960-1980 and the one shown in Fig. 2-3 has been in use since 1980. This will only give a broad idea about the age of the bridge approach. Depending upon the individual judgement, the estimated age might vary substantially. However, this inaccuracy may not be of any concern since the actual age of the bridge can be obtained from the ODOT Bridge Division records.

4. Type of maintenance performed:

Generally four types of corrective measures are used to rectify approach pavement faults:

(a) Local patching is the maintenance performed at localized spots in the pavement

(b) Level patching involves maintenance of the entire width of the pavement

(c) Mudjacking is generally performed on rigid pavements and the evidence is shown by the mudjacking holes on the pavement. A pavement which has been mudjacked might crack frequently due to overstress produced by the mudjacking operation

(d) Asphalt overlay is generally done to improve the riding conditions of the entire roadway surface.

A combination of the different types of maintenance is possible depending upon the approach settlement history and maintenance measures undertaken.

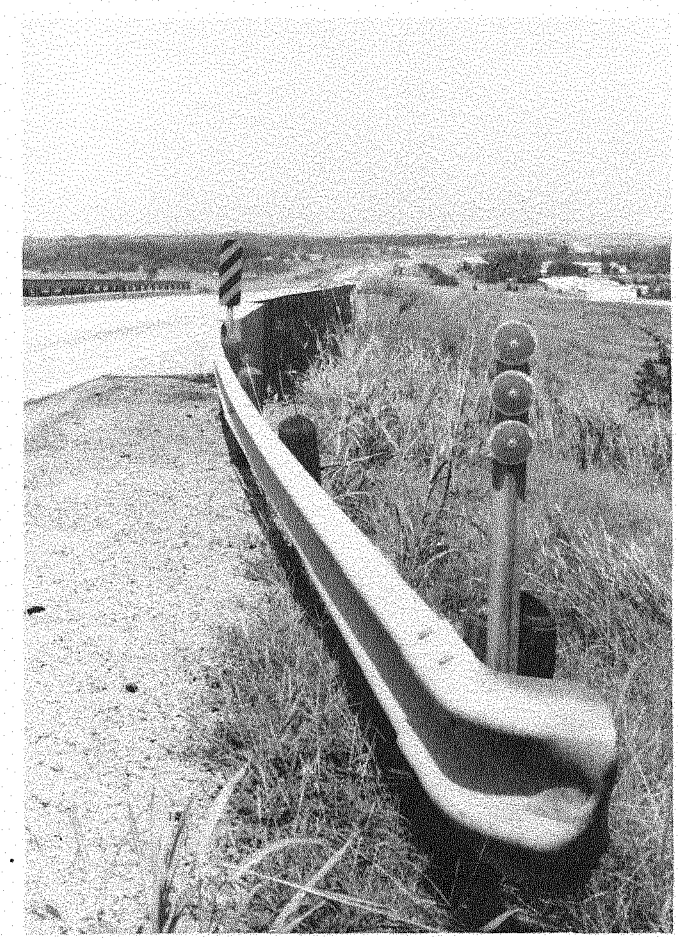

Fig. 2-1. Approach guardrail used during the period 1930-1960

Fig. 2-2. Approach guardrail used during the period 1960-1980

Fig. 2-3. Approach guardrail used since 1980

5. Frequency of maintenance:

It indicates the total number of times an approach has required some form of maintenance work. Level patching at different times would show different colors due to different degrees of weathering. Mudjacking from one time to another may be distinguished by careful observation of the holes, crack pattern and pavement distress. Sometimes the evidence of previous patching, mudjacking and overlay may be buried under a new overlay. The general outlook of the approach was proven to be helpful.

It should be noted that completing this data from the field survey may be very difficult, particularly when problematic and older approaches are involved. A careful observation of the site and analysis of maintenance work are needed for a realistic assessment of the maintenance history.

6. The approach design:

All rigid approaches were considered as specially designed approaches in the present survey. However, it would be appropriate to review the design details to group an approach pavement in this category.

7. Length of the approach slab:

This is applicable only for rigid approaches. The length of the approach is estimated in feet. In case of a skewed bridge, the length along the centerline of the approach slab is considered as the approach length.

8. Extent of approach pavement distress:

This represents the estimated length of the approach pavement, in feet, measured from the bridge abutment, in which some form of pavement distress is noticeable. Individual judgement is required in estimating this distance.

9. Total settlement:

This is an estimate of the settlement, in inches, that the approach has experienced since its opening to traffic. It may be estimated by examining the movement of the curb, thickness of cumulative overlay, thickness of cumulative patching, or other noticeable evidences at the site (Figs. 2-4, 2-5). In case of nonuniform settlement, the maximum settlement is recorded.

10. Present condition of the approach:

This relates to the existing condition of the approach in terms of settlement and approach roughness.

(a) Settlement: The existing settlement is recorded as explained under item 9. If the settlement is less than 1 inch, it is designated as minor, 1 to 3 inches of settlement is considered as moderate, and over 3 inches as extensive.

(b) Surface roughness:

Surface roughness may be categorized as rough, moderately rough or smooth. This does not indicate the extent of settlement but rather gives an idea about the present condition of the riding surface. Hence an approach may have undergone excessive settlement but at the time of survey it may be smooth if appropriate maintenance measures were undertaken. An illustration of various types of roughness are shown in Figs. 2-6, 2-7 and 2-8.

11. Type of embankment:

(a) Valley fill embankments are those which have been constructed by filling up valleys with borrow or locally available fill materials.

(b) Side hill fills are embankments constructed by cutting hills or elevated places.

(c) Grade separation embankments are those which embody a bridge that passes over another highway or railroad.

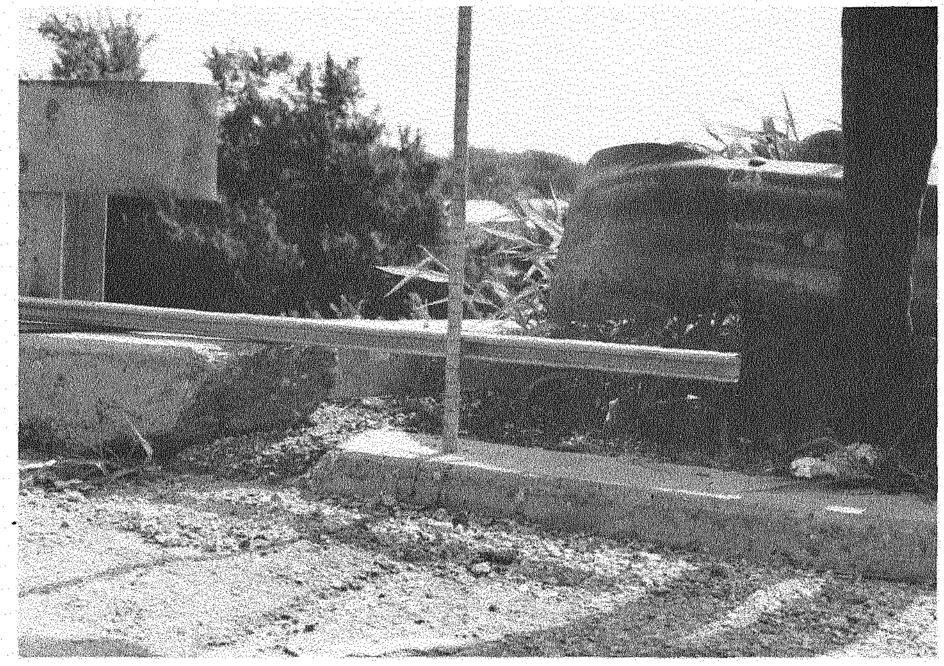

Fig. 2-4. Settlement estimate of bridge approach from the differential settlement of the curb

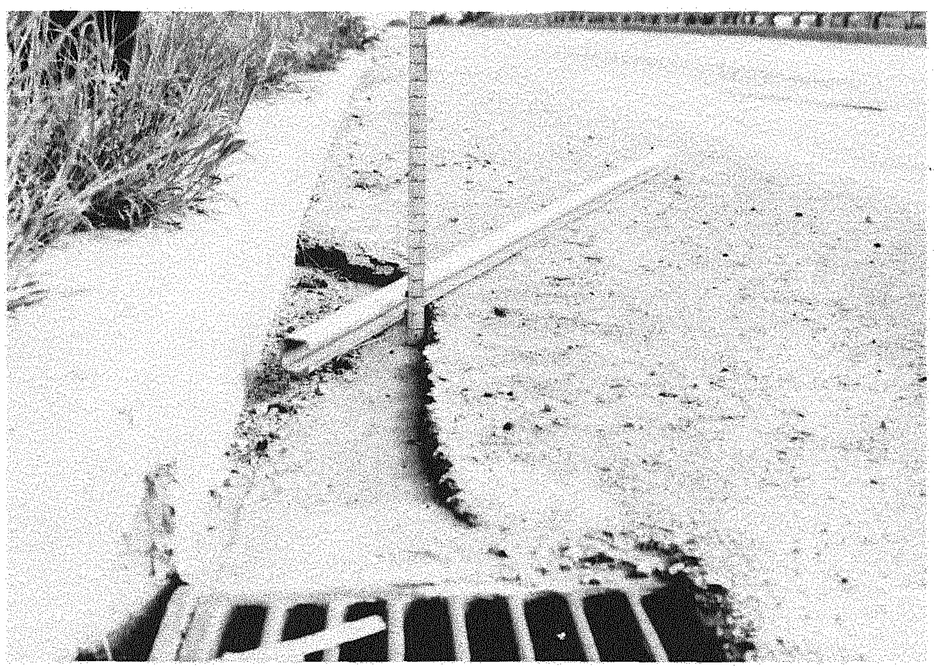

Fig. 2-5. Settlement estimate of bridge approach from the thickness of overlay or level patching

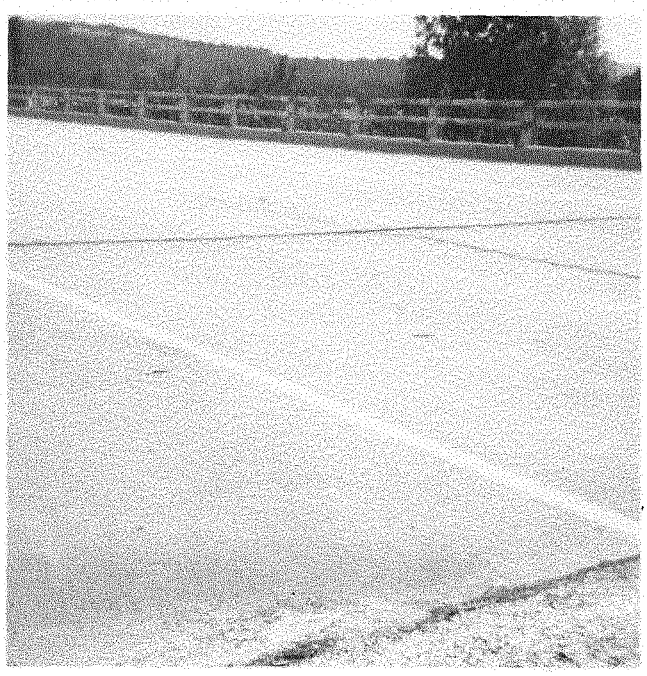

Fig. 2-6. A smooth bridge approach

Fig. 2-7. A moderately rough bridge approach

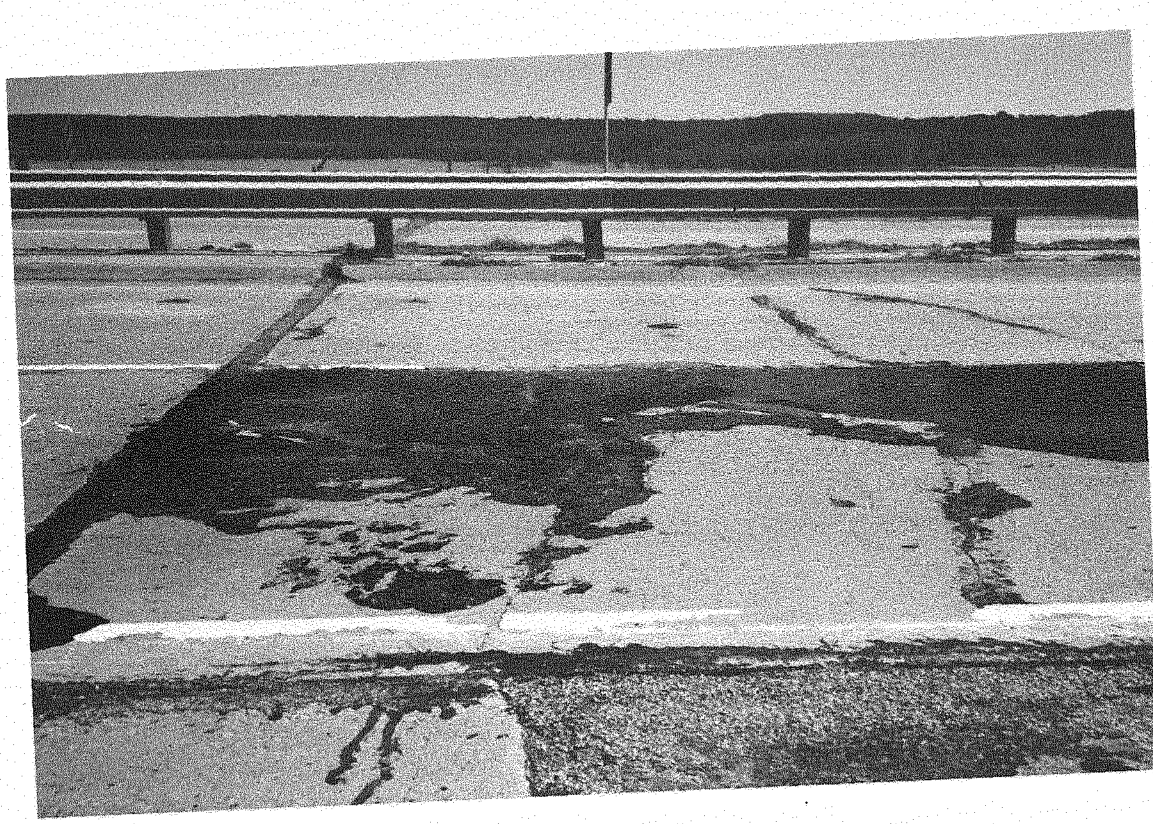

Fig. 2-8. A rough bridge approach

12. Type of embankment material:

Realistically this information can be obtained by drilling through an approach embankment and classifying the soil from test data. In the field survey conducted herein, a grossly simplified approach was used to categorize the embankment soil type. Embankment was bored to a depth of at least 1½ feet. The embankment materials were classified as sand, silt, clay, gravel, shale, caliche or a mixture of some of the above by visual observation.

13. Skewness of a bridge:

Skewness of the bridge is defined here as the angle in degree between the centerline of the abutment and a line normal to the roadway centerline (Fig. 2-9).

14. Condition of slope protection structure:

Slope protection structures are provided to prevent failure of the embankment slope, especially in the longitudinal direction. For most of the valley fill or side-hill fill embankments, rip rap structure is used for protection of the slope. In case of embankments at grade separation a concrete slope protection structure is generally used. The slope protection structure is evaluated to check the degree of cracking and settlement. The rating of extensive, moderate or minor are qualitative. Individual judgement should be exercised to obtain the appropriate grouping. Figure 2-10a shows a slope protection structure with moderate cracking and settlement. A slope protection structure with extensive cracking and settlement is shown in Figure 2-10b.

15. Condition of embankment slope near abutment:

Embankment slope erosion aggravates the settlement problem. The slope near the abutment should be checked for evidence of erosion or settle-

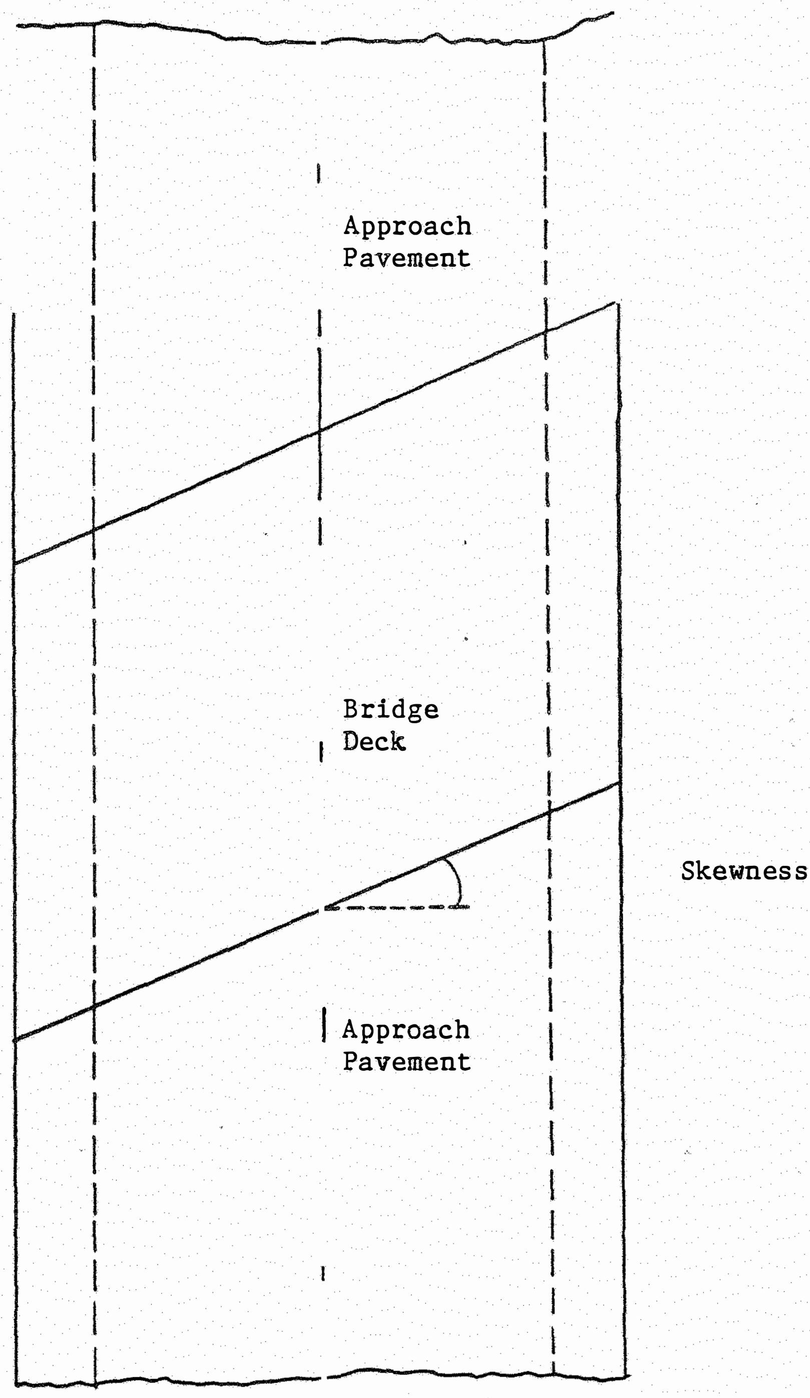

Fig. 2-9 Schematic diagram showing skewness of a bridge

Fig. 2-10a. A slope protection structure showing moderate cracking

Fig. 2-10b. A slope protection structure showing extensive cracking and settlement

ment. Figure 2-11 shows a severely eroded approach embankment slope.

16. Estimated embankment height:

This entry represents an estimate of embankment height, in feet, measured from the original ground level. The estimated value could be readily checked for accuracy from the project files available at ODOT.

17. Classification of abutment:

Different types of abutments are shown in Fig. 2-12. The desired classification can be done easily from the field observation. Also, the data can be verified from the information available in the project file at ODOT.

18. Condition of abutment headwall:

(a) The movement of the abutment headwall may be indicative of longitudinal movement of the embankment. The headwall movement is categorized as extensive, moderate, minor or none based on individual judgement. Figures 2-13, 2-14, 2-15 may be used as a broad guideline.

(b) Headwall cracking may also be an indication of nonuniform movement of embankment. The cracking may be categorized as extensive, moderate, minor or none based on the degree of severity. Figures 2-16, 2-17, 2-18 show the different degrees of severity of cracking.

19. Tilting of expansion devices:

Tilting of expansion devices is related to movement of the bridge structure. Figures 2-19, 2-20, 2-21 show expansion devices with minor, moderate and considerable tilting.

20. Performance of truck lane vis-a-vis the non-truck lane:

Here truck lane means the right most lane when facing the direction of

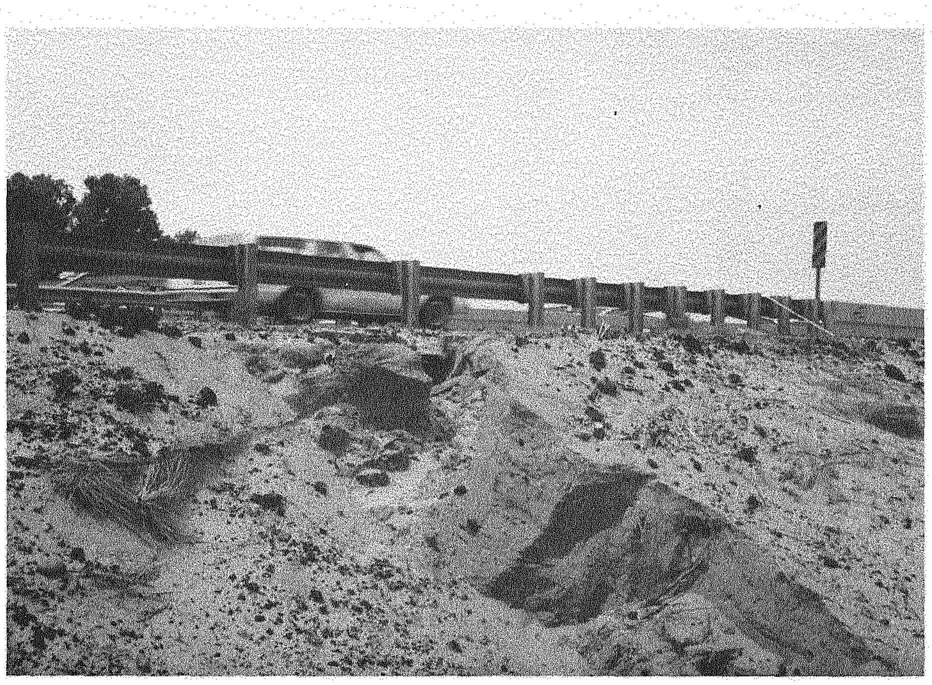

Fig. 2-11. An approach embankment showing erosion

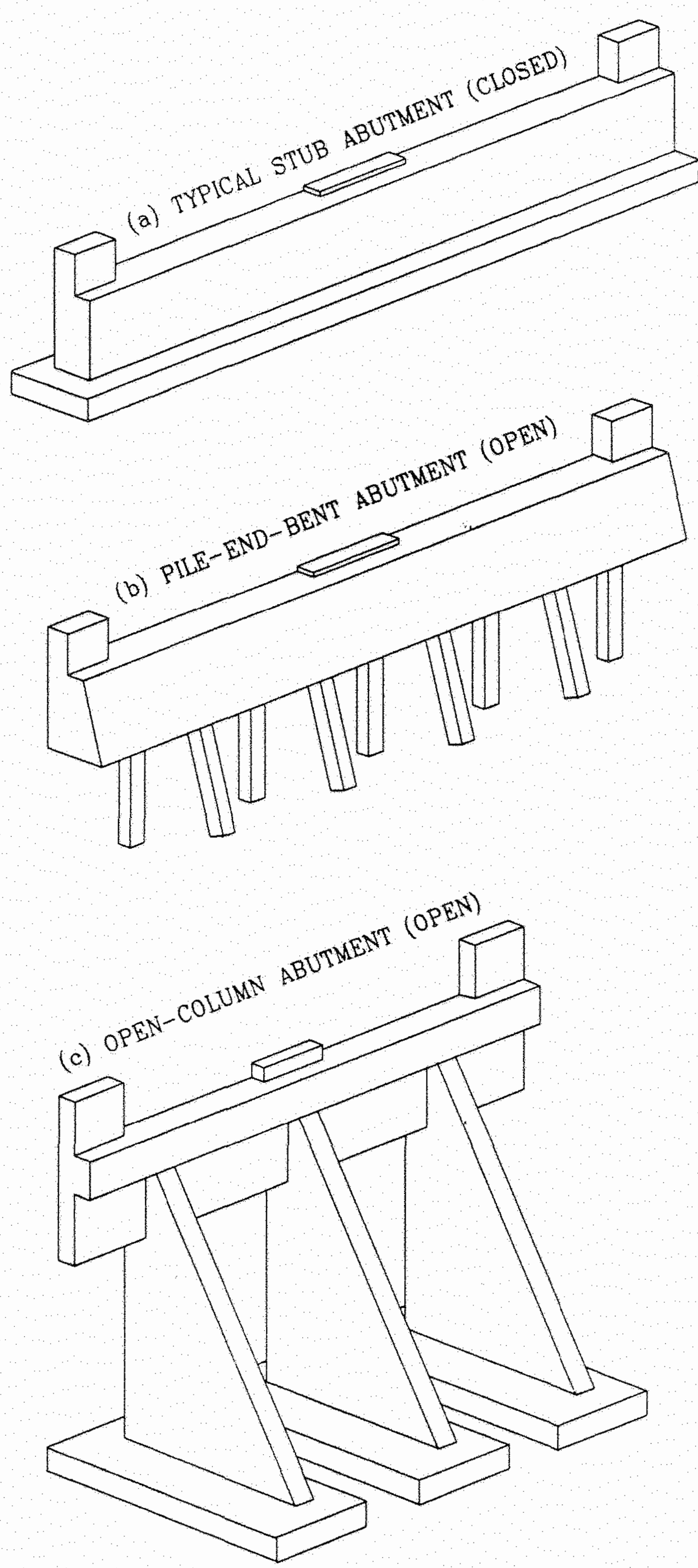

Fig. 2-12 Typical types of abutments used in Kentucky
(after Hopkins, 1969)

Fig. 2-13. Evidence of a minor movement of the abutment headwall

Fig. 2-14. Evidence of moderate movement of the abutment headwall

Fig. 2-15. Evidence of extensive movement of abutment headwall

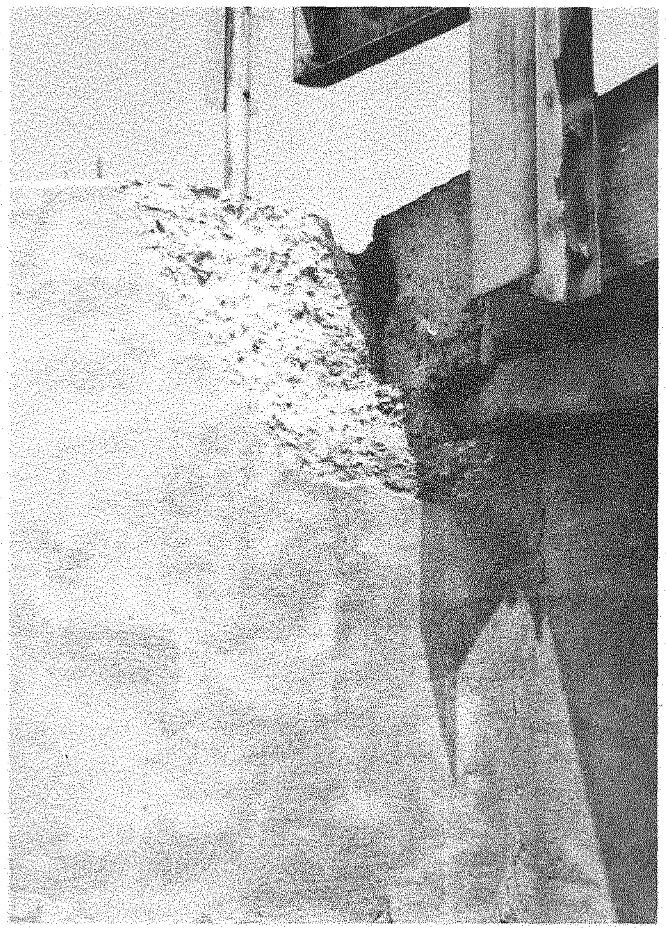

Fig. 2-16. An abutment headwall showing minor cracking

Fig. 2-17. An abutment headwall showing moderate cracking

Fig. 2-18. An abutment headwall showing extensive cracking

Fig. 2-19. Expansion device showing minor tilting

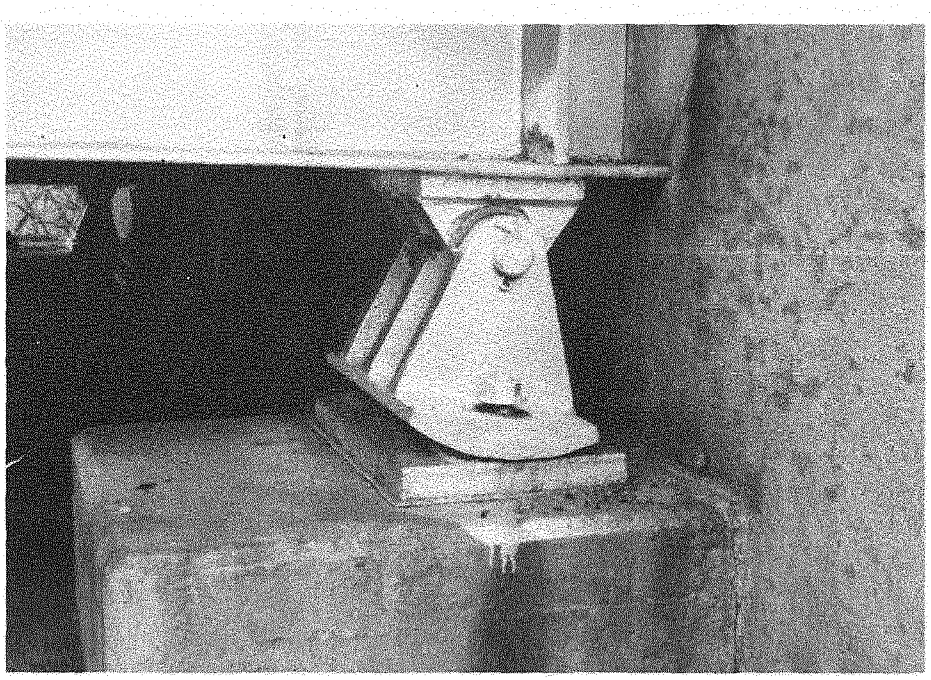

Fig. 2-20. Expansion device showing moderate tilting

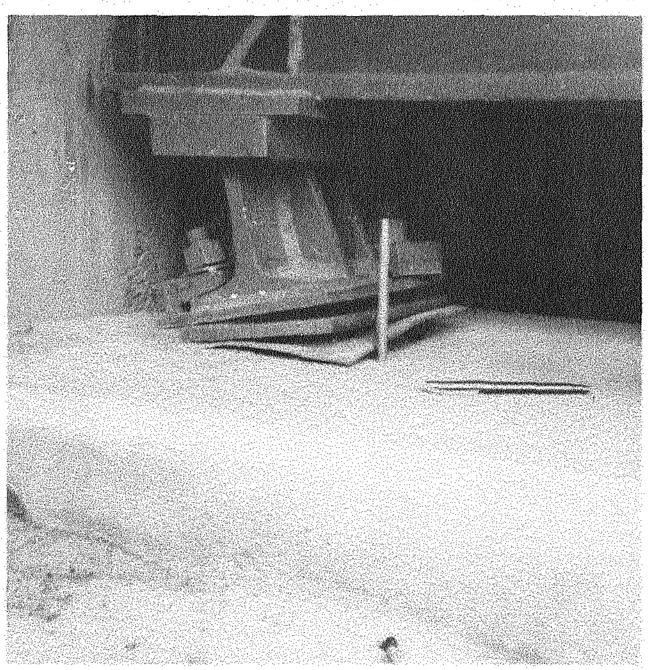

Fig. 2-21. Expansion device showing extensive tilting

Fig. 2-22. Differential settlement between truck lane and nontruck lane

traffic flow. The degree of settlement in the right most lane should be compared to other lanes for evidence of influence of truck traffic on the settlement problem. Figure 2-22 shows the differential settlement between truck lane and nontruck lane.

In addition to the above guidelines, individual judgement must be applied in assigning a rank or group for a given factor, so as to minimize the inconsistencies of the survey data.

In addition to the stated criteria to be evaluated by the surveyor, the first page of the survey form includes information pertaining to the identification of the bridge. The information contained in each item is explained below:

1. Bridge #: The bridge is identified by numbers such as 30-10X1278. Here the first two digits indicate the county number, (30 is for Harper County), the second two digits indicate control section number, X indicates that it is a bridge subsection and the last four digits indicate that it is located at a distance of 12.78 miles from the beginning of the control section 10. The bridges selected for the level-one survey are listed in Appendix III.
2. TYP: This indicates whether the bridge is over a creek, river, railroad or another highway. For example, a bridge over a waterway is designated as BRDG. The various types of bridge classifications are shown in Table 2-1. (Refer, Page 14a, 1987 needs study and sufficiency rating report, ODOT).
3. Date: It indicates date of the field survey.
4. Div.: This identifies the ODOT division in which the particular bridge is located.

Table 2-1. Description of Different Bridge Types

Bridge Type	Description
BRDG	Highway over a waterway
BXBR	Concrete box without handrails
BXWH	Concrete box with handrails
BXUF	Concrete box under fill
OP-R	Highway over a railroad
OP-H	Highway over highway
H-RW	Highway over railroad and waterway
H-HW	Highway over highway and waterway
H-HR	Highway over highway and railroad
UP-R	Highway under railroad
UP-H	Highway under highway
UPML	Highway underpass multiple level
UP-O	Highway underpass other
UP-P	Highway under pedestrian crossing
HHRW	Highway over highway, railroad, and waterway
OTHR	Multi-level structure
OP-P	Highway over pedestrian crossing
UPHP	Highway under highway and pedestrian crossing
UPHR	Highway under highway and railroad

5. Highway: This entry represents the highway type, such as state, interstate, or county road. Since county roads are generally identified by their names rather than numbers, in the level-one survey conducted here the county bridges were identified by the county number and a two digit number to designate a given bridge (see Appendix III).

6. County: The name of the county in which the approach is located.

7. Crossing: The name of creek, river, highway, railway or county road that is under the bridge.

8. BRDG END: Indicates either the north, south, east or west end of a bridge.

9. BRDG LNG: The length of the bridge in feet.

10. BRDG WDTH: Indicates the roadway width in feet.

11. Weather: Comment on the general weather condition at the time of the survey.

12. Location: The location of the bridge as reported in the bridge subsection summary book published by ODOT.

13. Surv. by: The names of the persons conducting the survey.

2.5 Selection of Bridges

It was proposed to select approximately 250 to 400 sites for the level-one survey. Selection of these sites was considered to be a key element in the study. The sites were selected in a way that they covered a wide range of parameters/factors that contribute to the referenced settlement problems in the state. The selection of the sites was governed by four major criteria: materials, design, construction and maintenance. More specifically, the selection process was influenced by the following items, among others:

(1) Type of highway/roadway system (e.g., interstate, state highway, county roads, etc.).

(2) Geologic features of the site (e.g., topography, soil type and thickness, water table, oxbow lakes, nature of drainage, etc.).

(3) Traffic volume and composition (e.g., heavy truck, cars, farm vehicles, etc.).

(4) Climate (e.g., rainfall, temperature, freeze-thaw cycle, etc.).

(5) Abutment type (e.g., open-column, pile- end- bent, stub, etc.).

(6) Degree and composition of fill (e.g., height, fill type - sand, clay, etc.).

(7) Maintenance history.

(8) Approach pavement characteristics (i.e., rigid, flexible, length, thickness, etc.).

Since the information (design details, construction, maintenance, etc.) on the county roads is very limited or not available at all, it was decided that the unpaved approaches would not be considered for such bridges. The number of sites in the urban areas with heavy traffic flow was also kept low because of the possibilities of traffic flow interruption and surveyor's safety consideration. In coordination with ODOT it was decided to conduct the level-one survey extensively in three selected ODOT divisions (Divisions 3, 6 and 8). Of these three, Divisions 3 and 8 are thought to be having more settlement problems than Division 6, which is believed to have minimum settlement problems. By extensive surveying it is meant that an average of approximately 14 bridge approaches were surveyed in each county of these divisions. In the remaining Divisions (i.e., 1,2,4,5 and 7) approximately 7 approaches on the average were selected for each county.

To obtain an unbiased database, it was decided to randomly select bridges for each county. While it was envisioned that randomness will encompass all the criteria for selection noted above, it was also ascertained that no one type or factor had significant dominance on the selection process. County maps, ODOT bridge subsection summary books, control section maps published by ODOT planning division, and ODOT needs study and sufficiency rating reports were used to enhance the selection process. The bridges selected randomly from the control section listing were plotted on the county map. Figure 2.23 shows such a plot for Mayes County. Emphasis was given to ascertain broader geographical distribution of sites within the county. Geological features, highway type and traffic volume often played an important role in the selection process. Occasionally, a selected site was not included in the survey if the field visit indicated reasons for such action (e.g., old bridge, inability to trace maintenance history). Also, sometimes new bridges were added to the list on the basis of the recommendation of the maintenance crew. A list of the selected bridges is attached in Appendix III. It should be noted that this random selection may have led to the exclusion of some of the worst problematic bridge approaches in the state but it is envisioned that the statistical analysis will not be affected by such exclusion.

The total number of bridge approaches selected was 758. Of these 636 were over waterways and 122 were overpass or underpass. Of the total 758 approaches, 320 are rigid, 438 fall in the flexible category. Geographically they are distributed all over the state. The bridge approaches vary widely as far as maintenance history, embankment soil, embankment height, traffic volume, and foundation soil type are considered. Hence, the data acquired are expected to encompass a wide range of parameters under consideration. Selection of county bridges was somewhat difficult due to the lack of data. County maps were used to select these bridges. Unpaved approaches, box culverts or bridges with wooden decks were not considered in this study.

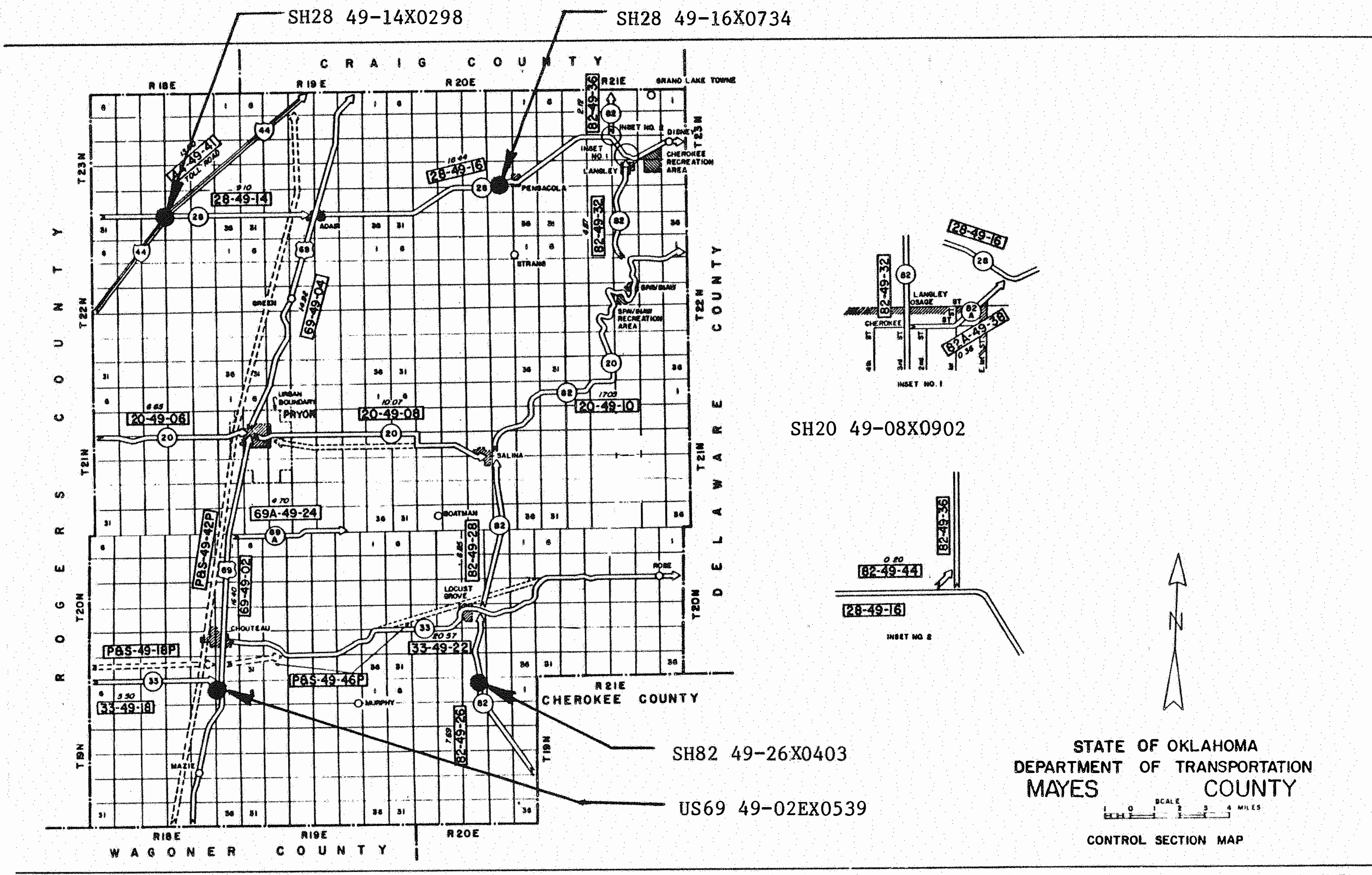

Fig. 2-23 Bridge locations shown on county map

2.6 Collection of Field Data

The field survey was conducted by at least two personnel from the University of Oklahoma research team. The survey form shown in Appendix III was completed for each end of the bridge. All qualitative parameters were rated by the criteria described in Section 2.4. Personal judgement was also essential in such ratings. The various items in the survey form were discussed in detail with the ODOT personnel from Research, Materials and Maintenance Divisions. Several joint field trips were undertaken to the various geographical regions of the state and a number of bridges was surveyed. It helped to develop a general consensus about some of the qualitative factors discussed in Section 2.4. Hence, it is expected that the ratings would be consistent and reasonable. The quantitative parameters like embankment height or skewness of bridge, etc. were estimated, while others such as settlement were measured. To determine the type of embankment material, soil samples were taken using the post auger hole method. The soil conditions were identified to a depth of approximately 1½ feet. To record the special features of an approach schematic sketches were drawn.

The maximum total settlement at any approach was estimated by several methods. The differential settlement between the curb on the bridge and that on the approach gave a good approximation of the total settlement occurring at the approach (see Fig. 2.4). The thickness of level patching or overlay on the original pavement was also used to estimate the settlement. In cases where the approach pavement was mudjacked, the number of mudjacking operations was estimated from the evidence in the field. The settlement was then estimated based on the times of mudjacking. Few other notes on the field survey are worth mentioning. In some cases it is estimated that the total settlement of an approach pavement is several inches (say 3 inches). This does not mean that there was a drop of 3 inches at the junction of the bridge deck and the approach pavement, which may be experienced by a moving vehicle. The settlement profile could be gradual and in the most critical spot a settlement of this magnitude (3 inches) may exist before any maintenance is performed on the pavement to correct the problem. Some limitations of the survey are discussed in the following section in order to attain a clear picture of the overall study and the difficulties involved.

2.7 Limitations of Field Data

Due to the specific objectives of the level-one survey, the investigation at the bridge approach sites was limited to the collection of data from visual observations and limited measurements. Some of the data are qualitative in nature, and as such their specific accuracy cannot be ascertained. This section discusses some of the limitations that may have an influence in imparting some degree of inaccuracy in the field data. As discussed in the previous section, some field data (age, embankment height, skewness, etc.) which were estimated during the survey, were verified subsequently from other existing sources, while some other parameters could not be checked for accuracy (e.g., estimated settlement).

In the case of a rigid pavement which has been mudjacked, the number of mudjacking operations was estimated by careful observation of evidence in the field. For some sites it might not be possible to obtain one single estimate. Also, it might be difficult to estimate the movement of approach slab due to mudjacking. In some cases it was possible to check the accuracy from the information provided by the maintenance personnel. But such verification in some cases remained incomplete where the maintenance crew could not provide such information. This was particularly applicable to older sites.

In some cases the rigid approach may have been mudjacked but all evidence of mudjacking is buried under the asphalt overlay. The maintenance history of some of these approaches was probably unveiled from the interview of the maintenance crew, while other information remained unknown due to the lack of appropriate recordkeeping procedure. Since mudjacking is rather limited in Oklahoma as a means to correct approach faults, it is envisioned that the degree of inaccuracy caused by such uncertainties would be minimum.

For flexible pavements, the chances of erroneous estimation were greater. A bridge approach that has been level patched a few times to correct the settlement problem may not show or reveal such maintenance measures due to burial of previous operations by a new overlay. An example is a bridge (75-010X0849) on State Highway 152 in Washita County. The maintenance crew had reportedly level patched the approaches 12 times in the past 12 years, correcting a total settlement of approximately 18 inches, but the field evidence does not show any trace of previous settlement. Thus, it is possible that in some cases the settlement of the flexible pavements were severely underestimated. Due to lack of information, the data on the county bridges could not be verified for accuracy.

Another limitation of field data relates to the type of embankment material. Since only the top 1½ feet of the embankment material was checked, there is a possibility of inaccurate identification of embankment material, except for uniform/homogeneous embankments. These limitations of the collected field data demand a careful analysis and interpretation of the Statistical analysis results presented in Chapter V.

CHAPTER III

INTERVIEW OF MAINTENANCE PERSONNEL

3.1 Objective and Procedure

One of the most important components of the level-one survey was the information related to maintenance. From the maintenance history of a particular site highly significant information may be obtained such as, amount of total settlement, frequency and type of maintenance, type and evidence of any special problem(s). While maintenance history may be somewhat pieced together from the evidences in the field, it was decided that more accurate information could be obtained by interviewing the personnel of ODOT involved in maintenance of bridge approaches. ODOT has seventy-seven district maintenance units under its eight divisions. Each district has a maintenance crew under the supervision of a district maintenance supervisor. The district maintenance crew performs routine maintenance work such as local patching or level patching. For specialized maintenance work such as mudjacking, the special crew from the division office is called upon. The district maintenance offices are in charge of maintenance of state highways only. For the maintenance of interstate highways there are additional maintenance crews, known as interstate units, under each division. Any bridge approach on an interstate highway or any other highway over it are maintained by interstate units. It was decided to interview the district maintenance supervisors as well as the interstate unit supervisors with an objective to

(i) obtain maintenance history of all the bridge approaches surveyed in the field,

(ii) obtain information regarding the existence of any special maintenance problem for a bridge approach,

(iii) evaluate the field estimates in the light of maintenance information,

(iv) evaluate the bridge approach settlement causes from the point of view of personnel directly involved in maintenance, and

(v) evaluate the existing recordkeeping procedure regarding maintenance of bridge approaches.

With these objectives in mind, a general procedure was established to interview the maintenance personnel. A list of the bridge approaches selected for field survey in each county was sent to the division maintenance engineer of the appropriate division. The division engineer would contact all the supervisors of district and interstate maintenance units under the division, provide them with a list of the bridge approaches for which maintenance information was sought, schedule interviews with the OU research team. The maintenance supervisors were also independently contacted. Such advance notification was helpful for the maintenance supervisors to collect information about the selected bridge approaches by exchange of experience with other maintenance crews. On the scheduled date, two persons from the OU research team visited the district maintenance office and filled out the Section C of the survey form, titled "Information from Maintenance." In many cases, the maintenance supervisors visited bridge approach sites with OU research personnel. In these interviews the supervisors were generally assisted by other experienced crew members of the district office. A critical review of the information obtained from maintenance personnel is given in Section 3.3.

3.2 Preparation of Interview Form

As mentioned in Section 2.3 of this report, the survey form is one of the most important components of the information collection system. To obtain the information regarding maintenance of the bridge approaches, answers to the following questions were sought:

1. How many times the approach needed any corrective measures for settlement?
2. How much settlement was corrected in each maintenance?
3. How far from the bridge deck the settlement problem existed?
4. What type of maintenance was done each time?

The interview form, titled "Information from Maintenance", is the Section C of the field survey form attached in Appendix I. The beginning of the interview form is the same as for the field survey and is related to the identification of the bridge approaches. The four items in the interview form are described below:

1. Number of times maintenance performed:

   This indicates the total number of times any kind of maintenance work was done on the approach to correct settlement problem since its opening to traffic. If the approach was quite old and the information was not available since opening, then the number of times maintenance had been performed within a known period of time was recorded.

2. Type of maintenance:

   (a) Level patching:

      (i) Number of times and dates: This entry indicates the total number of times of level patching done to correct the settlement problem and the years in which such maintenance works were undertaken.

      (ii) Extent: Indicates the distance from the bridge deck to the end of level patching.

(iii) Thickness: Denotes the settlement corrected by each level patching.

(b) Local patching:

(i) Number of times and dates: This item represents the total number of times any local patching has been done and the corresponding years.

(c) Overlay:

(i) Number of times and dates: The total number of overlays done since the approach was opened to traffic and the corresponding year are recorded under this item.

(ii) Extent: Generally an overlay extends over a long stretch of pavement beyond the approach slab. In such cases "the entire roadway" is recorded.

(iii) Thickness: Indicates the thickness of the overlays which were applied to correct the settlement problem, but not for the overall maintenance of the pavement.

(d) Mudjacking:

(i) Number of times and dates: Total number of mudjacking operations performed since the approach was opened to traffic and the corresponding years.

(ii) Amount of mud injected: This information is sought to estimate the amount of settlement corrected in each mudjacking operation. If this information is unavailable, which was the case for the sites surveyed in this study, the approximate settlement corrected in each mudjacking operation is recorded.

3. Pavement replaced?

The appropriate answer is checked.

4. Type of replacement:

In case an approach was replaced due to severe cracking, the type of replacement should be documented briefly.

The information above was recorded on the basis of interviews with maintenance personnel. There are some severe limitations which must be reviewed and taken into consideration in order to provide a degree of reliability on these information. Section 3.3 discusses these limitations.

3.3. Limitations

Collection of information related to the maintenance of the bridge approaches was difficult due to the nonexistence of maintenance records specifically for bridge approaches. Any maintenance work performed is billed through the control section of pavements, the approach being a small section of it. Hence all information gathered during the course of this study was provided by the maintenance personnel based on their memory. Consequently, there is always a possibility of inaccuracy due to human error. A district maintenance supervisor would try to remember all the maintenance works performed on a particular bridge approach and estimate the total settlement corrected by such maintenance works. Hence there is always a chance of omission of some maintenance works performed. In many cases the supervisor had been working for a particular county for a length of time much smaller than the age of the approach. As a result information related to the maintenance of that approach would be incomplete. In some cases, most of the settlement of a bridge approach might take place within the first few years after the roadway is opened to traffic. A supervisor who started to work in the county after the settlement had already taken place and the problem been corrected, would probably not be aware of the settlement problem with that approach. For such cases it is likely that the information is incomplete or misleading. Of course, in such cases, efforts were made to consult other members of the maintenance crew who had been employed in the county for a longer period and have better knowledge of the site. In some cases, a bridge may have been maintained by some other agencies, such as a city administration, for a few years and then the maintenance responsibility has been passed on to ODOT. Information regarding these cases was also incomplete. The maintenance of the bridges on the county roads is performed by the county offices. Due to the difficulties involved in getting such information for every county in the available time, it was not pursued.

CHAPTER IV

INFORMATION FROM ODOT BRIDGE DIVISION

4.1 Objective and Procedure

There are many causative factors involved in the settlement of bridge approaches. Researchers in this area have been able to identify many of those factors in a general manner. For a specific bridge approach one or a combination of these factors may be responsible for the settlement. The level-one survey was undertaken so as to relate the settlement of the approaches to these factors and also to identify their relative significance. Information on these factors or parameters for a bridge approach were recorded from site visits. There were cases, however, wherein information on some other parameters related to bridge approach, bridge structural components, embankment, foundations and traffic, etc. was either not available at the site or was only an estimate of the actual dimensions or values. It was decided to collect this information from the records maintained by ODOT with the following objectives:

(i) To obtain construction history of embankment, bridge structure and the bridge approach.

(ii) To obtain information regarding embankment and foundation soil.

(iii) To record any special design or construction procedure implemented in a site.

(iv) To check the accuracy/reliability of some of the parameters estimated in the field.

(v) To evaluate the recordkeeping procedure.

With the above objectives in mind, a form was prepared which was filled out for each bridge approach. In the initial discussion with the ODOT

Research Division it was decided to obtain the information from the records maintained at each divisional office. Visits to Division 3 office in Ada were made to check the type of information available from their records. Division office maintains a box for each bridge. The construction diary records each activity on a daily basis and thus would give the information regarding the construction history. The drawback was that to obtain information one had to read through all the entries in the construction diary. This would take an excessive amount of time for all the bridge approaches surveyed in this study, and yet answers to some specific questions (e.g. embankment soil properties) could not be obtained in most cases. Also the records for many old bridges were not available in the division office. Another alternate source was the ODOT bridge division office in Oklahoma City where a file for each bridge is maintained. The file contains general plan and elevation maps, soil profiles and bridge inspection reports. Much of the information sought was available in this file and the time required for collecting the information was reasonable. Thus it was decided to collect the available information from the ODOT Bridge Division files. A person from the OU research team visited the ODOT bridge division office regularly and collected the information.

4.2 Preparation of Information Form

The form filled out for each bridge approach contains information related to the following items:

(1) Construction history of embankment, bridge structure and bridge approach

(2) Embankment and foundation

(3) Approach type

(4) Abutment type

(5) Traffic volume

(6) Special construction techniques

A form was prepared with items related to the above list. The form, titled "Information from Field Office", constitutes the Section B of the field survey form attached in Appendix I. The beginning of the form is the same as that of the field survey and contains information related to the identification of the bridge approach. The different items in the form are described below:

Items 1 - 6 are self explanatory.

7. Embankment height: This entry refers to the embankment height near the bridge deck and is obtained from the general elevation map of the bridge and the pavement.

8. Average thickness of foundation soil: The depth of the bedrock from the original ground level is recorded. This is obtained from the soil profile at the bridge site. In cases where boring is not continued down to the bedrock, the maximum depth of boring is taken as the thickness of the foundation soil.

9. Embankment soil type: Indicates the general type of the embankment soil.

10. Embankment soil classification: Represents the embankment soil classification based on the AASHTO classification.

11. Foundation soil type: From soil profile of the bridge site, the type of foundation soil is decided based on the predominance of certain layers of soil.

12. Foundation soil classification: Foundation soil is classified according to the AASHTO classification.

13. Approach slab design: The bridge plans will show the approach slab separately if it is specially designed.

14. Type of special design: The design type (e.g., slabs of uniform thickness, slabs of non-uniform thickness, pile supported slabs) of the approach slab is recorded.

15. Drainage behind the abutment: If there is any drainage system installed behind the abutments, it is recorded.

16. Type and extent of drainage methods: The drainage system is described briefly.

17. Specified compaction for embankment soil: This entry is same for all the bridge approaches and it is 95%.

18. Compaction attained in the field: The average compaction attained in the field is recorded.

19. Compaction equipment: Type of equipment used for compacting the embankment soil.

20. Interruption of construction: If there were an interruption in the construction of embankment and/or approach pavement, it is recorded.

21. Reason for interruption: A brief account of the reason and type of interruption is recorded.

22. Abutment type: Abutment type (e.g., stub, pile-end-bent, open-column) is noted from the bridge elevation maps.

23. Surcharge: If the foundation soil was preloaded to enhance consolidation, it is noted.

24. The details of surcharge height, extent and type are recorded.

25. Traffic count: Average daily traffic on a specific approach is recorded.

26. Geologic unit: Geologic unit of the bridge approach is determined using the geologic maps of Oklahoma (see Appendix IV.)

4.3 Limitations

The data form was prepared with the objectives of collecting all the information related to the six components mentioned in the previous section. However, all of the information was not available from the records at ODOT bridge division. In this section a critical review of the information collected is made and the limitations discussed.

To objectively study the settlement process at any bridge approach it is important to know the construction history so as to estimate the consolidation settlement of the embankment and foundation. In this regard the dates of beginning and end of construction of embankment, and of the bridge and bridge approach were sought. All the information except the year of construction of bridge was unavailable. However, it is not viewed as a serious limitation for this phase because detail prediction of settlement is not within the scope of this phase. However in the next phase this information will be extremely critical. It is expected that with the significantly less number of sites to be investigated in the next phase, it will be possible to pursue all sources of information within the time frame available.

Embankment soil type is an important parameter in this study. In the field a somewhat crude estimate of embankment soil type was made. Due to the unavailability of the data, it could not be checked for accuracy. The soil profile at the site is shown on the general elevation plan maps of the bridges. These soil profiles were not available for many older bridges. Also in many cases, the soil profiles were given in a too general manner. As an example, the soil profile at a site sometimes has been labeled as "soil" and "rock", without specifying the type of soil. Such profiles could not be used in any meaningful manner. Also the reliability of these profiles was questionable. It was thus decided to use the county soil survey maps to determine the type of foundation soil. Some other parameters would have the same entry for all bridge approaches. For example, presently, drainage behind the bridge abutment is not provided anywhere in Oklahoma. Such is also the case with surcharge. Compaction attained in the field was not available from the records at ODOT bridge division. Nor was information available related to compaction equipment and interruption of construction. The geologic unit for a particular bridge site is determined by using the hydrologic Atlas published by the Oklahoma Geological Survey.

Though all the information sought was not available, it is envisioned that the intended objectives (qualitative assessment of the causative factors, extent of approach settlement, etc.) of this phase will not be significantly affected. In Phase III more sources will be sought to collect more detailed information on a bridge approach.

CHAPTER V

STATISTICAL ANALYSIS OF SURVEY DATA

5.1 Data Base Development

As mentioned in Chapter II, the level-one survey was conducted for a total of seven hundred and fifty eight bridge approaches across the state. For each bridge approach, information was obtained from three different sources (i) field visits to the bridge approach site, (ii) interview of maintenance personnel, and (iii) bridge records maintained at ODOT bridge division. A large volume of records and information was generated in the process. Storing, retrieving and analysis of the collected data required a microcomputer-based efficient database. Many software are commercially available to accomplish this task.

At the initial stage of the survey, the data were stored in a database developed by using the software called "PFS:FIRST CHOICE." But as the number of information increased tremendously, the PFS:FIRST CHOICE became inadequate in handling/manipulation of the data. The information stored in the PFS:FIRST CHOICE was then moved to another database developed by the more versatile software "dBASE III PLUS".

The entries in the database field are organized into records and fields. The database can accommodate a maximum of one billion records. Each database field has a name of maximum 10 characters in length. In the present database, each record (i.e., data from a given site) contains 92 fields. The information gathered for each bridge approach is stored in one record and 92 fields. Thus, there are 758 records in the bridge approach database developed in this study. This information can be stored, edited, organized and printed in the desired form by using appropriate dBASE III PLUS commands.

5.2 Analysis Procedure Adopted

Two types of analyses were performed utilizing the data acquired in the level-one survey. The first type of analysis was intended to evaluate the relationship of the settlement of bridge approaches with the various causative factors such as embankment height, age of the approach, type of the approach, foundation soil type, traffic count, etc. These relationships were established by extracting appropriate information from the database.

The second type of analysis involved the statistical evaluation of the information with the purpose of establishing an empirical relationship between the settlement and the various causative parameters. In the statistical analysis, the relative significance of the various causative parameters was also studied. This section presents an overview of the statistical analysis, while the results of both types of analyses are presented in the next section.

Statistical analyses were carried out by using various SAS regression analysis packages available at the University of Oklahoma mainframe computer system. SAS package has many regression analysis options such as REG, RSQUARE, STEPWISE, NLIN, RSREG, GLM, AUTOREG, SYSLIN, SYSNLIN, and PDLREG. In the present study, the GLM, RSQUARE and STEPWISE options were used.

The GLM procedure uses the method of least square to fit general linear models. GLM can include classification variables with discrete levels, as well as continuous variables, which measure quantities. GLM can be used for both simple as well as multiple regression analysis.

RSQUARE procedure selects optimal subsets of independent variables in a multiple regression analysis. The largest and the smallest number of independent variables in a subset and number of subsets of each size can be specified. The R^2 statistic is the criterion for selecting subsets.

The STEPWISE procedure is most helpful for exploratory analysis because it can give an insight into the relationships between the independent variables and the dependent or response variable. STEPWISE has five different methods for developing a regression model. The forward-selection (FORWARD) technique begins with no variables in the model. For each of the independent variables, the package (FORWARD) calculates the F statistics reflecting the variables contribution to the model, if it is included. FORWARD adds the variable that has the largest F statistic to the model. It then calculates F statistics for the variables still remaining outside the model, and the evaluation process is repeated. Variables are added one by one to the model until no remaining variable produces a significant F statistic.

The backward elimination technique (BACKWARD) begins by calculating the F statistics for a model, including all of the independent variables. Then the variables are deleted from the model one by one until all the variables remaining in the model produce F statistics significant at the specified level. At each step, the variable showing the smallest contribution to the model is deleted. The STEPWISE technique is a modification of the forward selection technique and differs in that the variables already present in the model do not necessarily stay there. After a variable is added, stepwise method looks at all the variables already included in the model and deletes a variable that does not produce a significant F statistic.

The MAXR method begins by finding the one-variable model producing the highest R^2. Then another variable, the one that yields the greatest increase in R^2, is added. Once the two-variable model is obtained, each of the two variables in the model is compared to the variables not present in the model. For each comparison MAXR determines if removing one variable and replacing it with another increases R^2. Comparisons begin again, and the process continues until MAXR finds that no switch could increase R^2. Thus, the two-variable model achieved is considered the "best" two-variable model the technique can find. Another variable is then added to the model, and the comparing and switching process is repeated to find the best three-variable model, and so forth.

The minimum R^2 improvement technique (MINR) closely resembles MAXR, but the switch chosen is the one that produces the smallest increase in R^2. For a given number of variables in the model, MAXR and MINR usually produce the same "best" model.

For the statistical analysis in the present study, the GLM technique was used to study the correlation of each parameter with the settlement. Based on the relative contribution of different variables, as depicted by their respective correlation coefficients, a number of variables was chosen. Procedure STEPWISE was then used to study the relative significance of each variable. The MAXR technique was used to evaluate the best possible model within the framework of realistic number of variables. The criterion to select a model was based on R^2 which is a measure of the usefulness of the model and is defined by:

$$R^2 = 1 - \frac{\Sigma\ (Y_i - \hat{Y}_i)^2}{\Sigma\ (Y_i - \bar{Y}\ )^2}$$

where $\hat{Y}_i$ is the predicted value of Y_i for the model and $\bar{Y}$ is the mean of the Y_is.

R^2 is a sample statistic that represents the fraction of the sample variation of the Y value that is attributable to the regression model. Thus $R^2 = 0$ implies a complete lack of fit of the model to the data set, and $R^2 = 1$ implies a perfect fit, with the model passing through every data point. In general, the larger the value of R^2, the better the model fits the data set.

Another statistic that can be used for selecting a model is "C_p" which is a measure of the total squared error defined as

$$C_p = \frac{SSE_p}{S^2} - (N - 2p)$$

where S^2 is the MSE (Mean Square Error) for the full model and SSE_p is the sum of squares error for a model with p variables plus the intercept. If C_p is graphed with p, the model where C_p approaches p is recommended. The results of both types of analyses are discussed in the next section.

5.3 Results

5.3.1 General

In level-one survey a total of 758 bridge approaches were surveyed. Of these 58 were on interstate, 622 on state highways and 78 on county roads. Of the 758 approaches 636 were on waterways and 122 were other types such as overpasses on highways or railways. 438 approaches were flexible while 320 were rigid pavements. The number of approaches in each division are shown in Table 5-1.

5.3.2 Results of exploratory analysis

The exploratory analysis was performed to assess the relationship of various approach characteristics with the settlement of the approach. The information from the database was extracted as necessary and tables and/or bar graphs were prepared to display these relationships. Initially the analysis was performed for all 758 bridge approaches. Subsequently it was found that a significant amount of data/information relating to the 78 county bridge approaches was missing because of the inadequate recordkeeping procedure. Hence the county bridges were excluded and the subsequent analyses were performed

Table 5-1. Divisionwise Distribution of the Bridge Approaches

Division	Number of Approaches	Flexible	Rigid	Total	Percent of Total Approaches
1	66	26	40	66	8.71
2	44	34	10	44	5.81
3	178	107	71	178	23.48
4	70	44	26	70	9.23
5	90	66	24	90	11.87
6	108	81	27	108	14.25
7	70	39	31	70	9.23
8	132	41	91	132	17.42
Total		438	320	758	

for the remaining 680 bridge approaches.

Figure 5-1 shows the statistics of different approach classification in each division. Three types of classification were considered:

SN: Approach settled but no maintenance performed

SM: Approach settled and maintenance performed

OS: No significant settlement evident

The same information is presented in tabular form in Table 5-2. Based on the present database, it is observed from Fig. 5-1 that Division 1 had the highest percentage (82%) of approaches under SM classification. The highest percentage (17%) of approaches under SN classification exists in Division 4, while Division 6 has the highest number of approaches in the OS classification. This indicates that the approaches in Division 6 have undergone less settlement than in other divisions. The percentages shown in Table 5-2 are for each division separately. Thus, of all the 132 approaches surveyed in Division 8, approximately 9.5% had settled but never maintained, 72.4% settled and maintained while 18.1% did not experience any settlement. Figure 5-2 shows the percentage of the approaches settled, i.e., in SM and SN category for each division. Overall 12% of the total approaches had settled but never maintained, 71.2% had settled and had been maintained and only 16.8% of the approaches did not experience any noticeable settlement. Thus, 83.2% of the approaches surveyed had experienced settlement.

Table 5-3 shows the bridge approaches in each division for different age groups. The same information is also presented in Figure 5-3. The highest percentage of the approaches fall in the above 30 years age group. Division 6 has the highest percentage (52%) of older bridges followed by Division 7, which has about 43% approaches older than 30 years. This may have resulted in

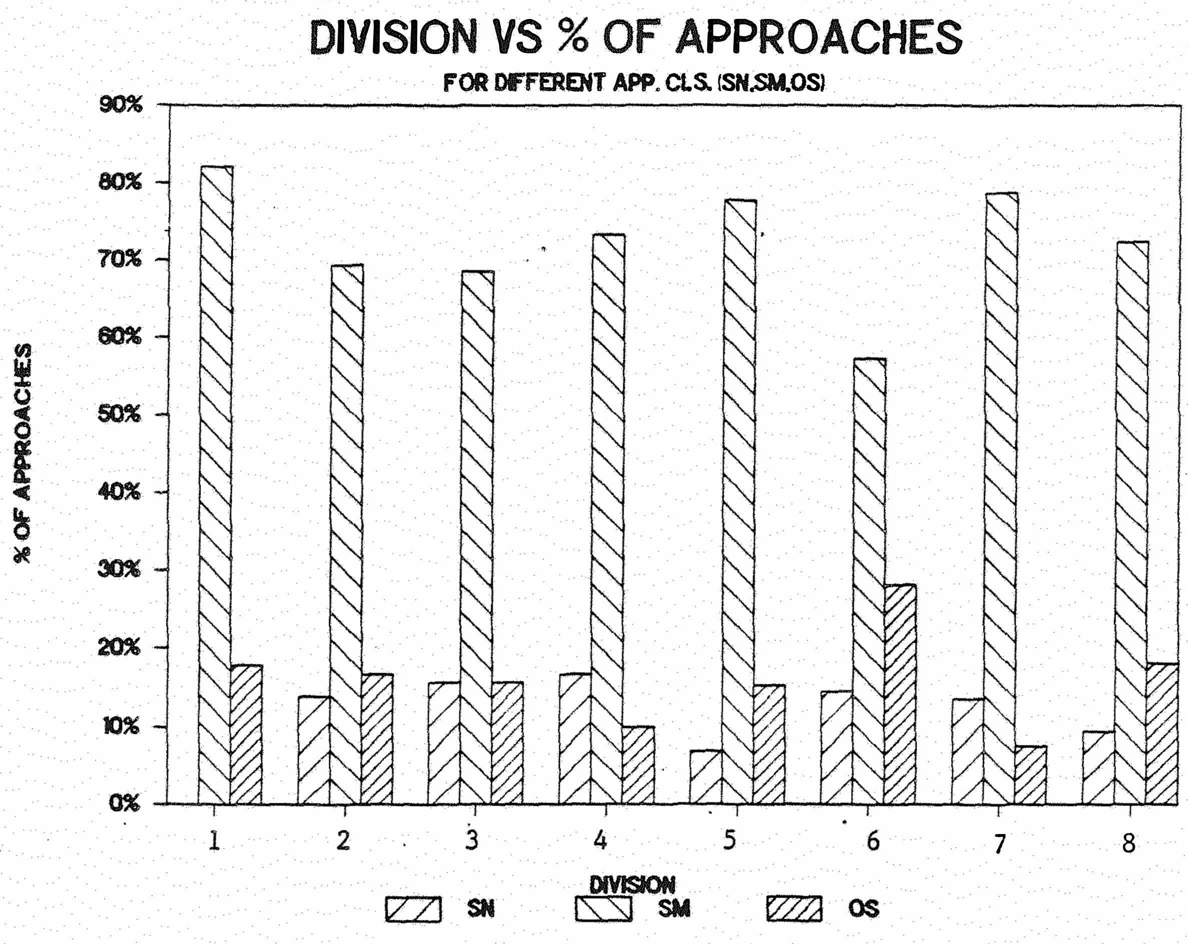

Fig. 5-1. Percentage of approaches under SM, SN and OS classification for each division.

Table 5-2. Statistics of Approach Classification

Division	Classification of Approach						
	SN		SM		OS		
	Number of Approaches	Percentage	Number of Approaches	Percentage	Number of Approaches	Percentage	Total Number Approaches
1	0	0	46	82.14	10	17.86	56
2	5	13.89	25	69.44	6	16.67	36
3	28	15.73	122	68.54	28	15.73	178
4	10	16.67	44	73.33	6	10.00	60
5	5	6.94	56	77.78	11	15.28	72
6	14	14.58	55	57.29	27	28.13	96
7	9	13.64	52	78.79	5	7.57	66
8	11	9.48	84	72.41	21	18.11	116
Total	82		484		114		680

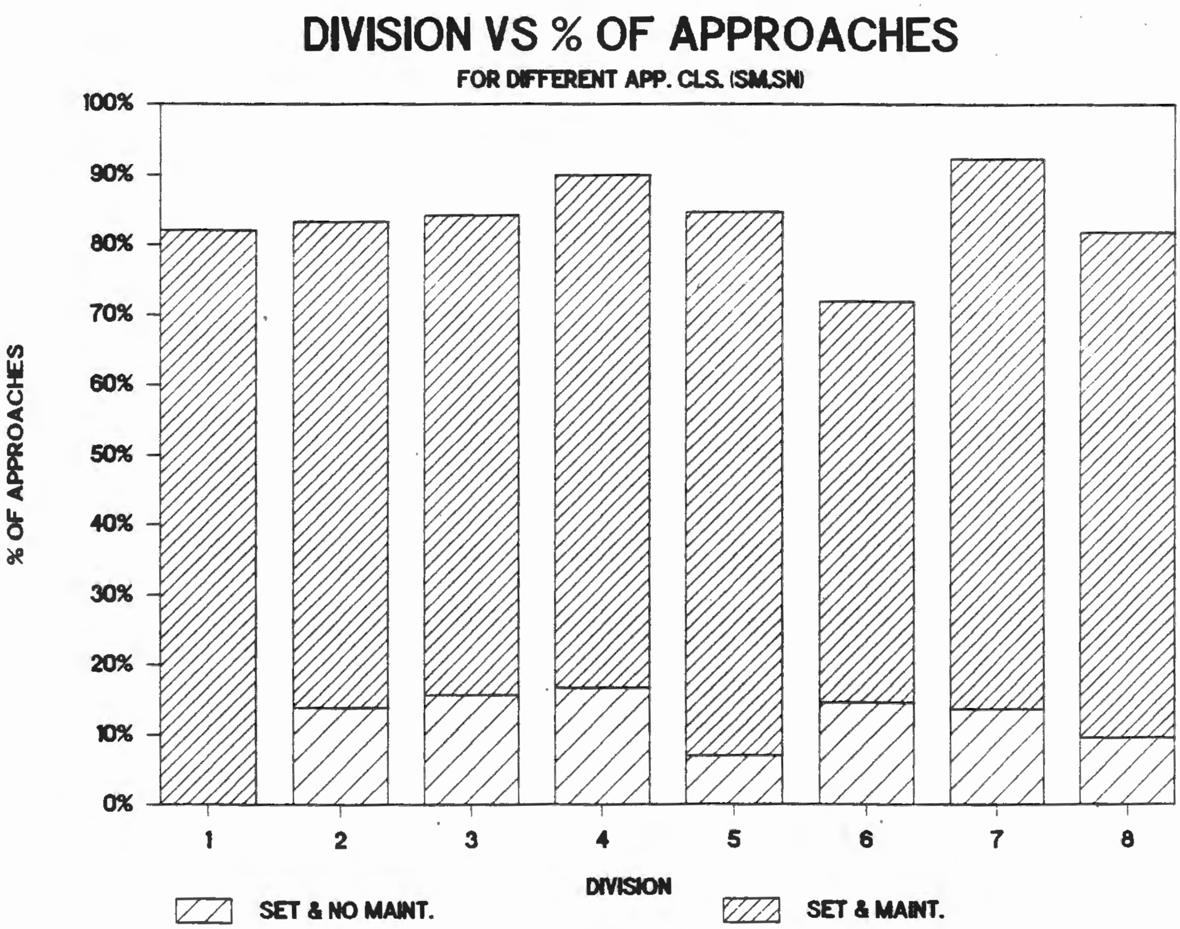

Fig. 5-2. Stack bar showing the percentage of approaches experiencing settlement (SM & SN) in each division.

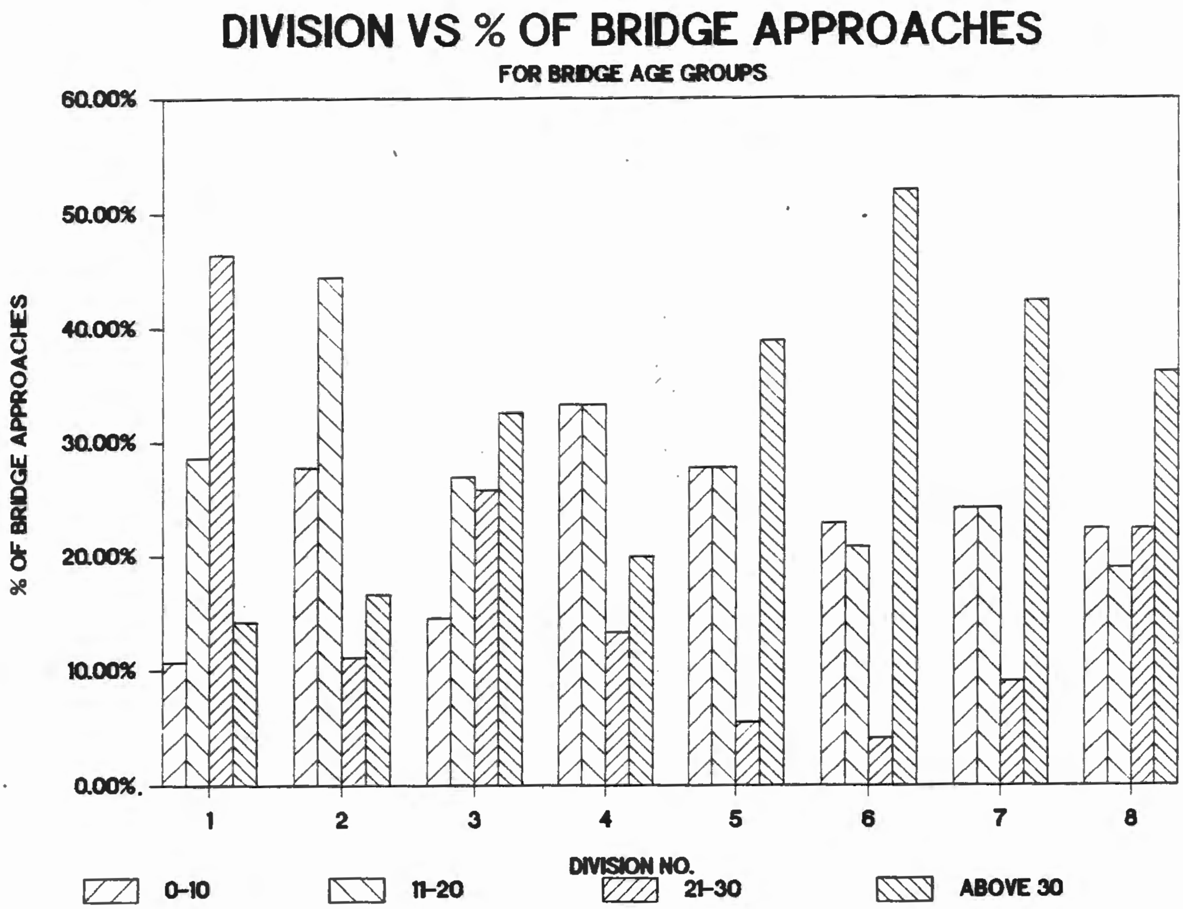

Fig. 5-3. Percentage of approaches for various age groups in each division.

Table 5-3. Division versus Number of Bridge Approaches (for different age groups)

Division	Age, yrs. 0-10 Number	0-10 Percent	11-20 Number	11-20 Percent	21-30 Number	21-30 Percent	Above 30 Number	Above 30 Percent	Total Number of Approaches
1	6	10.71	16	28.57	26	46.43	8	14.29	59
2	10	27.78	16	44.44	4	11.11	6	16.67	36
3	26	14.61	48	26.97	46	25.84	58	32.58	178
4	20	33.33	20	33.33	8	13.33	12	20.00	60
5	20	27.78	20	27.78	4	5.56	28	38.89	72
6	22	22.92	20	20.83	4	4.17	50	52.08	96
7	16	24.24	16	24.24	6	9.09	28	42.42	66
8	26	22.41	22	18.97	26	22.41	42	36.21	116
Total	146		178		124		232		680

a larger error in estimating the approach settlement in these two divisions than in the other divisions.

Figure 5-4 shows the average settlement versus age of the approach relationships. It is seen that the average settlement of approaches for the age group 11-20 are much higher than that for age group 0-10. The settlement of age group 21-30 is only slightly higher than that of the previous age group (11-20). This implies that the major portion of the settlement of the approaches occur within the first 20 years. The approaches then become more stable. For age groups above 30 years, the settlement variation pattern is not very consistent. This may be attributed to two reasons:

(1) Though the approaches experience most of the settlement by the age of 30 years, some unusual developments, e.g., erosion or other factors may cause older bridges to undergo settlement in isolated cases. Thus, no consistent pattern may be expected .

(2) The information for the older bridges is likely subject to more inaccuracies because of the inadequate recordkeeping procedure, lack of input from maintenance personnel and the difficulty in estimating settlement in the field. Also, in many instances due to repeated overlaying, mudjacking, etc., it is difficult to estimate the actual settlement.

Figure 5-5 shows similar relationship for flexible and rigid pavements separately. It is observed that in the initial periods flexible pavements undergo a higher average settlement than rigid pavements. With the passage of time, the difference in average settlement is reduced. This was observed in similar studies conducted by Hopkins, et al. (1969) in Kentucky and by the California Department of Transportation (1985). Initially the stiffness of the rigid approaches keep the settlement lower but over a long period of time the rigid pavements undergo similar settlement as the flexible approaches.

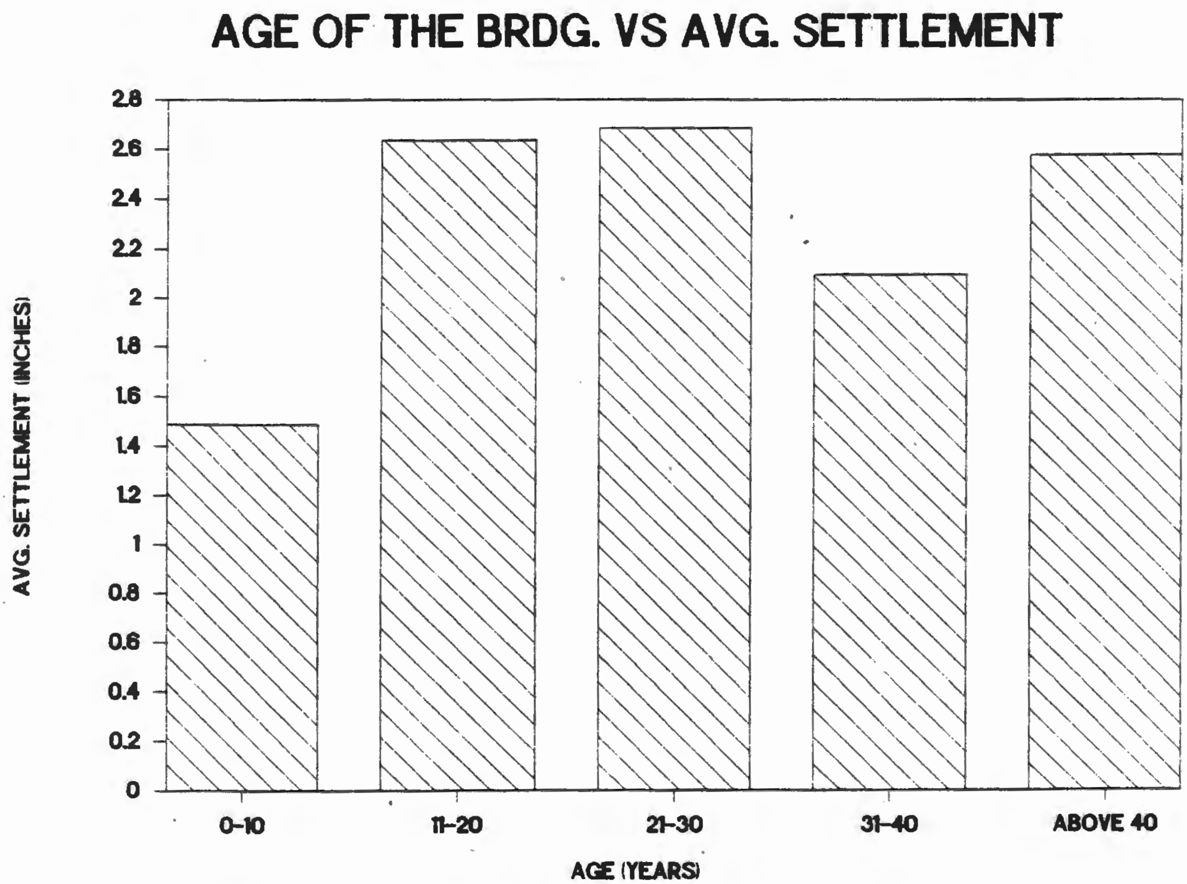

Fig. 5-4. Settlement vs. approach age relationship.

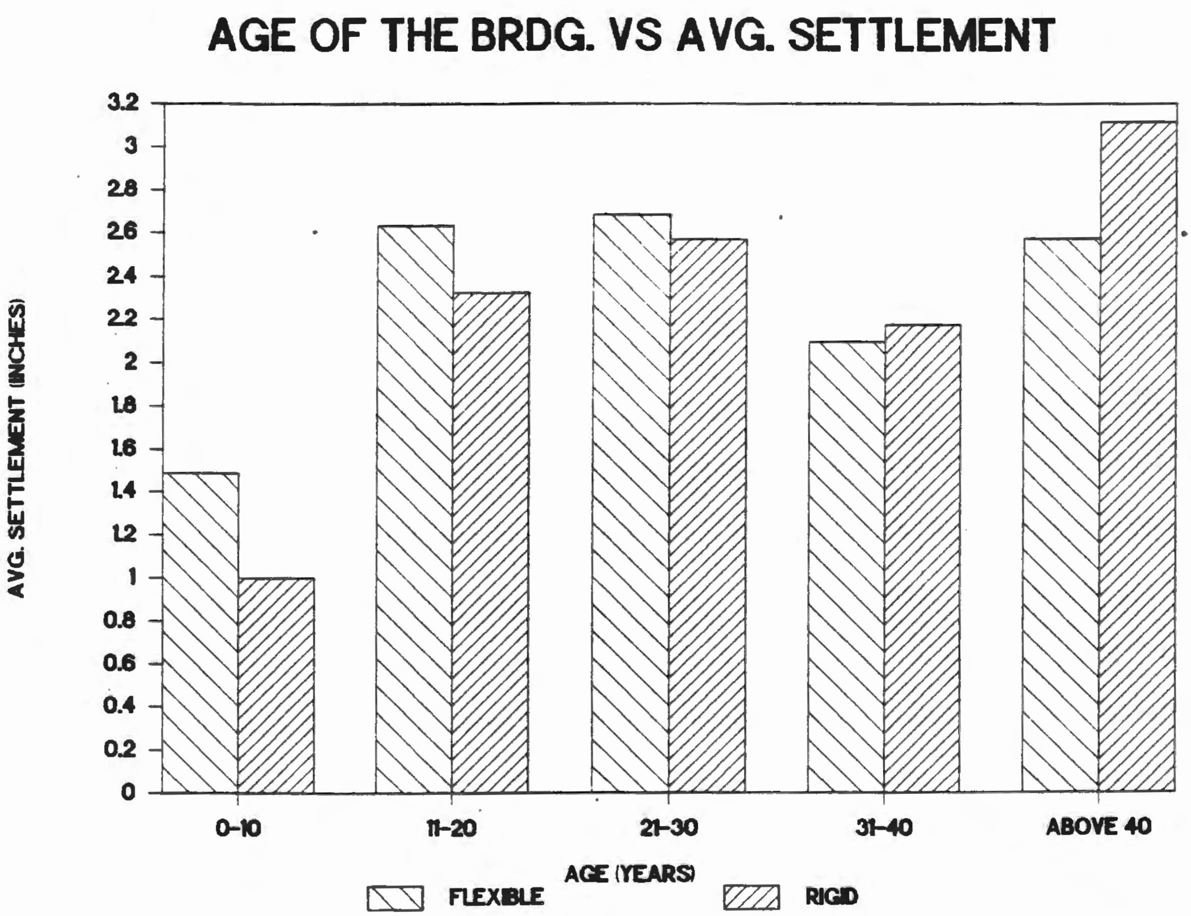

Fig. 5-5. Settlement vs. approach age relationship for flexible and rigid approaches.

For approaches older than 30 years, rigid approaches seem to have settled more than flexible approaches. This inconsistency in results may be attributed to the inaccuracies involved in estimating settlements of flexible approaches.

Figure 5-6 shows the average settlement of approaches for each division. This figure may not be representative of the problem that is in actual existence in different divisions. The average settlement in a division depends on the number and type of bridge approaches surveyed in that division. Selection of a larger number of older bridges in a division is likely to cause an overestimate of the average settlement in that division. More representative of the actual situation will be figures (e.g., Figs. 5-1 and 5-2) showing the percentage of approaches in each division under various classifications, such as SN, SM, and OS.

Figure 5-7 shows similar relationship as in Figure 5-6, for flexible and rigid pavements separately. Table 5-4 shows the divisionwise distribution of different abutment types. Figure 5-8 shows the average settlement versus abutment type (for pile- end- bent and stub only) relationship. In general, stub type abutments seem to be associated with less settlement than pile end bent type abutments. However, due to high skewness in data, the conclusions may not be reliable. Figure 5-9 shows the relationship between the settlement and the approach embankment height. It is observed that approaches with higher embankment height undergo larger settlements. This is consistent with the general expectation.

Figure 5-10 shows the relationship between approach settlement and the geologic unit as described in Appendix V. The bridge approaches were located in fifty-four different geologic units. All these geologic units were grouped under four broad categories for convenience.

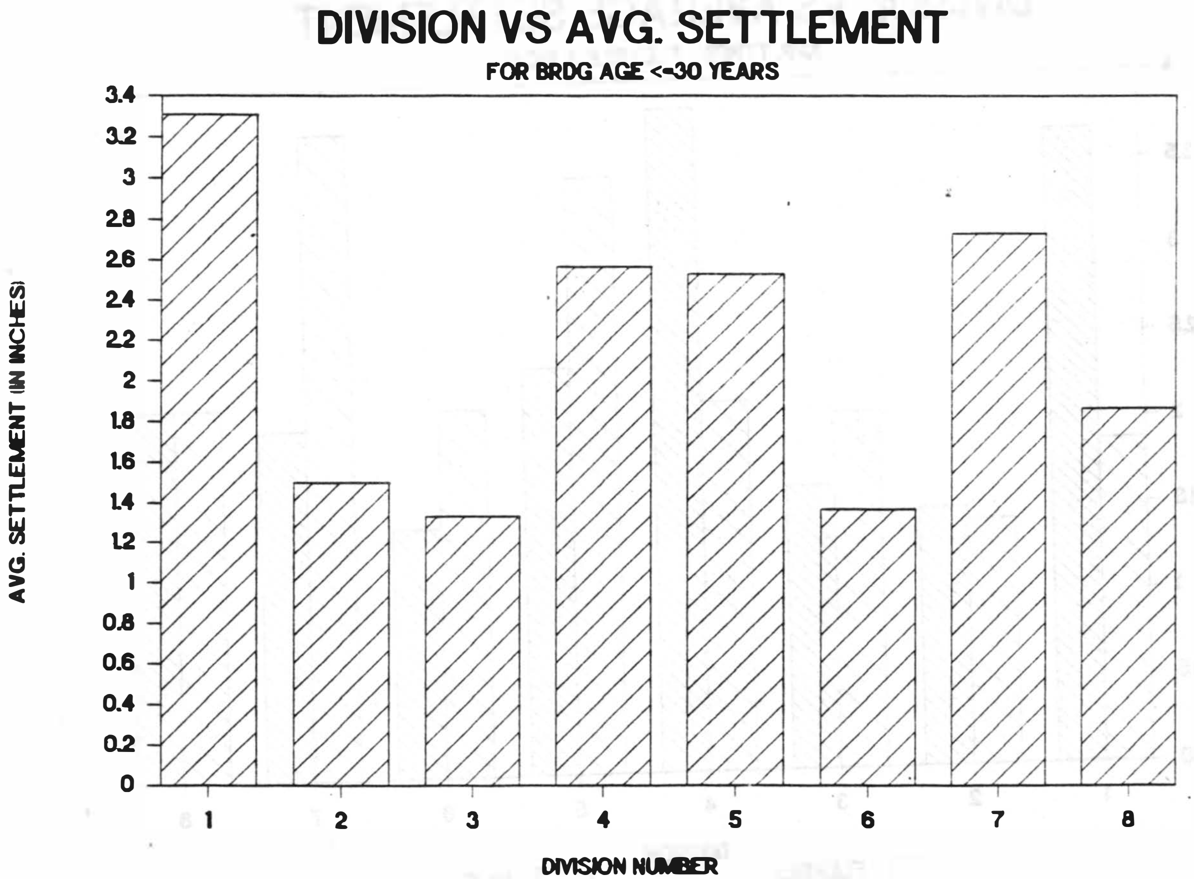

Fig. 5-6. Average settlement of approaches in each division.

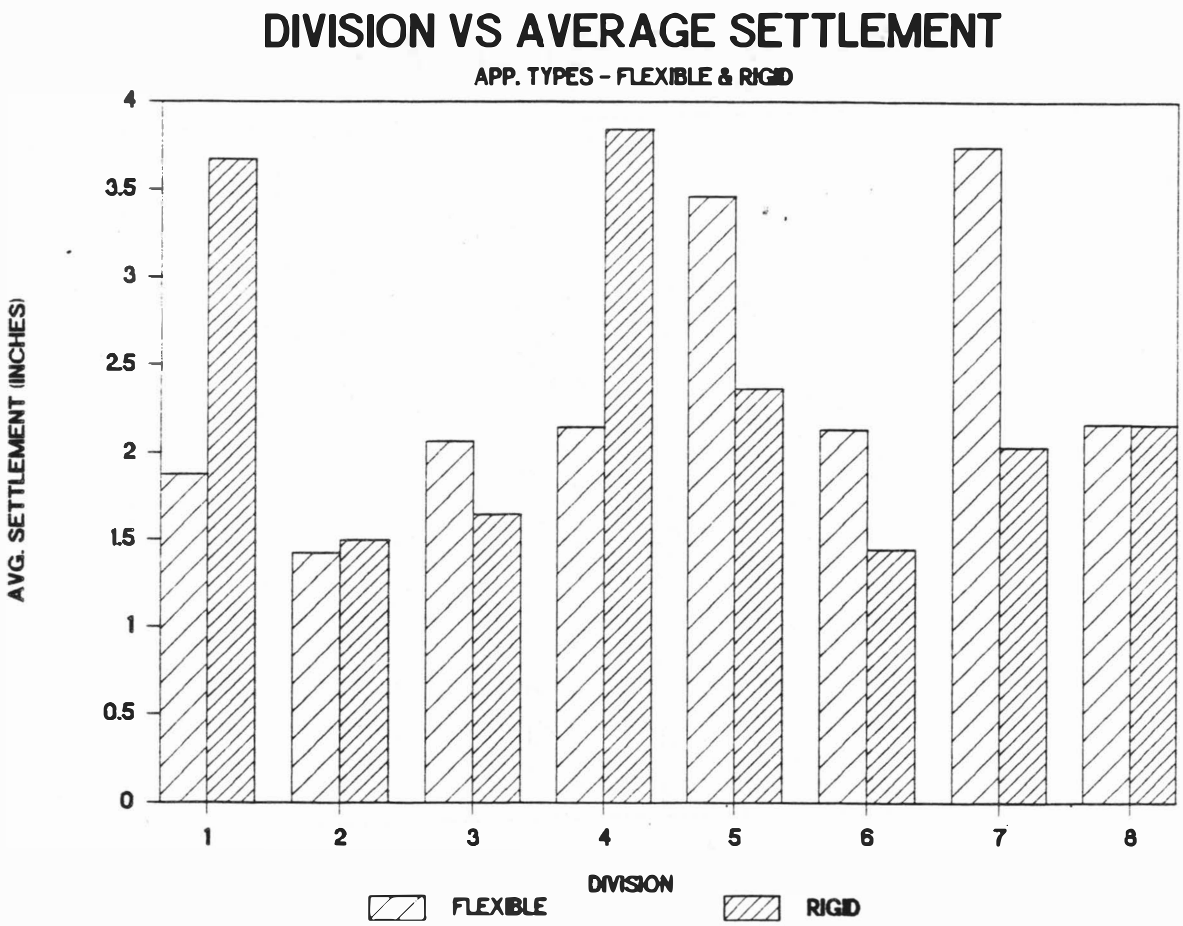

Fig. 5-7. Average settlement of approaches in each division for flexible and rigid approaches.

Table 5-4. Divisionwise Distribution of Different Abutment Types

Division	Type of Abutments			
	Pile end bent (PEB)	Stub	Open-column	Others
1	45	9	0	2
2	29	5	0	2
3	144	16	2	16
4	45	10	0	5
5	62	8	0	1
6	79	14	0	3
7	57	6	0	4
8	86	24	5	1
Total	547	92	7	34

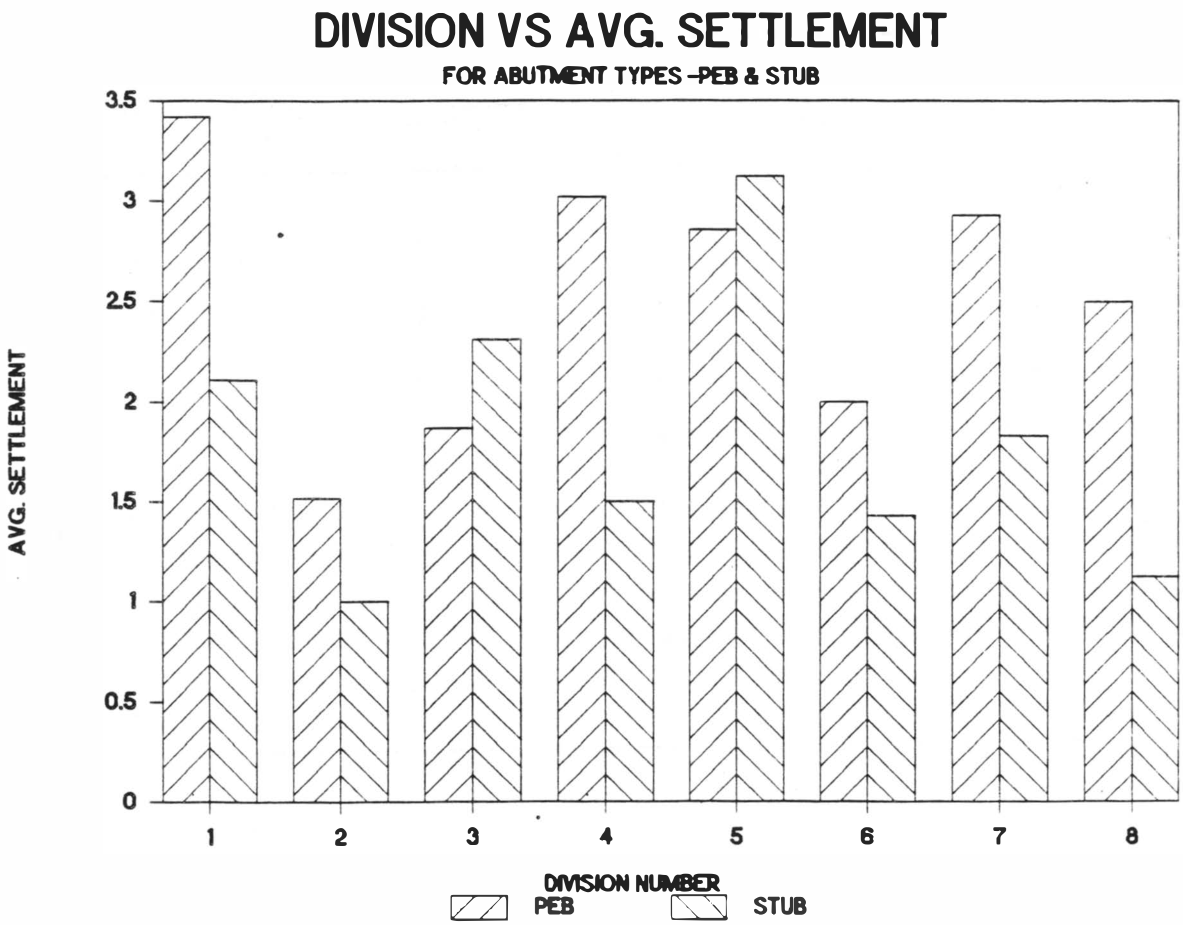

Fig. 5-8. Settlement vs. abutment type relationship.

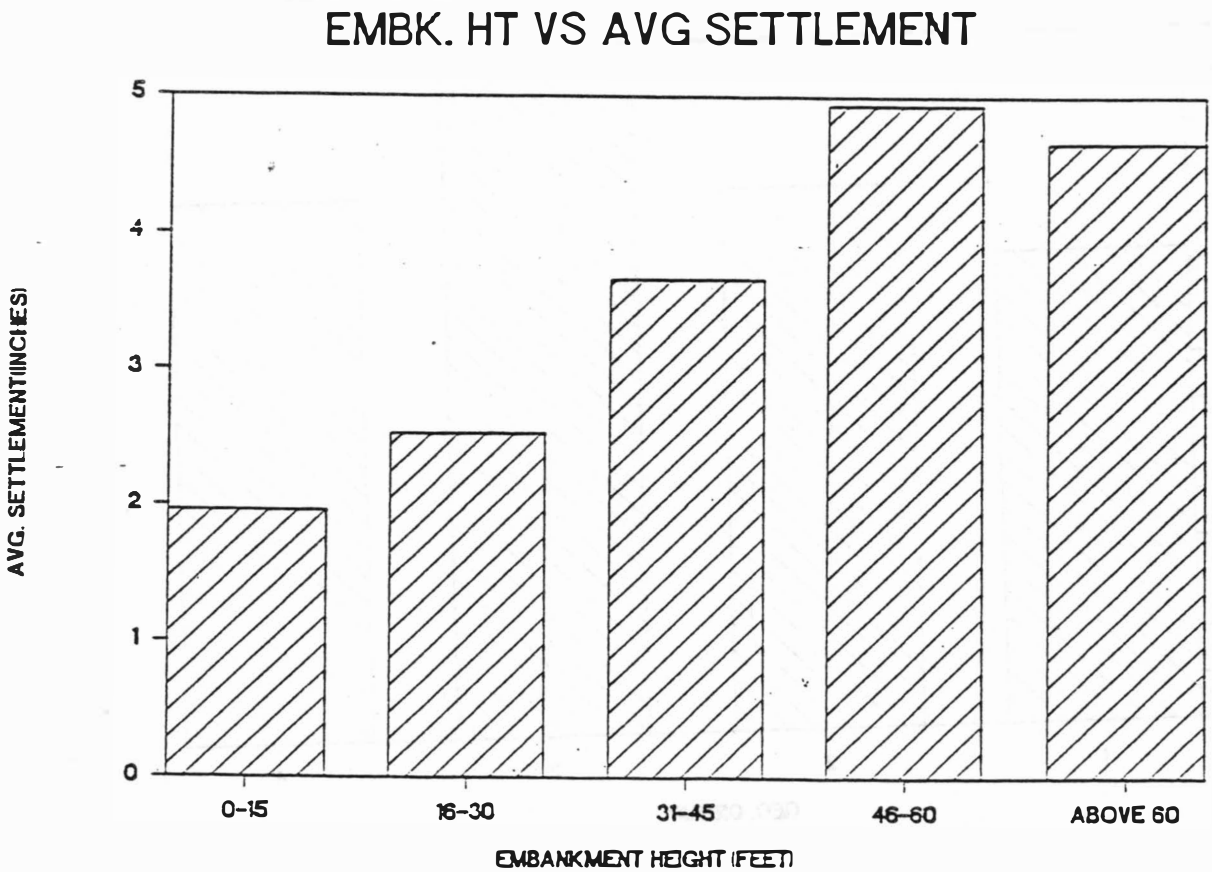

Fig. 5-9. Settlement vs. approach embankment height relationship.

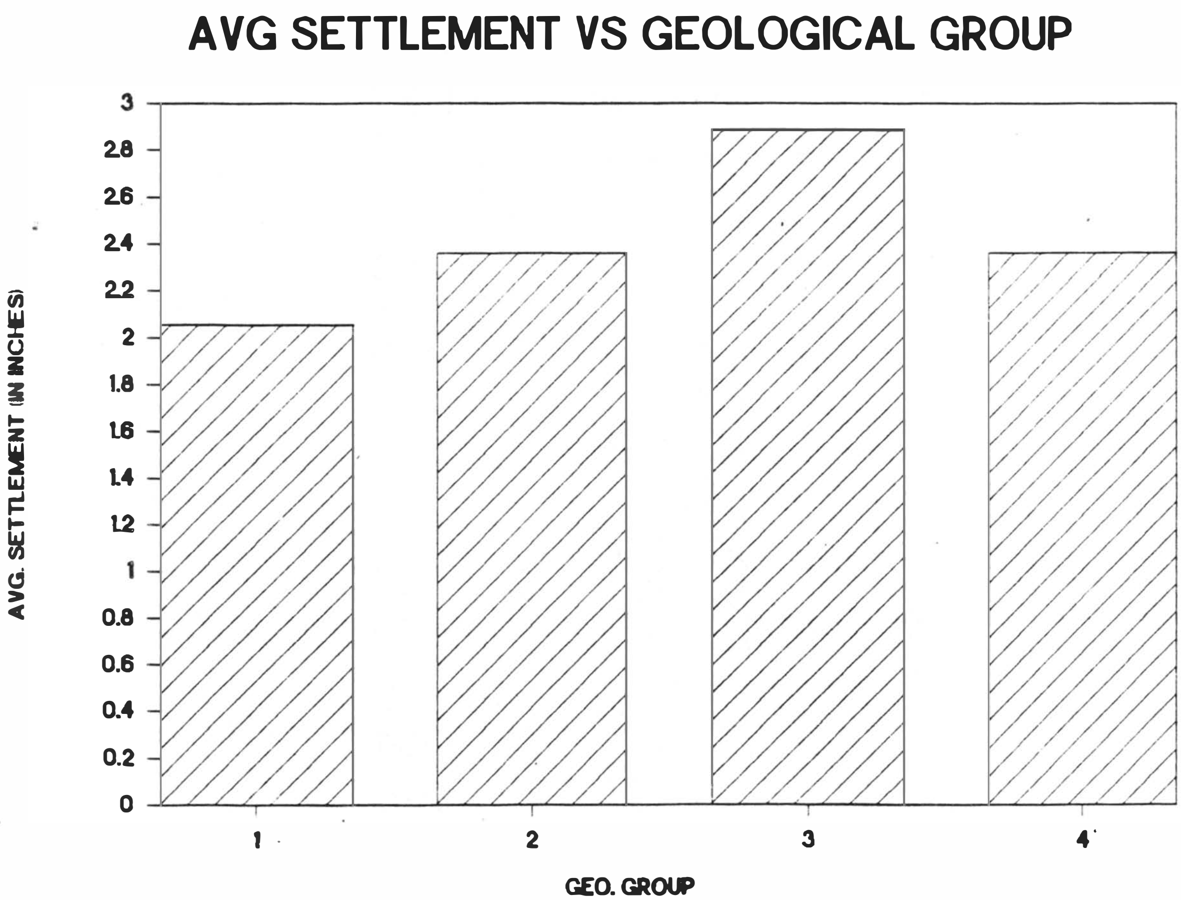

Fig. 5-10. Settlement vs. geologic unit relationship.

1. Shale

2. Sandstone, siltstone or loess

3. Limestone or gypsum

4. Interstratified or mixtures (includes alluvium and terrace)

It is observed that bridge approaches located on limestone or gypsum geologic unit undergo higher average settlement. The general expectation that alluvium soil would undergo larger settlement is not reflected here. The division of fifty-four geologic units into four broad categories may be too general to reflect the true picture. Figure 5-11 shows the relationship between approach settlement and foundation soil type. Twenty-eight different combinations of soil types based on AASHTO classifications were classified under three broad categories:

1. Coarse grained soils (more than 50% retained on No. 200 sieve).

2. Silts and clays (liquid limit 50% or less).

3. Silts and clays (liquid limit greater than 50%).

It is observed that higher settlement is associated with the approaches built on foundation of silts and clay with liquid limit 50% or less. Here again the findings should be judged carefully because thickness of the compressible layer was not taken into consideration due to lack of data and limited scope of the level-one survey. Generally, at a given site different layers will possess different degrees of compressibility. The approach settlement at the site would depend upon the total compressibility. Also, the amount of settlement will be influenced by the embankment height and other factors such as the level of compaction and drainage conditions. Therefore, isolating the effect of foundation soil type on approach settlement is probably not feasible.

5.3.3 Results of Statistical Analysis

As mentioned earlier, various SAS procedures were used to develop the em-

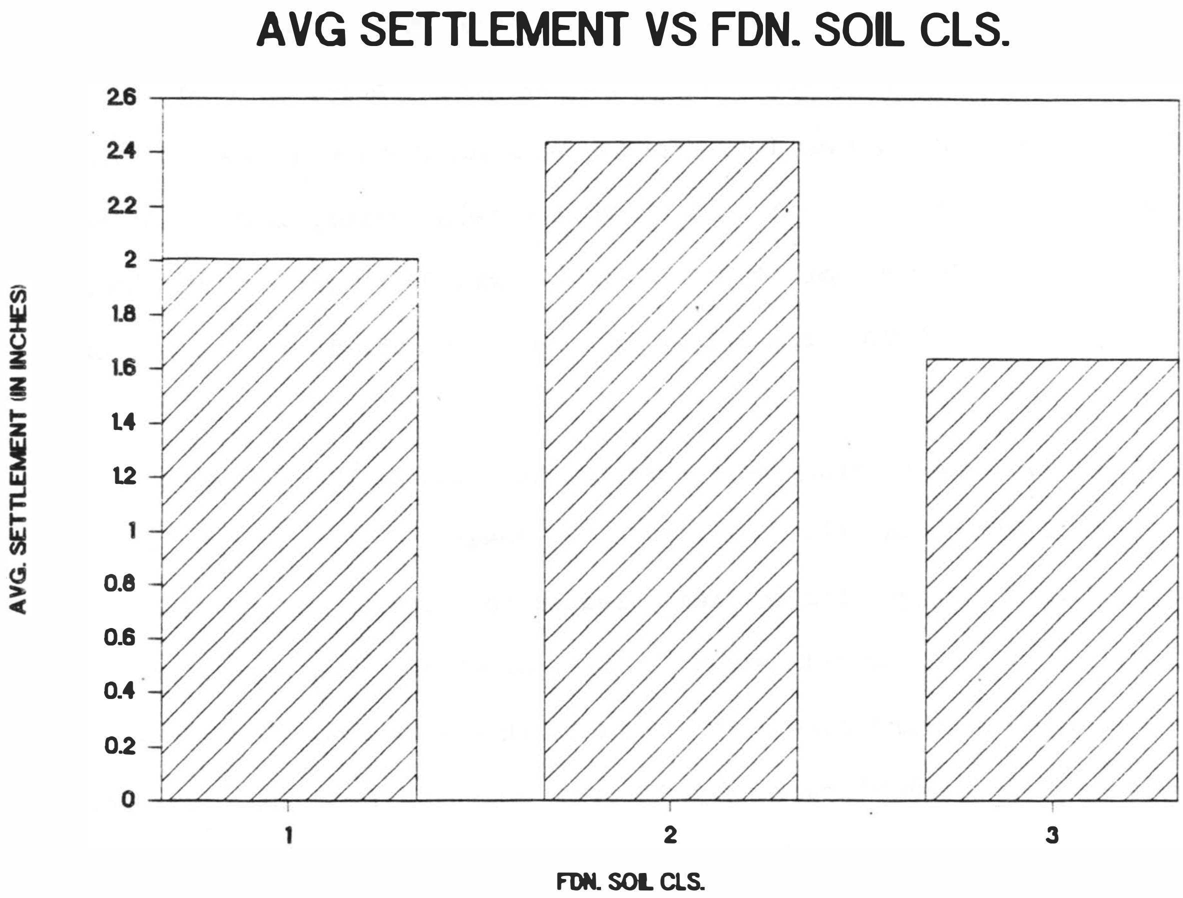

Fig. 5-11. Settlement vs. foundation soil type relationship.

pirical relationships between the approach settlement and various causative parameters. The response variable is the settlement of approach and the regressors are the causative factors such as age of the approach, embankment height, traffic, skewness of the approach, foundation soil depth, approach type, geologic unit, and foundation soil type. Of the eight factors considered in the regression analysis, five are quantitative and three are qualitative. It is realized that the approach settlements are influenced by other causative factors. Due to the lack of data and limited scope of the level-one survey, the regression analysis focused on these eight factors only. Initially the GLM procedure was used to assess the relationship of each parameter separately with the settlement. All possible relationships such as linear, quadratic, cubic, logarithmic, exponential, etc., were investigated. In the next step significant relationships were retained for a multiple regression analysis using the STEPWISE procedure. The following generic model was used for the multiple regression analysis:

TSET = AGE AGE2 AGE3 LAGE EHGT EHGT2 EHGT3
LEHGT EAGE EEHGT SKEW SKEW2 SKEW3
TRAFFIC TRAFFIC2 ESKEW LSKEW LTRAFFIC

where

TSET = Total approach settlement, inch

AGE = Age of the approach, years

AGE2 = AGE^2; AGE3 = AGE^3; LAGE = Log (AGE); EAGE = e^{AGE}

EHGT = Embankment height, ft.

EHGT2 = $EHGT^2$; EHGT3 = $EHGT^3$; LEHGT = Log (EHGT); EEHGT = e^{EHGT}

SKEW = Skewness of the approach, degree

SKEW2 = $SKEW^2$; SKEW3 = $SKEW^3$; LSKEW = Log (SKEW); ESKEW = e^{SKEW}

TRAFFIC = Average daily traffic (number)

$TRAFFIC2 = TRAFFIC^2$; LTRAFFIC = Log (TRAFFIC)

The above eighteen regressors were used to find the empirical equation. Table 5-5 shows the results of the analysis for flexible approaches. Only the significant terms were retained in the analysis. The model R^2 is 0.74. Table 5-6 shows the results of analysis for "Rigid with asphalt overlay" approaches. The model R^2 is 0.975. Table 5-7 shows the result for "Rigid" approaches. The model R^2 in this case is 0.881.

Though the model R^2 for these three cases shows a good correlation, the resulting model is not very reliable because certain regressors like Log (SKEW) resulted in the elimination of a large number of data points. Also it was observed that the exponential terms did not have any significant contribution towards the model, and hence multiple regression was carried out excluding the exponential terms and Log (SKEW). Table 5-8 shows the result for flexible approaches with the model $R^2 = 0.496$. Table 5-9 shows the results for "rigid with asphalt overlay" approaches. The model R^2 for this case is 0.673. Table 5-10 shows the result for rigid approaches. The model $R^2 =$ 0.605. Though the R^2 here is lower than for the model with 18 variables, this model will be more reliable because of the number of data points used for its development is significantly more than in the other cases. The equations may be expressed as follows:

<u>Flexible</u>:

$$\begin{aligned} TSET = {} & .000011\ AGE^3 + .639760\ \text{Log}\ (AGE) - .000037\ (EHGT)^3 \\ & + .323710\ \text{Log}\ (EHGT) - .004373\ SkEW \\ & + .008223\ \text{Log}\ (TRAFFIC) + .002497\ (AGE \times EHGT) \end{aligned} \quad (5.1)$$

<u>Rigid with asphalt overlay</u>:

$$\begin{aligned} TSET = {} & .000150\ AGE^3 - 4.206597\ \text{Log}\ (AGE) - .000015\ (EHGT)^3 \\ & + 2.658108\ \text{Log}\ (EHGT) + .029693\ (SKEW) \\ & - .000913\ (AGE \times EHGT) + .606243\ \text{Log}\ (AGE \times TRAFFIC) \end{aligned} \quad (5.2)$$

Table 5-5 Stepwise Regression for Flexible Approach (18 Variables)

R SQUARE =	0.740245		C(P)=	9.899822	
	DF	SUM OF SQR.	MEAN SQUARE	F	PROB>F
REGRESS	11	442.666487	40.242408	11.920000	0.0001
ERROR	46	155.333513	3.376815		
TOTAL	57	598.000000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
AGE	-10.474919	4.254717	20.467619	6.06	0.0176
AGE2	0.421455	0.184141	17.689213	5.24	0.0267
AGE3	-0.006739	0.003114	15.816109	4.68	0.0357
LAGE	36.990612	13.637931	24.842390	7.36	0.0094
EHGT	-3.050903	1.336335	17.600827	5.21	0.0271
EGHT2	0.089156	0.043109	14.443255	4.28	0.0443
EGHT3	-0.001022	0.000539	12.168830	3.6	0.0639
LEHGT	13.914162	5.818826	19.308596	5.72	0.0209
TRAFFIC	0.003564	0.001127	33.770930	10	0.0028
TRAFFIC2	-0.000000	0.000000	24.942227	7.39	0.0092
LTRAFFIC	-3.664198	0.988225	46.425131	13.75	0.0006

TABLE 5-6 Stepwise Regression for Rigid Approach with Asphalt Overlay (18 Variables)

R SQUARE = 0.974766 C(P)= 11.402736

	DF	SUM OF SQR.	MEAN SQUARE	F	PROB>F
REGRESSION	13	726.200831	55.861602	35.66	0.0001
ERROR	12	18.799169	1.566597		
TOTAL	25	745.000000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
AGE	365.673197	114.753602	15.907833	10.15	0.0078
AGE2	-9.550760	3.067720	15.184547	9.69	0.009
AGE3	0.101280	0.033603	14.231626	9.08	0.0108
LAGE	-2032.212958	629.105051	16.347431	10.43	0.0072
EHGT	-49.816004	13.639485	20.897736	13.34	0.0033
EGHT2	1.130499	0.317243	19.893618	12.7	0.0039
EGHT3	-0.010695	0.003221	17.272561	11.03	0.0061
LEHGT	339.757700	94.742275	20.146909	12.86	0.0037
SKEW	134.547099	41.785109	16.242879	10.37	0.0074
SKEW2	-3.872584	1.202106	16.258240	10.38	0.0073
SKEW3	0.034978	0.010866	16.231824	10.36	0.0074
TRAFFIC	-0.001415	0.000366	23.451350	14.97	0.0022
TRAFFIC2	0.000000	0.000000	24.957976	15.93	0.0018

Table 5-7 Stepwise Regression for Rigid Approach (18 Variables)

R SQUARE = 0.880511 C(P)= 8.132199

	DF	SUM OF SQR.	MEAN SQUARE	F	PROB>F
REGRESSION	7	309.059214	44.151316	41.06	0.0001
ERROR	39	41.940786	1.075405		
TOTAL	46	351.000000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
AGE	-0.363550	0.081254	21.528609	20.02	0.0001
LAGE	3.473123	0.631469	32.531801	30.25	0.0001
EHGT	-0.443136	0.089874	26.144667	24.31	0.0001
EHGT2	0.017206	0.003621	24.271746	22.58	0.0001
EHGT3	-0.000157	0.000039	17.698538	16.46	0.0002
EAGE	0.000000	0.000000	49.901625	46.4	0.0001
SKEW2	0.000944	0.000194	25.497067	23.71	0.0001

Table 5-8 Stepwise Regression for Flexible Approach (14 Variables)

R SQUARE = 0.49611086 C(P)= 7.00000000

	DF	SUM OF SQR.	MEAN SQUARE	F	PROB>F
REGRESS.	7	1257.641040	179.663006	26.3	0.0001
ERROR	187	1277.358960	6.830797		
TOTAL	194	2335.000000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
AGE3	0.000011	0.000062	0.220474	0.03	0.8576
LAGE	0.639761	0.370605	20.355568	2.98	0.086
EHGT3	-0.000038	0.000028	12.745666	1.87	0.1736
LEHGT	0.323711	0.473015	3.199159	0.47	0.4946
SKEW	-0.004374	0.010268	1.239584	0.18	0.6706
LTRAFFIC	0.008224	0.174032	0.015252	0	0.9624
AGEHGT	0.002497	0.002951	4.891834	0.72	0.3985

Table 5-9 Stepwise Regression for Rigid Approach with Asphalt Overlay (14 Variables)

R SQUARE = 0.672541 C(P)= 7.000000

	DF	SUM OF SQR.	MEAN SQUARE	F	PROB>F
REGRESS.	7	854.127414	122.018202	17.31	0.0001
ERROR	59	415.872586	7.048688		
TOTAL	66	1270.000000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
AGE3	0.000151	0.000073	29.704707	4.21	0.0445
LAGE	-4.206597	1.284317	75.618075	10.73	0.0018
EHGT3	-0.000015	0.000011	12.676370	1.8	0.185
LEHGT	2.658109	1.001882	49.615817	7.04	0.0102
SKEW	0.029694	0.018520	18.120231	2.57	0.1142
AGEHGT	-0.000913	0.002180	1.236435	0.18	0.6769
LAGETRAF	0.606244	0.362216	19.745455	2.8	0.0995

Table 5-10 Stepwise Regression for Rigid Approach (14 Variables)

R SQUARE = 0.605047 C(P)= 7.000000

	DF	SUM OF SQR.	MEAN SQUARE	F	PROB>F
REGRESSION	7	812.577932	116.082562	33.27	0.0001
ERROR	152	530.422068	3.489619		
TOTAL	159	1343.000000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
AGE3	-0.000033	0.000032	3.653750	1.05	0.3078
EHGT3	-0.000003	0.000003	3.329755	0.95	0.3302
LEHGT	-0.079418	0.328941	0.203412	0.06	0.8095
SKEW	0.010870	0.008732	5.407641	1.55	0.2151
LTRAFFIC	0.069696	0.302477	0.185269	0.05	0.8181
AGEHT	0.003869	0.001159	38.896133	11.15	0.0011
LAGETRAF	-0.022570	0.234192	0.032413	0.01	0.9233

Rigid:

$$TSET = .000032\ AGE^3 - .000003\ EHGT^3 - .079417\ Log\ (EHGT)$$
$$+ .010869\ (SKEW) + .069695\ Log\ (TRAFFIC)$$
$$+ .003868\ (AGE \times EHGT) - .022570\ Log\ (AGE \times TRAFFIC) \qquad (5.3)$$

In equations (5.1) through (5.3), the form of the independent variables are based on the preliminary regression analyses. At present, more detailed statistical analyses are being pursued to improve upon these forms.

5.4 Ranking of Causative Factors

Many factors such as approach type, age of the approach, traffic, embankment height, embankment material, foundation soil type, foundation soil depth, drainage condition, construction technique, compaction of embankment material, skewness of the approach, creep of the embankment, erosion of embankment soil, etc., are believed to have influence on the settlement of the bridge approaches. In the level-one survey information was collected on selected items as discussed previously. Therefore, the statistical analyses were limited to only a few factors. The effect of some of the most important physical attributes such as compaction of embankment material, creep of the embankment, drainage, etc., could not be assessed because of unavailability of data/information. From the overall field survey and interviewing of the maintenance personnel, it is evident that for embankments of sandy material, erosion is one of the most important causes for the settlement. Since adequate drainage behind the abutment is not provided, water entering the embankment can easily erode the cohesionless material. Secondary creep of the embankment is a very important factor causing long term settlements, too. This was concluded by a study in Kentucky by Hopkins, et al. To assess the effect of secondary creep, instrumentation of the site is necessary.

In the statistical analysis performed, the procedure STEPWISE selects the most important factors first and in steps goes on selecting parameter according to their level of contribution in the model. The ranking of the quantitative variables chosen by the STEPWISE procedure is as follows:

1. Age of the bridge approach
2. Height of embankment
3. Average daily traffic
4. Skewness

It must be emphasized that in arriving at the above ranking, only preliminary statistical analyses were made. More sophisticated analysis procedures are being pursued at present for more accurate ranking of the causative parameters. From the analyses it is evident that the effect of qualitative variable such as approach type is significant. Separating the analysis for flexible, rigid with asphalt overlay and rigid pavements is likely to improve the prediction capability of the model. In the next phase, detail site-specific properties, to be determined as a part of the level-two survey, are expected to reveal the contribution of other important factors.

CHAPTER VI

COMPREHENSIVE STUDY OF TWO SELECTED SITES

6.1 Purpose of the Study

Although the level-one survey discussed in the preceding chapters provided some first-hand information and insight into the approach pavement settlement problems in the State, the information obtained from this survey is, to some extent, qualitative in nature, because the inputs are obtained from visual inspections of a site. The visual inspection of existing conditions may not provide the desired information for assessment of settlement history and the associated causative factors. A site which has been overlaid recently, may not show adequate evidence of previous maintenance operations such as mudjacking or local/level patching or previous overlaying, although such information is essential for estimating the approach settlement history. Also, site-specific material properties pertaining to compaction, creep, consolidation and drainage are required for a quantitative characterization of approach settlement. The important elements in this characterization process are the embankment and foundation soil characteristics. Most of the bridges which were surveyed during this study have either very limited or no information on such factors, particularly with respect to embankment soil.

Site specific embankment and foundation soil properties will be evaluated for some 20-30 sites across the State as a part of the "level-two" survey in Phase III. To prepare the desired background for the Phase III, with ODOT's approval the original (Phase II) proposal was modified to include comprehensive laboratory testing of soil sampled from two selected sites for the purpose of determining their site-specific embankment and foundation soil characteristics. The results of this study are presented in this chapter.

6.2 Overview of the Study Sites

In coordination with ODOT's Research, Materials and Bridge divisions approximately seven sites were selected initially for field visits. Each of these sites had experienced excessive settlement and the approach pavement had required very frequent maintenance. Along with some ODOT personnel, these sites were visited to visually inspect their present conditions, maintenance measure undertaken, geologic features of the area, embankment height, traffic volume and other factors having significance to approach settlement problem. Of these seven sites, the following two were selected for the study:

1. Bridge 63-23 WX0465 on US 270 in Pottawatomie County (Fig. 6-1.)
2. Bridge 67-02 X0894 on US 270 in Seminole County (Fig. 6-2.)

Both bridges are over twenty five years old and have apparently experienced settlements ranging from six to ten inches. They have been mudjacked, level patched and overlaid a few times. Other considerations in their selection were the considerable embankment height (25-30 ft.) and foundation soil thickness (over 40 ft.), since they are considered conducive to settlement. The traffic count on both the bridges is about 5000 vehicles per day.

Description of the foundation soil characteristics

According to the soil survey map of Seminole County, the foundation soil at the Wewoka Creek bridge area consists of Gowton loam or Tullahassee fine sandy loam. Generally these loams are deep, nearly level, somewhat poorly drained and are subject to frequent flooding. Typically, the surface layer is grayish brown fine sandy loam about 8 inches thick. The underlying material is pale brown fine sandy loam to a depth of about 30 inches. Below that are buried layers of an older soil. These layers are mottled, gray loam to a depth of about 4 feet and mottled, brown loam to a depth of 5 feet. Included

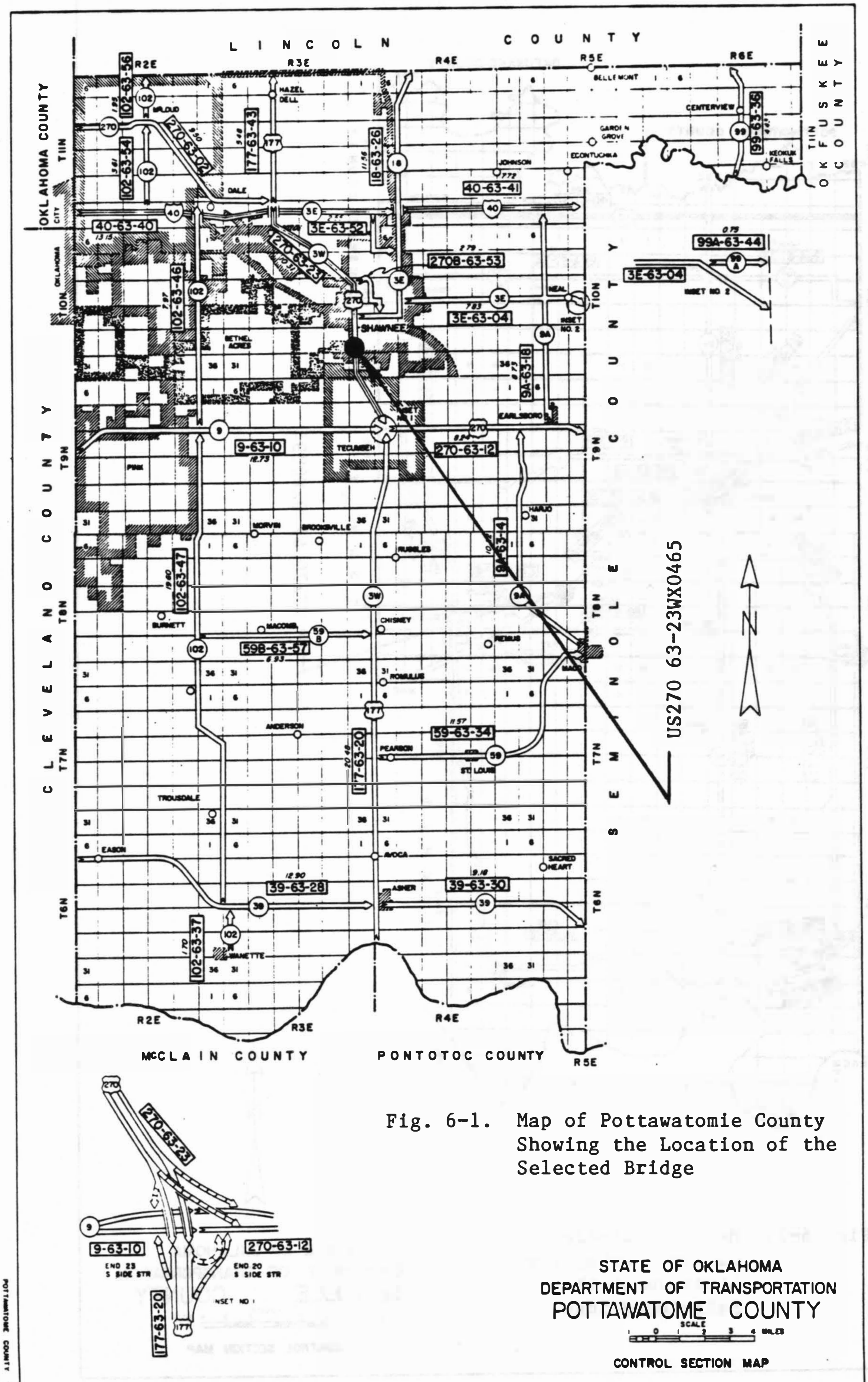

Fig. 6-1. Map of Pottawatomie County Showing the Location of the Selected Bridge

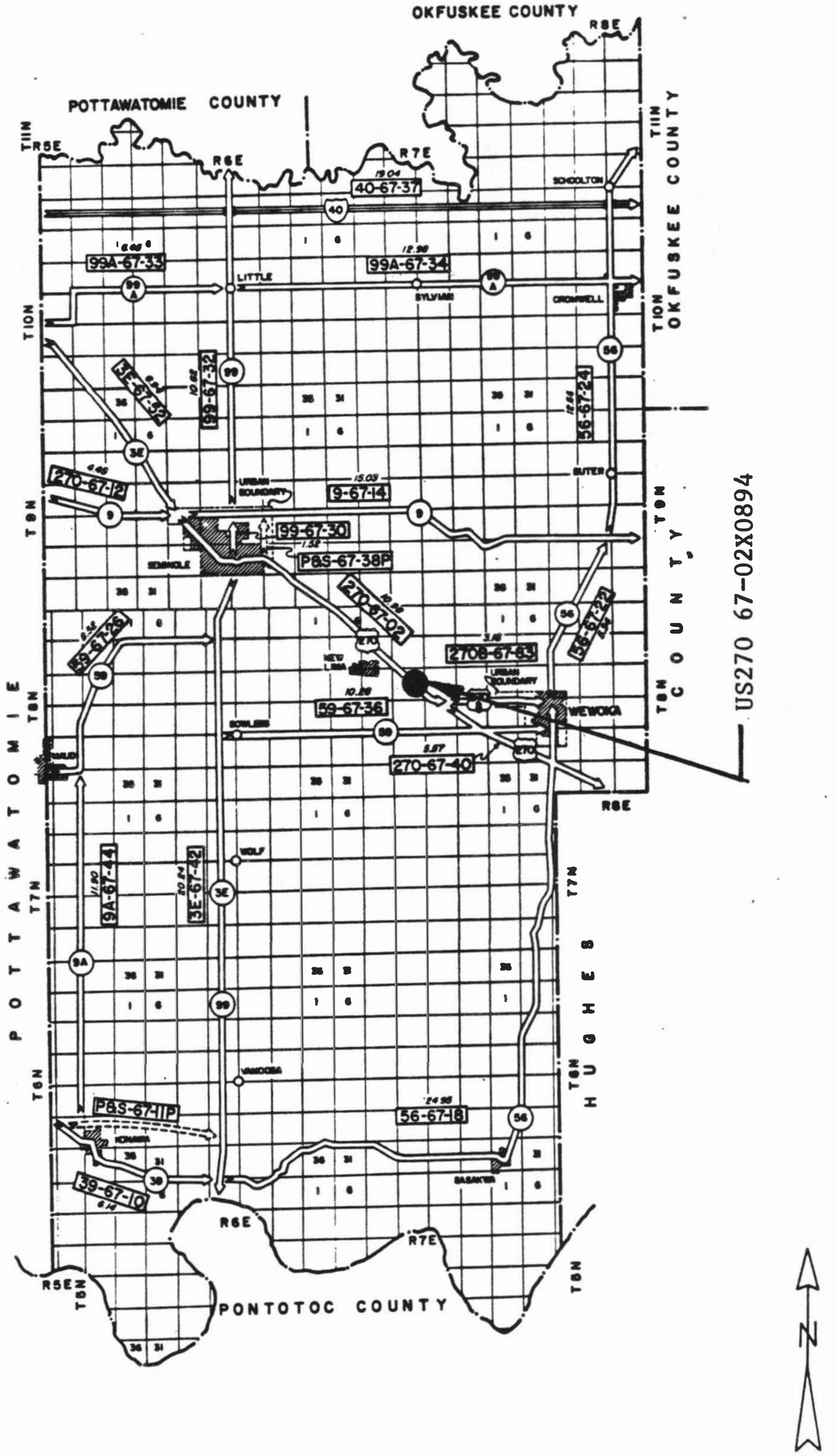

Fig. 6-2. Map of Seminole County Showing the Location of the Selected Bridge

STATE OF OKLAHOMA
DEPARTMENT OF TRANSPORTATION
SEMINOLE COUNTY
SCALE 1 0 1 2 3 4 MILES
CONTROL SECTION MAP

with this soil are soils that do not have buried layers within a depth of 5 feet and soils that have a water table at a depth of 3 to 5 feet during most of the growing season. The foundation soil thickness in this region ranges from about 30 - 100 ft. and probably averages about 50 ft. along major streams. Along minor streams the thickness ranges from a few feet to about 50 ft. and probably averages about 25 ft. Alluvium is a major aquifer in parts of the quadrangle. The soil composition at the bridge site in Pottawatomie County (referred to as the Shawnee site) consists of lenticular beds of sand, silt, clay and gravel. Thickness ranges from a few feet to almost 100 ft. and probably averages about 50 ft. along major streams. These deposits are major aquifers along the Cimmarron, the Canadian and the North Canadian rivers.

6.3 Soil Sampling

The soil sampling was done during the period November 1987 to May 1988 (Table 6.1) by the ODOT sampling crew with assistance from Materials, Research and Field divisions personnel. A total of seven borings were drilled at the two study sites, five on the approach pavement and two under the bridge. Drilling in borehole #4 was limited and was discontinued due to equipment failure. Location of the boreholes for the two sites are shown in Figs. 6.3 and 6.4. For each site, continuous sampling was done in at least one hole to obtain site-specific information (i.e., soil type, profile, etc.) and then an off-set hole was drilled to obtain undisturbed samples at desired depths. Standard penetration tests (SPT) were conducted at two boreholes, one at each site, to correlate the soil properties with the SPT values. At the Shawnee site, drilling was limited to one end of the bridge, while at the Wewoka Creek site both ends were drilled.

Samples were obtained both from the embankment and the foundation soil.

Table 6.1 Summary of the soil sampling boreholes

Borehole number	Location	Type of sampling			
		Drilling date	Continuous	Undisturbed	S.P.T.
1	US 270 63-23X0465 (under the bridge)	11-16-87	Yes	No	Yes
2	US 270 63-23X0465 (on the south approach)	11-17-87	Yes	No	No
3	US 270 67-02X0894 (on the west approach)	11-19-87	Yes	No	No
4	US 270 63-23X0465 (under the south approach)	12-1-87	No	*	No
5	US 270 67-02X0894 (under the bridge)	12-2-87	Yes	No	Yes
6	US 270 67-02X0894 (on the east approach)	12-3-87	Yes	No	No
7	US 270 73-23X0465 (on the south approach)	5-3-88	No	Yes	No

* Drilling was abandoned due to equipment failure.

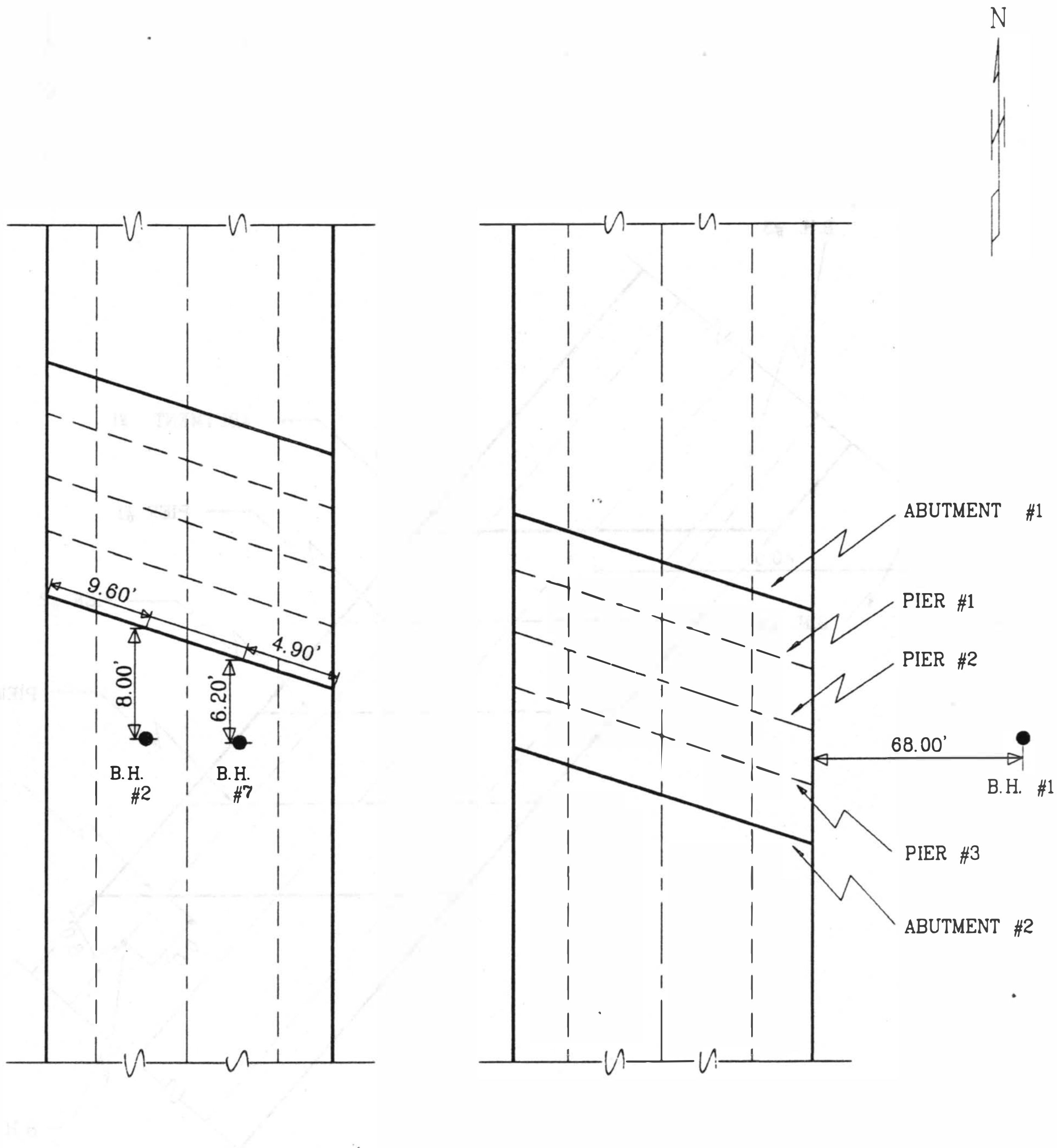

Fig. 6-3. Borehole Locations for Shawnee Site (US 270 63-23 X0465)

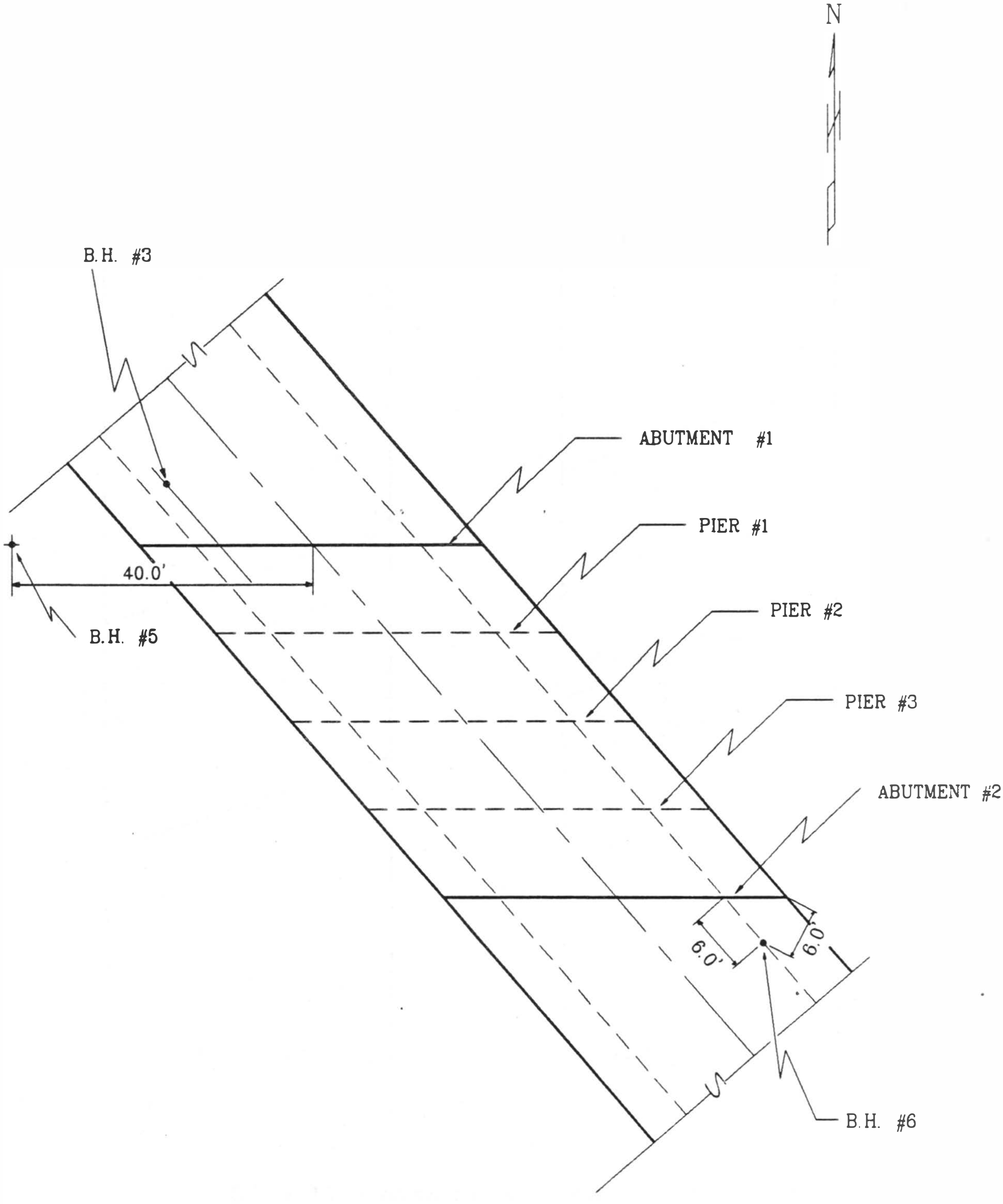

Fig. 6-4. Borehole Locations for the Wewoka Creek Site
(US 270 67-02 X0894)

Boreholes were located both under the bridge and on the embankment. Borings under the bridge were thought to be essential for two reasons: first, it reduced the drilling cost significantly due to the absence of the embankment, and second, it provided site-specific properties of the original foundation soil. Also, at some sites drilling under the bridge would be imperative where embankment height and foundation soil thickness are large and drilling down to the bedrock is necessary as was the case at the Wewoka Creek site where drilling over 90 feet through the approach embankment and foundation soil did not reach the bedrock. To examine the influence of compaction of abutment backfill, it was necessary to locate the boreholes on the embankment. Samples obtained from continuous boring were sealed in the polyethylene/plastic bags to avoid any substantial loss of moisture and were transported to the laboratory in the same day for laboratory testing. Undisturbed samples were collected at the desired depths using a push-tube type sampler. The push-tubes were sealed at both ends in the field and were transported to ODOT for extraction and waxing. The waxed samples were subsequently transported to the University of Oklahoma Soil Mechanics Laboratory for testing. Adequate precautions were taken to minimize the effects of disturbance and moisture loss/migration. Table 6.1 shows a summary of the type of sample collected and tests conducted at each site. For boreholes #1 (Shawnee site) and #5 (Wewoka Creek site) standard penetration tests (SPT) were conducted to provide an assessment of the in situ soil properties.

6.4 Estimate of Total Settlement

An attempt was made to estimate the total settlement by measuring the cumulative thickness of the overlays. A summary of the results for both sites is included in Table 6.2. A careful analysis of these results indicate that maintenance history could not be properly assessed from coring through the

Table 6.2 Pavement thickness measured from coring of pavement

Borehole number	Location	Thickness, ft.	
		asphalt overlay	concrete pavement
1	US 270 63-23X0465 (under the bridge)	N.A.*	N.A.
2	US 270 63-23X0465 (on the south approach)	0.19	1.16
3	US 270 67-02X0894 (on the west approach)	0.10	1.05
4	US 270 63-23X0465 (on the south approach)	0.19	1.16
5	US 270 67-02X0894 (under the bridge)	N.A.	N.A.
6	US 270 67-02X0894 (on the east approach)	0.08	0.98
7	US 270 63-23X0465 (on the south approach)	0.19	1.16

* not applicable

pavement alone for various reasons, such as:

1. A sample obtained by coring the approach pavement would exhibit the evidence of recent overlays, but it might not show the adequate evidences of all previous overlays.
2. Effect of mudjacking operation may not be evident from pavement coring particularly if the slurry used in mudjacking had not flown evenly and not been penetrated during the drilling operation.
3. Before putting a new level patch or overlay, the maintenance crew normally removes by scraping a portion of the old patching/overlay. A pavement core is unlikely to display such effects.

Each of the two sites has reportedly settled at least six inches, but the maximum cumulative thickness of overlays was found to be in the order of 2.4 inches. This demonstrates clearly that an assessment of total settlement from approach pavement coring is likely to provide an underestimate for the aforementioned and other reasons. Nonetheless, the information obtained from the coring of approach pavement was found extremely valuable for both sites. It demonstrated the extent of approach fault and provided an assessment of the previous maintenance measures. Coring of approach pavement at a site might display evidence of voids under the rigid approach pavement and consequently provide a basis for estimating the future settlements at the site. For example, drilling at the south approach (borehole #6) of the Wewoka Creek site showed a 5 inch void under the pavement indicating the possibility of further settlement at this site.

6.5 Laboratory Tests and Discussion of Results

Selection of laboratory tests was guided by the overall scope of the study - evaluation of approach settlement. The tests pertaining to soil type, compressibility and swelling characteristics were considered important.

Therefore the following tests were included: field moisture content, field density, Atterberg limits, grain size distribution, maximum dry density and consolidation.

Of the above tests, only field moisture test was performed on every sample of each borehole. Due to budgetary and time constraints, other tests were conducted on a selective basis. Also, the number of samples for each category of test varied depending on the time requirement for that test. Since a number of hydrometer tests can be conducted simultaneously, the number of hydrometer tests conducted was relatively large, compared with the number of consolidation tests which required more time. The selection of the samples for the tests was based on the physical description of the soil. Samples with similar descriptions and characteristics were grouped and one representative sample from the group was tested. Occasionally more than one sample was tested from the same group as a means of ascertaining the desired quality of the results. Table 6.3 shows a summary of the laboratory tests conducted in this study. All the tests were conducted according to AASHTO and ASTM specifications. The results of the tests are tabulated in Table IV.1 through IV.5 in Appendix IV.

The soil profiles obtained from continuous sampling at both sites are shown in Figure IV.1 through IV.5 in Appendix IV. Comparison of the profiles for boreholes #1 (drilled under the bridge) and #2 (drilled through the approach embankment) shows that at the Shawnee site the embankment height is approximately 30 ft. (at the location of the borehole #2) and it consists primarily of lean clay which is conducive to settlement. The foundation soil is comprised of lean clay up to a depth of approximately 3 ft., underlayed by sandy clay, silty sand and sand layers. The weathered shale, where the blow count (N values) was in excess of 50, exists at a depth of approximately 40

Table 6.3 Summary of Laboratory Tests Conducted

NO	TYPE OF TEST	BORE HOLES #2 Planned	#2 Completed	#3 Planned	#3 Completed	#4 Planned	#4 Completed	#5 Planned	#5 Completed	#6 Planned	#6 Completed	Total
1	O.M.C	7	7	11	11	NA	NA	NA	NA	2	2	20
2	Hydrometer	9	9	16	16	NA	NA	6	6	12	12	43
3	Consolidation	2	3	9	8	4	4	NA	NA	5	5	20
4	Field Dry Density	18	18	28	28	NA	NA	NA	NA	19	19	65
5	Atterberg Limits	20	20	31	31	NA	NA	NA	NA	17	17	68
6	Field Moisture Content	93	93	136	136	NA	NA	NA	NA	129	129	358
7	Approximate Gradation	19	19	21	21	NA	NA	NA	NA	19	19	59

N.A. = Not Applicable; O.M.C. = Optimum Moisture Content ft. from the original ground surface.

An analysis of profiles for boreholes #3, 5 and 6, all three pertaining to the Wewoka site, indicates that at this site the embankment height was in the order of 30 ft. but the foundation soil thickness was much larger (more than 60 ft.) compared with the Shawnee site. Both foundation and embankment soils at this site were of clay, silty clay and silty sand type, all appeared to have a high degree of compressibility and hence settlement. Relatively speaking, the Wewoka Creek site appears to be more conducive to settlement than the Shawnee site based on the soil characteristics alone.

Discussion of Results

At the Wewoka Creek site boreholes # 3 and # 6 were drilled on the west approach and under the bridge, respectively. From Tables IV.2 and IV.4 in Appendix IV it is evident that the field moisture content is greater than the optimum moisture content by as much as 8 percent. The field moisture content was in the range of 18 to 25 percent, while the optimum moisture content was substantially lower (only 15 to 18 percent). This condition might result in lower dry density and reduction of the bearing capacity of the soil. This problem of higher field moisture content may be related to improper or inadequate drainage provided for runoffs resulting from heavy rainfall. Since water was used in the drilling process, it is possible that the field moisture content may have been overestimated by a few percentage points. Nonetheless, high field moisture content creates an environment for more settlement due to reduced effective stress and lower shear strength. Large embankment height (average 28 ft.) has probably aggravated the settlement problem. The soil at this (Wewoka) site is mainly clay in the embankment and sand and silt in the foundation. At a depth of 20 ft., the liquid limit and the plasticity index were as high as 49 and 20, respectively. Based on the select materials currently used for approach embankments in several states, the fraction passing the No. 40 sieve shall have a liquid limit not to exceed twenty-five and a plasticity index not greater than six as determined by AASHO Test Methods. Also, the select backfill materials shall meet the following requirements:

Percent passing 2 inch sieve	100
Percent passing 1 inch sieve	70-100
Percent passing No. 4 sieve	30-75
Percent passing No. 10 sieve	20-60
Percent passing No. 40 sieve	10-35
Percent passing No. 200 sieve	0-10

Thus, both based on the gradation and flow criteria, this type of soil appears to be unsuitable for embankment construction and is susceptible to settlement. The compression index (C_c) values (0.0016 to 0.0078 in^2/min.) obtained from laboratory tests indicate that the upper soil layers are not as well compacted as the lower layers, because C_c values were relatively large for the upper layers. The results obtained for liquid limit and plasticity index indicate that the soil can be classified as sandy clay according to the Unified System. Although the soil samples appear to be quite uniform, they can be broadly divided into two categories: silt and clay. In borehole #3 (also at the Wewoka Creek site) the soil down to about 25 ft. has a liquid limit and plasticity index lower than the soil below it. In borehole #6 (under the bridge at the Wewoka Creek site), the clay content in the layer sandwiched between the topmost and the bottommost layer is significantly lower than in the other layers. Even with these variation of properties in the different layers, the soil type at this site can be approximately classified as, "sandy clay," under both the Unified and the AASHTO classification systems.

The soil at the second bridge site in Shawnee was sampled from two boreholes (#2 and #7). Analysis of results in Table IV.1 and IV.5 in Appendix IV indicate that the first five feet of the embankment soil at the Shawnee site is non-plastic. But the remaining embankment soil has higher liquid limit (LL) and plasticity index (PI) than acceptable for select backfill material. The maximum LL (48) and PI (29) for this case occurred at a depth of approximately 11 feet from the approach pavement surface. The gradation analysis, as in the previous case, indicates the presence of a very large percentage (as high as 84%) of silt/clay content which does not meet the criterion for select backfill material. At this site also the field moisture content was higher than the optimum moisture content, indicating susceptibility to settlement.

For boreholes #1 (Shawnee site) and #5 (Wewoka creek site) standard penetration tests (N values) were conducted and the results are shown in Figs. 6-5 and 6-6, respectively. Generally, the density of the soil increases with the increase in N values. In this case, the maximum N value (Fig. 6-5, Shawnee site) was of the order of 50 and occurred at a depth of approximately 37 ft. The minimum N value (10), on the other hand, occurred at a depth of 21 ft., indicating the presence of a relatively high compressible layer within the embankment. Overall, the N values suggest low penetration resistance at depths down to 27 ft. and then the values increase. The settlement problem may have been aggravated due to poor drainage condition of the site and the poor backfill materials used to construct the embankment.

6.6 Summary of Findings

The comprehensive study of the two selected sites was undertaken to obtain the desired background for the "level-two survey" which will be conducted in Phase III of the project. The findings of this study are summarized below:

1. Sampling and comprehensive laboratory and field testing of soil can provide the desired flow, strength and settlement-related properties of

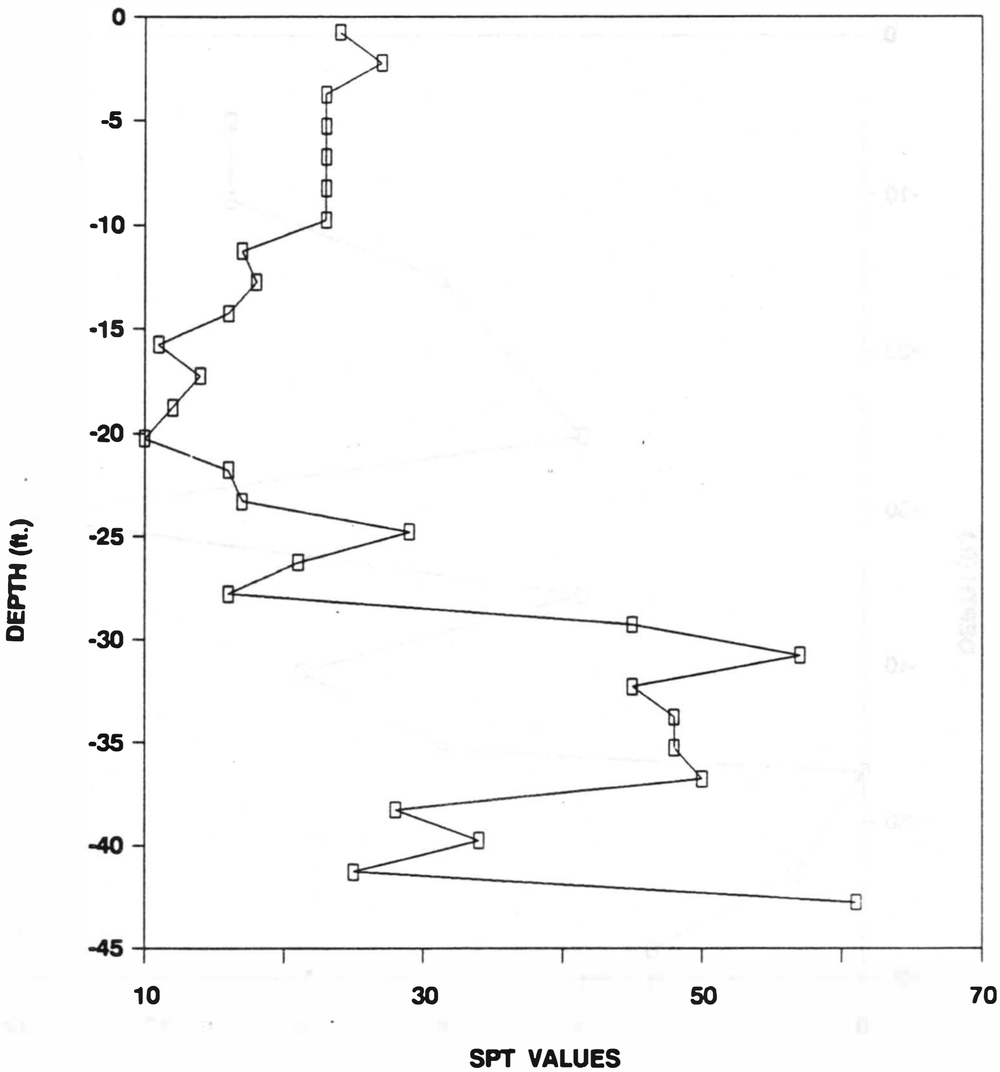

Fig. 6-5. Plot of Standard Penetration Test Values for Borehole #1 at Shawnee Site (US 270 63-23 X0465)

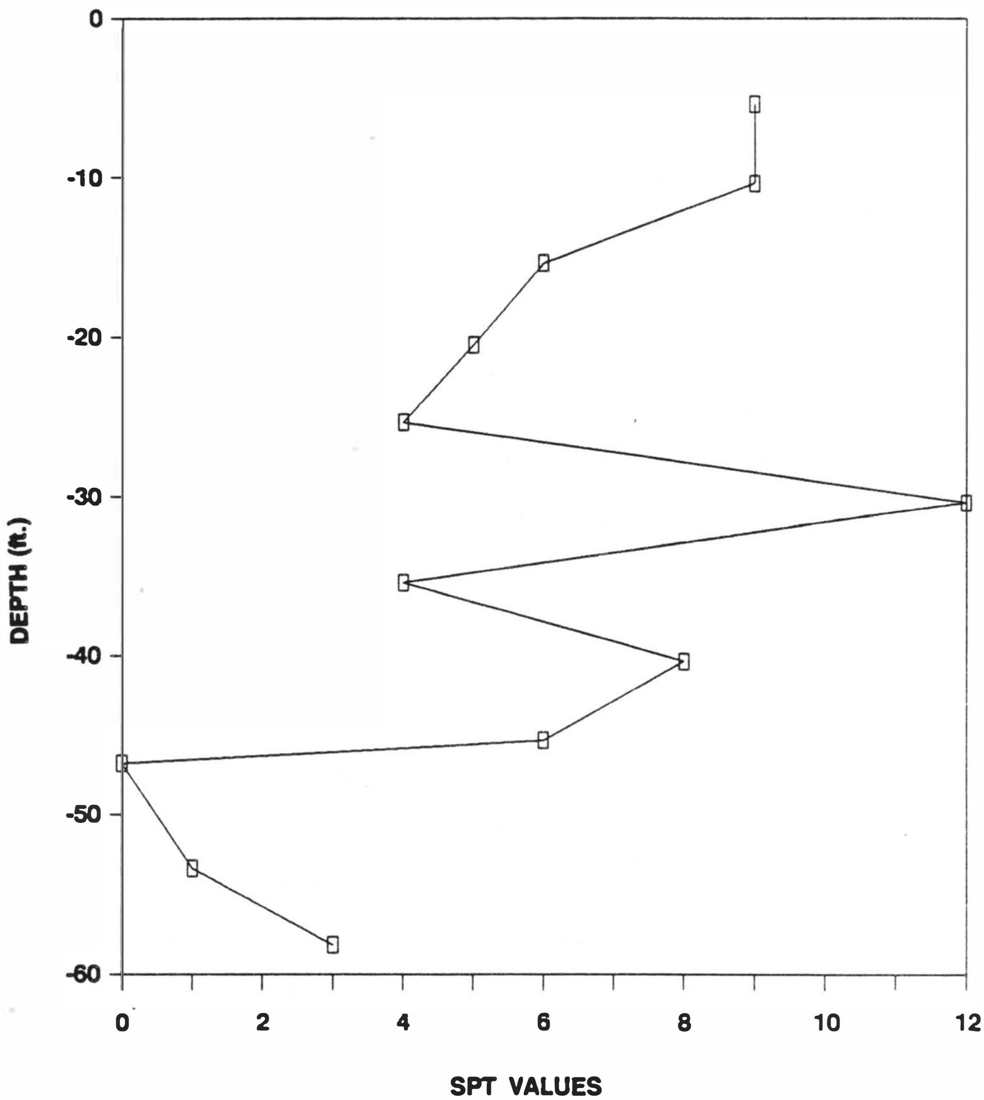

Fig. 6-6. Plot of Standard Penetration Test Values for Borehole #5 at Wewoka Creek Site (US 270 67-02 X0894)

embankment and foundation soil. These properties can be used to characterize the approach settlement process and to predict the settlement-time history in a meaningful manner, which would be difficult otherwise. For the two sites studied here, as well as the additional sites to be studied in Phase III, the prediction of settlement history will be pursued in Phase IV of the project.

2. Drilling of the approach pavement provides an assessment of the previous maintenance measures at a site which could not be obtained otherwise due to the existing inadequate recordkeeping procedure.

3. For the Shawnee site, the liquid limit (LL) and the plasticity index (PI) values were substantially higher indicating larger clay/silt content in the embankment soil. The poor quality embankment soil has likely contributed to excessive approach settlement at this site.

4. Excess field moisture content is indicative of inadequate drainage conditions at both sites. This must have been contributing factor also.

5. High embankment appears to have aggravated the approach settlement problems at both sites.

6. Although the contributions of embankment height and soil type are similar for both sites, the foundation soil at the Shawnee site appears to be less susceptible to settlement than that at the Wewoka site. Therefore, the Wewoka site appears to be more problematic among the two.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This report discusses the findings of Phase II of the research project entitled "Evaluation of Causes of Excessive Settlements of Pavements Behind Bridge Abutments and Their Remedies." In Phase I of this project a comprehensive review of literature and a survey of state DOTs indicated that the approach pavement settlement problems are quite extensive in many states in the country as well as in Oklahoma. In this phase a level-one survey of selected bridge approaches was undertaken to obtain first-hand information on the extent of approach pavement settlement problems in Oklahoma. A total of 758 bridge approaches in seventy-seven counties were surveyed. Information regarding the construction and maintenance of these approaches were collected. A database was developed for storing and sorting the information using the commercially available software, dBase III Plus. Exploratory as well as statistical analysis was performed on this data. The results of the analyses are presented in Chapter V. Regression analysis was performed to establish a relationship between the settlement of the approach and other parameters such as embankment height, age of the approach, skewness, average daily traffic, foundation soil depth, foundation soil type, approach type, and geologic conditions. A set of equations to predict the approach settlement is proposed in the previous chapter. Comprehensive studies of two selected sites were conducted. Soil samples were collected and detailed laboratory testing of soils from these two sites were performed with the purpose of determining site-specific embankment and foundation soil characteristics.

In Section 1.3 it was mentioned that the answers to the questions related to (i) extent of the approach pavement settlement problem in Oklahoma, (ii) characterization of the problem in qualitative and quantitative terms, (iii) type of data, pertinent to the referenced settlement problems, available at ODOT, and (iv) additional data required to develop specific remedial measures for the referenced settlement problems, would be sought in the level-one survey. The following paragraphs provide the summary of the findings relating to the answer to these questions.

From the level-one survey it is evident that approach pavement settlement problem is very extensive in Oklahoma. About 83% of the approaches surveyed experienced settlement.

The settlement problem may be characterized qualitatively using the information obtained from the level-one survey. For quantitative characterization, detailed boring and testing of soil samples are required for determining the site-specific properties. The level-two survey to be conducted in Phase III would give more insight into the quantitative characterization of the approach settlement.

The data available at ODOT are very limited. At present, ODOT does not keep records pertaining to the maintenance of the approach pavement in sufficient detail. The data related to construction are also limited and at times not available for older bridges. The data on embankment or foundation soil at the bridge sites are inadequate and not very useful for the purpose of using in prediction of approach settlement.

The type of additional data required for developing specific remedial measures include site-specific material properties which may be obtained by detailed testing of embankment and foundation soil at different sites in Oklahoma.

7.2 Conclusions

1. From level-one survey it is evident that approach pavement settlement problem is very extensive in Oklahoma. About 83% of the approaches surveyed experienced settlement.

2. The settlement problem is less frequent in the northwestern region of Oklahoma.

3. Settlement problem is aggravated by the absence of any drainage in the fill behind the abutment.

4. The long term performance of rigid and flexible approaches are similar. However in the short term performance, rigid approaches undergo lower differential settlements.

5. A major portion of the settlement of the approaches occurs within the first twenty years of the service life of the bridge approach.

6. Pile supported abutments are associated with more approach settlement than the stub type.

7. Higher embankment heights might be partly responsible for larger settlements. This finding is in contradiction with the study conducted by California Department of Transportation.

8. In general skewed approaches have a higher approach settlement than non-skewed approaches. However, a consistent trend of higher settlement with higher skewness could not be established.

9. The ranking of the quantitative causative parameters according to significance are: (i) age of the approach, (ii) height of embankment, (iii) average daily traffic, and (iv) skewness of the approach. The contribution of traffic volume to the settlement of the approach is not very significant even though it is ranked third.

10. Effect of some of the very important parameters such as drainage, creep

of embankment, compaction of fill material, etc., could not be assessed from the data collected in the level-one survey. However, interviewing the maintenance personnel did reveal the extreme importance of drainage in controlling the settlement process.

7.3 Recommendations

1. It is recommended that the approach pavement be designated as a separate control subsection. For rigid approaches the subsection will have a length equal to that of the approach pavement. For flexible approaches an appropriate length (e.g., 50 ft.) may be specified which will be designated as the approach.
2. A database should be developed to store all information regarding the approach pavement, approach foundation and construction and maintenance of approach pavement.
3. Drainage of the fill should be installed in some new sites and its effect be investigated.
4. The cost of maintenance of rigid and flexible pavements should be recorded to evaluate the total annual cost needed for correcting approach settlement problems.

7.4 Overview of Level-Two Survey

Although the level-one survey provided some first-hand information on the approach pavement settlement problems in Oklahoma, the information is mostly qualitative in nature. This is because such information is obtained from visual inspections of some selected sites. Also, due to existing inadequate recordkeeping procedures, some of the information/data are either unavailable or are difficult to obtain. Site-specific material properties pertaining to compaction, creep, consolidation and drainage, among others, are required for a quantitative characterization of approach settlement. The primary purpose of the level-two survey is to develop an in-depth understanding of the approach settlement process through field and laboratory testing, as well as monitoring of settlement and creep movements, at some selected bridge approaches across the state. The level-two survey will involve sampling and testing of soil, as well as instrumentation and monitoring of selected sites. The level-two survey is expected to accomplish three major goals:

1. Provide comprehensive site-specific data which can be used for a quantitative characterization of causes and mechanisms of approach settlements.
2. Provide data for validation of the numerical model to be developed in Phase IV of this project for prediction of approach pavement settlement.
3. Provide a database which can be used for assessment or estimation of settlement at similar sites.

Another objective will be to give a meaningful definition of the terms "excessive settlements" or "bumps" at the two ends of a bridge.

The following tasks have been identified for Phase III.

1. Selection of bridge approaches for survey.
2. Collection of soil samples from these sites and laboratory testing thereof.
3. Instrumentation and monitoring of selected sites.
4. Quantitative characterization of approach settlement causes and mechanisms based on survey data.
5. Literature search and field measurements, if necessary, to obtain a meaningful definition of "excessive settlements" or "bumps" at the ends of a bridge.

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APPENDIX I

ORIGINAL SURVEY FORM USED IN
LEVEL-ONE SURVEY

A. FIELD SURVEY OF BRIDGE APPROACHES

(Revision - 2, July 1987)

DATE ____________________ BRIDGE ________________________

HIGHWAY ________________ COUNTY ________________________

BRIDGE END ____

LENGTH ___________________Ft. WIDTH ____________________Ft.

LOCATION ____

SURVEYED BY ____

WEATHER ____

1. Type of Bridge Approach:

________ (a) Rigid

________ (b) Flexible

________ (c) Rigid with asphalt overlay.

2. Classification of the Approach According to Following Criteria:

_______ (a) No significant settlement evident.

_______ (b) Settlement occurred and maintenance performed.

_______ (c) Settlement occurred but no maintenance performed.

3. Age of the Bridge Approach:

________ years.

4. Type of Maintenance Performed:

________ (a) Local patching

________ (b) Level patching

________ (c) Mudjacking

________ (d) Asphalt overlay

________ (e) Mudjacking and patching

________ (f) Mudjacking and asphalt overlay

________ (g) None

5. Frequency of Maintenance (i.e. no. of times the approach has been patched or mudjacked): ______________________________

6. Is the Approach Slab Specially Designed? (e.g. flexible pavement but rigid approach)

________ (a) Yes

________ (b) No

7. Length of Approach Slab (if the response is yes in #6) ________________ ft.

8. Extent of Approach Pavement Distress (i.e. distance from the abutment through which any pavement distress is noticeable) ________________ ft.

9. Total Settlement Since The Approach was Opened to Traffic ________________inch.

10. Present Condition of the Approach:

(a) Settlement/uplift ________inch:

________ (i) Extensive

________ (ii) Moderate

________ (iii) Minor

________ (iv) None

(b) Surface roughness

_______ (i) Rough

_______ (ii) Moderately rough

_______ (iii) Smooth

11. Type of Embankment:

_______ (a) Valley fill

_______ (b) Side-hill fills.

_______ (c) Grade separation

_______ (d) Other (please explain) ____________________

____

12. Type of Embankment Material:

_______ (a) Sand

_______ (b) Silt

_______ (c) Clay

_______ (d) Other (please explain) ____________________

____

13. Skewness of Bridge:

___________________________ degree

14. Condition of Slope Protection Structure:

(a) Cracking

_______ (i) Extensive

_______ (ii) Moderate

_______ (iii) Minor

(b) Settlement

_______ (i) Extensive

_______ (ii) Moderate

_______ (iii) Minor

15. Condition of Embankment Slope Near Abutment:

_______ (a) Eroded

_______ (b) Slumped

_______ (c) OK

16. Estimated Embankment Height: _______________ft.

17. Classification of Abutment:

_______ (a) Stub type

_______ (b) Open column

_______ (c) Pile end-bent

_______ (d) Other (pl. explain) _______________________

____

18. Condition of Abutment Headwall:

(a) Movement

_______ (i) Extensive

_______ (ii) Moderate

_______ (iii) Minor

_______ (iv) None

(b) Cracking

_______ (i) Extensive

_______ (ii) Moderate

_______ (iii) Minor

_______ (iv) None

19. Tilting of expansion devices at the Bridge End:

_______ (a) Considerable

_______ (b) Moderate

_______ (c) Minor

_______ (d) None

20. Performance of Truck Lane Vis-a-Vis the Nontruck Lane:

_______ (a) Much worse

_______ (b) Worse

_______ (c) Similar

_______ (d) Not applicable

21. Comments (sketches etc.):

B. INFORMATION FROM FIELD OFFICE

DATE ____________________ BRIDGE ____________________

HIGHWAY ____________________ COUNTY ____________________

BRIDGE END ____

LENGTH ____________________Ft. WIDTH ____________________Ft.

LOCATION ____

SURVEYED BY ____

1. Date of Beginning of Embankment Construction: ____________
2. Date of End of Embankment Construction: ____________
3. Date of Beginning of Approach Pavement Construction: ______
4. Date of Opening the Approach to Traffic: ____________
5. Date of Beginning of Bridge Construction: ____________
6. Date of End of Bridge Construction: ____________
7. Average Embankment Height (maximum): ____________
8. Average Thickness of Foundation Soil: ____________
9. Embankment Soil Type:

   ______ (a) Sand ______ Local

   ______ (b) Silt ______ Transported

   ______ (c) Clay

   ______ (d) Other (pl. explain) ____________

   ____

10. Embankment Soil Classification ____________

11. Foundation Soil Type:

_______ (a) Sand

_______ (b) Silt

_______ (c) Clay

_______ (d) Other (pl. explain) ________________________
____

12. Foundation Soil Classification ______________________

13. Approach Slab is Designed Specially:

_______ (a) Yes

_______ (b) No.

14. If Response is Yes in #13, Please Specify the Type of Special Design ______________________________________
____
____

15. Drainage Behind the Abutment?

_______ (a) Yes

_______ (b) No

16. If Response is Yes in#15, Please Specify the Type and Extent of Drainage Methods: ______________________________
____
____
____

17. Specified Compaction for Embankment Soil: ____________%.

18. Compaction Attained in the Field: __________________%.

19. Compaction Equipment: _______________________________

20. Interruption of Construction:

_______ (a) Yes

_______ (b) No

21. If Response to #20 is Yes, Reason: ______________________________
____

22. Abutment Type:

_______ (a) Stub type

_______ (b) Open Column

_______ (c) Pile end-bent

_______ (d) Other (Pl. explain) ______________________
____

23. Surcharge Applied?

_______ (a) Yes

_______ (b) No

24. If Response is Yes in #23,

(a) Height of Surcharge ____________Ft.

(b) Extent of Surcharge (i.e. length of embankment surcharged) _____________Ft.

(c) Type of Surcharge ___________________________________.

25. Traffic Count ____________.

26. Geologic Unit: ____

C. INFORMATION FROM MAINTENANCE

DATE ____________________ BRIDGE ____________________

HIGHWAY ____________________ COUNTY ____________________

BRIDGE END ____

LENGTH ____________________Ft. WIDTH ____________________Ft.

LOCATION ____

SURVEYED BY ____

1. No. of Time Maintenance Performed ____________________

2. Type of Maintenance:

   (a) Level Patching:

      (i) Number of Times & Dates ____________________

      (ii) Extent ____________________Ft.

      (iii) Thickness ____________________inch

   (b) Local Patching:

      (i) Number of Times & Dates ____________________

   (c) Overlay:

      (i) . Number of Time & Dates ____________________

      (ii) Extent ____________________Ft.

      (iii) Thickness ____________________

   (d) Mudjacking:

      (i) Number of Times & Dates ____________________

      (ii) Amount of Mud Injected ____________________cft.

3. Pavement Replaced?

_______ (a) Yes

_______ (b) No

4. If Response is Yes in #3, Please Specify the Type of Replacement ____

____

APPENDIX II

MODIFIED SURVEY FORM USED IN
LEVEL-ONE SURVEY

RIDGE #: ________________ TYP: ___________ DATE: ______________ DIV: _____

IGHWAY: ______________ COUNTY: ___________________ CROSSING: _________________

RDG END: _____ BRDG LNG: ________ BRDG WDTH: ________ WEATHER: ______________

OCATION: ____

____ SURV BY: ____________________

IELD SURVEY ***:

PP_TYP: ___________ APP_CL: _____________ EST_AGE_F: ______________
RG-Rigid OS-no sign settle years
FL-Flexible SM-settle maint done
RA-Rigid w/ Asph SN-settle no maint

AINT_TYP: _____________ FREQ_M: ______________ APP_SPEC_DSGN_F: _________
LCP-local patch MDJK/LCP number y/n
LVP-level patch MDJK/LVP
MDJK-mudjack MDJK/AOVL
AOVL-asphalt over NONE

PP_LNG: ___________ APP_DIST: ___________ TOT_SETTLE_F: ________________
feet feet inches

PP_UPLIFT: _________ APP_DEG: ____________ APP_SURF: _____________________
+/- inch Ext, Mod, Min, Non RGH, MRGH, SM

MB_TYP: ________ EMB_MAT'L: __________________ EMB_SLP_@ABT: _____________
VF-vally fill GS-grade sep SAND SILT EROD, SLUMP, OK
SH-side-hill OT-other CLAY OTHER

MB_HT_F: _______ SKEW: _____ SLP_STCT_CRCK: _____ SLP_STCT_SETTLE: ________
feet deg Ext, Mod, Min Ext, Mod, Min

BT_TYPE_F: ________ ABT_HDWALL_MOVE: ____________ ABT_HDWALL_CRCK: ________
ST-stub PEB-pile end bent Ext, Mod, Min, Non Ext, Mod, Min, No
OC-open col OTH-other

XP_DEV_TILT: ____________ TRCK_LN: _________________ ABT_WALL_TYP: ________
Ext, Mod, Min, Non MWorse, Worse, SIM, NA

OMMENT_F: ____

____

____

ONSTRUCTION SURVEY **:

DATE_C: ______________

MB_CONST_ST: ______________________ EMB_CONST_END: _______________________

PP_CONST_ST: ______________________ APP_CONST_END: _______________________

RDG_CONST_ST: _____________________ BRDG_CONST_END: ______________________

GE_C: ______________

MB_HT_C: __________ EMB_MAT'L_C: ___________________ EMB_SOIL_CL: _______
feet sand, silt, clay, other

HCK_FDN_SOIL: _______ FDN_SOIL_TYP: __________________ FDN_SOIL_CL: _______
feet sand, silt, clay, other

BRIDGE # ________________________________ END ________________________

===

APP_SPEC_DSGN_C: ________ (y/n) APP_SLAB_TYP: ________________________________

DRAIN_@ABT: ______________ (y/n) ABT_DRAIN_TYP: ________________________________

EMB_SOIL_COMP_SPC: ________ (%) EMB_SOIL_COMP_ATT: __________ (%) EQUIP: __________

CONST_INTRPT: ______ (y/n) REASON: ____

ABT_TYPE_C: ___________ SRCHG: _________ (y/n) SRCHG_HT: __________ (feet) SRCHG_EXT: _______ (feet)

ST-stub PEB-pile end bent
OC-open col OTH-other

SRCHG_TYP: _____________ TRAF_CNT: _______________ GEO_UNIT: ____________

COMMENT_C: ____

____

MAINTENANCE SURVEY **

TOT_SETTLE_M: ____________ INTVW_BY: ________________________ DATE_M: ________

TOT_MAINT: _________________________

LVP_#: __________ M_LVP_DATE: ____

LVP_EXT: ____________________________ (feet) LVP_THCK: ________________________________ (inches)

LCP_#: ____

OVL_#: _________ M_OVL_DATE: ____

OVL_EXT: ____________________________ (feet) OVL_THCK: ________________________________ (inches)

MDJK_#: __________ M_MDJK_DATE: ____

MDJK_AMT: ____ (cft)

PAVMNT_REP: ________ (y/n) PAVMNT_TYP: ________________________________

COMMENT_M: ____

____

____

APPENDIX III

LIST OF BRIDGE APPROACHES SURVEYED

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
** COUNTY ADAIR				
01-006 X1066	N	US 59	ILLINOIS RIVER	1
01-006 X1066	S	US 59	ILLINOIS RIVER	1
01-06 X0729	N	US 59	BALLARD CREEK	1
01-06 X0729	S	US 59	BALLARD CREEK	1
** COUNTY ALFALFA				
02-04 X0803	N	US 64	WEST CLAY CREEK	6
02-04 X0803	S	US 64	WEST CLAY CREEK	6
02-09 X0312	NE	S 8	WEST CLAY CREEK	6
02-09 X0312	SW	S 8	WEST CLAY CREEK	6
02-20 X0361	E	S 11	CREEK	6
02-20 X0361	W	S 11	CREEK	6
02-20 X0891	E	S 11	SAND CREEK	6
02-20 X0891	W	S 11	SAND CREEK	6
02-34 X0879	N	S 38	SALT FK. OF.ARK RI	6
02-34 X0879	S	S 38	SALT FK. OF ARK RI	6
** COUNTY ATOKA				
03-02 X1083W	N	US 69	FRONTERHOUSE CREEK	2
03-02 X1083W	S	US 69	FRONTERHOUSE CREEK	2
03-12 X0333	E	S 3	SANDY CREEK	2
03-12 X0333	W	S 3	SANDY CREEK	2
** COUNTY BEAVER				
04-020 X0580	N	US 270	FULTON CREEK	6
04-020 X0580	S	US 270	FULTON CREEK	6
04-020 X1897	N	US 270	CLEAR CREEK	6
04-020 X1897	S	US 270	CLEAR CREEK	6
04-022 X1984	E	US 270	KIOWA COUNTY	6
04-022 X1984	W	US 270	KIOWA CREEK	6
04-20 X0496	N	US 270	AURORA CREEK	6
04-20 X0496	S	US 270	AURORA CREEK	6
04-24 X0092	E	S 3	FULTON CREEK	6
04-24 X0092	W	S 3	FULTON CREEK	6
COUNTY BRIDGE1	E	COUNTY ROAD	CLEAR CREEK	6
COUNTY BRIDGE1	W	COUNTY ROAD	CLEAR CREEK	6
** COUNTY BECKHAM				
05-22 X1749	N	S 34	CRI & P R.R	5
05-22 X1749	S	S 34	CRI & P R.R	5
05-32 X0345	E	S 152	TIMB. CREEK O'FL	5
05-32 X0345	W	S 152	TIMB. CREEK O'FL	5
COUNTY BRIDGE1	N	COUNTY ROAD	I-40	5
COUNTY BRIDGE1	S	COUNTY ROAD	I-40	5
** COUNTY BLAINE				
06-02 NX1029	E	US 270	N. CANADIAN RIVER	5
06-02 NX1029	W	US 270	CANADIAN RIVER	5
06-02 SX1029	E	US 270	N. CANADIAN RIVER	5

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
06-02 SX1029	W	US 270	N. CANADIAN RIVER	5
06-04 X0195	N	US 270	CANADIAN RIVER	5
06-04 X0195	S	US 270	CANADIAN RIVER	5
06-04 X0209	N	US 270	CANADIAN RIVER	5
06-04 X0209	S	US 270	CANADIAN RIVER	5
06-10 X1062	E	S 33	WATONGA CREEK	5
06-10 X1062	W	S 33	WATONGA CREEK	5
COUNTY BRIDGE1	E	COUNTY ROAD		5
COUNTY BRIDGE1	W	COUNTY ROAD		5
** COUNTY BRYAN				
07-003 X0731W	N	US 69	KO &G R.R	2
07-003 X0731W	S	US 69	KO &G R.R	2
07-010 X1465	E	US 70	BOKCHITA CREEK	2
07-010 X1465	W	US 70	BOKCHITA CREEK	2
** COUNTY CADDO				
08-004 X1226N	E	US 62	DELAWARE CREEK	7
08-004 X1226N	W	US 62	DELAWARE CREEK	7
08-004 X1226S	E	US 62	DELAWARE CREEK	7
08-004 X1226S	W	US 62	DELAWARE CREEK	7
08-018 X0402	E	S 9	WASHITA RIVER	7
08-018 X0402	W	S 9	WASHITA RIVER	7
COUNTY BRIDGE1	E	COUNTY ROAD		7
COUNTY BRIDGE1	W	COUNTY ROAD		7
COUNTY BRIDGE2	E	COUNTY ROAD		7
COUNTY BRIDGE2	W	COUNTY ROAD		7
** COUNTY CANADIAN				
09-012 X0205	N	US 81	N. CANADIAN RIVER	4
09-012 X0205	S	US 81	N. CANADIAN RIVER	4
09-036 X0826	E	S 152	CREEK	4
09-036 X0826	W	S 152	CREEK	4
** COUNTY CARTER				
10-012 X0331	N	US 177	WASHITA RIVER	7
10-012 X0331	S	US 177	WASHITA RIVER	7
10-02 X0177	E	US 70	RED OAK CREEK	7
10-02 X0177	W	US 70	RED OAK CREEK	7
10-030 X0797	E	S 53	WASHITA RIVER	7
10-030 X0797	W	S 53	WASHITA RIVER	7
10-035 X0376	N	S 142	G.C & S.F. R.R UNDER	7
10-035 X0376	S	S 142	G.C & S.F. R.R UNDER	7
** COUNTY CHEROKEE				
11-016 X0040	N	S 50	BARREN FORK CREEK	1
11-016 X0040	S	S 50	BARREN FORK CREEK	1
11-12 X0000	E	S 51	GRAND RIVER	1
11-12 X0000	W	S 51	GRAND RIVER	1
COUNTY BRIDGE1	N	COUNTY ROAD	BARREN FORK CREEK	1

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
COUNTY BRIDGE1	S	COUNTY ROAD	BARREN FORK CREEK	1
** COUNTY CHOCTAW				
12-02 X1078	E	US 70	MUDDY BOGGY CREEK	2
12-02 X1078	W	US 70	MUDDY BOGGY CREEK	2
12-14 X0463	N	S 93	LONG CREEK	2
12-14 X0463	S	S 93	LONG CREEK	2
** COUNTY CIMMARON				
13-002 X3314	E	US 56	RAILROAD	6
13-002 X3314	W	US 56	RAILROAD	6
13-006 X0986	N	US 287	BEAVER RIVER	6
13-006 X0986	S	US 287	BEAVER RIVER	6
13-010 X1315	N	US 287	CIMMARON RIVER	6
13-010 X1315	S	US 287	CIMMARON RIVER	6
13-017 X1121	N	US 385	BEAVER RIVER	6
13-017 X1121	S	US 385	BEAVER RIVER	6
13-02 X1979	N	US 56	BEAVER RIVER	6
13-02 X1979	S	US 56	BEAVER RIVER	6
COUNTY BRIDGE1	E	COUNTY ROAD	BEAVER RIVER	6
COUNTY BRIDGE1	W	COUNTY ROAD	BEAVER RIVER	6
** COUNTY CLEVELAND				
14-11 X1242	E	S 9	LITTLE RIVER	3
14-11 X1242	W	S 9	LITTLE RIVER	3
14-22 X0612	E	S 39	BUCKHEAD CREEK	3
14-22 X0612	W	S 39	BUCKHEAD CREEK	3
14-22 X1104	E	S 39	POND CREEK	3
14-22 X1104	W	S 39	POND CREEK	3
14-33 X0472	N	S 77H	LITTLE RIVER	3
14-33 X0472	S	S 77H	LITTLE RIVER	3
** COUNTY COAL				
15-016 X0911	N	S 48	CL BOGGY CREEK	3
15-016 X0911	S	S 48	CL BOGGY CREEK	3
15-06 X0534	E	S 3	K.O&G R.R UNDER	3
15-06 X0534	W	S 3	K.O&G R.R UNDER	3
15-06 X0764	E	S 3	LEADER CREEK	3
15-06 X0764	W	S 3	LEADER CREEK	3
15-12 X0336	NE	S 31	MUDDY BOGGY CREEK	3
15-12 X0336	SW	S 31	MUDDY BOGGY CREEK	3
15-12 X1248	N	S 31	SALT CREEK	3
15-12 X1248	S	S 31	SALT CREEK	3
** COUNTY COMANCHE				
16-003 X1022	E	US 62	CACHE CREEK	7
16-003 X1022	W	US 62	CACHE CREEK	7
16-018 NX0115	E	S 7	E. CACHE CREEK	7
16-018 NX0115	W	S 7	E. CACHE CREEK	7
16-018 SX0115	E	S 7	E. CACHE CREEK	7

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
16-018 SX0115	W	S 7	E. CACHE CREEK	7
16-03 X1104	N	US 62	OVERPASS US 62	7
16-03 X1104	S	US 62	OVERPASS US 62	7
16-12 X0115	E	US 277	E. CACHE CREEK	7
16-12 X0115	W	US 277	E. CACHE CREEK	7
** COUNTY COTTON				
17-014 X1244	E	S 5	E. CACHE CREEK	7
17-014 X1244	W	S 5		7
17-024 X0938	E	S 53	BEAVER CREEK	7
17-024 X0938	W	S 53		7
17-08 X1341	E	US 277	W. CACHE CREEK	7
17-08 X1341	W	US 277	BEAVER CREEK	7
** COUNTY CRAIG				
18-006 NX0349	E	US 60	BIG CABIN CREEK	8
18-006 NX0349	W	US 60	BIG CABIN CREEK	8
18-006 SX0349	E	US 60	BIG CABIN CREEK	8
18-006 SX0349	W	US 60	BIG CABIN CREEK	8
18-006 X0724	E	US 60	LITTLE CABIN CREEK	8
18-006 X0724	W	US 60	LITTLE CABIN CREEK	8
18-010 EX0348	N	US 69	TURNPIKE	8
18-010 EX0348	S	US 69	TURNPIKE	8
18-010 WX0348	N	US 69	TURNPIKE	8
18-010 WX0348	S	US 69	TURNPIKE	8
18-020 X0354	E	S 10	BIG CABIN CREEK	8
18-020 X0354	W	S 10	BIG CABIN CREEK	8
** COUNTY CREEK				
19-002 X0180	E	S 66	CAMP CREEKS	4
19-002 X0180	W	S 66	CAMP CREEK	4
19-002 X0792	E	S 66	LITTLE DEEP F. CK	4
19-002 X0792	W	S 66	LITTLE DEEP F.CK	4
** COUNTY CUSTER				
20-002 X1071W	N	I 40	US 183	5
20-002 X1071W	S	I 40	US 183	5
20-002 X1072E	N	I 40	US 183	5
20-002 X1072E	S	I 40	US 183	5
20-006 X0285	N	US 183	AT & S.F R.R UNDER	5
20-006 X0285	S	US 183	AT & S.F R.R UNDER	5
20-014 X0575	E	S 33	WASHITA RIVER	5
20-014 X0575	W	S 33	WASHITA RIVER	5
COUNTY BRIDGE	N	COUNTY ROAD	WASHITA RIVER	5
COUNTY BRIDGE	S	COUNTY ROAD	WASHITA RIVER	5
** COUNTY DELAWARE				
21-002 X0903	E	US 59	FLINT CREEK	8
21-002 X0903	W	US 59	FLINT CREEK	8
21-004 X1270	N	US 59	SPARINAW CREEK	8

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
21-004 X1270	S	US 59	SPARINAW CREEK	8
21-006 X1221	N	US 59	HONEY CREEK	8
21-006 X1221	S	US 59	HONEY CREEK	8
21-006 X1883	N	US 59	GRAND LAKE	8
21-006 X1883	S	US 59	GRAND LAKE	8
21-14 X0666	N	S 10	ELK RIVER	8
21-14 X0666	S	S 10	ELK RIVER	8
21-38 X0338	E	S 85A	HORSE CREEK	8
21-38 X0338	W	S 85A	HORSE CREEK	8
** COUNTY DEWEY				
22-008 X1675	N	US 183	S. CANADIAN RIVER	5
22-008 X1675	S	US 183	S. CANADIAN RIVER	5
22-20 X1348	N	S 34	S. CANADIAN RIVER	5
22-20 X1348	S	S 34	S. CANADIAN RIVER	5
** COUNTY ELLIS				
23-002 X0944	E	US 60	RED BLUFF CREEK	6
23-002 X0944	W	US 60	RED BLUFF CREEK	6
23-02 X0141	E	US 60	A.T & S.F R.R	6
23-02 X0141	W	US 60	A.T & S.F R.R	6
23-020 X0922	E	S 15	LITTLE WOLF CREEK	6
23-020 X0922	W	S 15	LITTLE WOLF CREEK	6
23-12 X1123	N	US 283	WOLF CREEK	6
23-12 X1123	S	US 283	WOLF CREEK	6
23-26 X0080	N	S 46	WOLF CREEK	6
23-26 X0080	S	S 46	WOLF CREEK	6
COUNTY BRIDGE1	N	COUNTY ROAD	WOLF CREEK	6
COUNTY BRIDGE1	S	COUNTY ROAD	WOLF CREEK	6
** COUNTY GARFIELD				
24-012 X1306W	N	US 81	CRI & PRR	4
24-012 X1306W	S	US 81	CRI & PRR	4
24-16 X0857	N	S 15	RED ROCK CREEK	4
24-16 X0857	S	S 15	RED ROCK CREEK	4
** COUNTY GARVIN				
25-02 X0295	E	US 77	WASHITA RIVER	3
25-02 X0295	W	US 77	WASHITA RIVER	3
25-02 X1239	N	U 77	WASHITA RIVER	3
25-02 X1239	S	U 77	WASHITA RIVER	3
25-06 X1080	N	US 177	BROOK CREEK	3
25-06 X1080	S	US 177	BROOK CREEK	3
25-08 X0566	E	S 19	WASHITA RIVER OVERFLOW	3
25-08 X0566	W	S 19	WASHITA RIVER OVERFLOW	3
25-12 X0201	E	S 19	WASHITA RIVER	3
25-12 X0201	W	S 19	WASHITA RIVER	3
25-12 X0753	E	S 19	PEAVINE CREEK	3
25-12 X0753	W	S 19	PEAVINE CREEK	3
25-14 X0127	E	S 19	SPRING BROOK CREEK	3

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
25-14 X0127	W	S 19	SPRING BROOK CREEK	3
25-20 X0153	E	S 29	SALT CREEK	3
25-20 X0153	W	S 29	SALT CREEK	3
25-20 X0903	E	S 29	EAST ROCK CREEK	3
25-20 X0903	W	S 29	EAST ROCK CREEK	3
25-27 X0248	N	S 74	SALT CREEK	3
25-27 X0248	S	S 74	SALT CREEK	3
25-28 X0842	N	S 74	RUSH CREEK	3
25-28 X0842	S	S 74	RUSH CREEK	3
25-30 X0141	N	S 74	WASHITA RIVER	3
25-30 X0141	S	S 74	WASHITA RIVER	3
25-32 X0597	N	S 76	SALT CREEK	3
25-32 X0597	S	S 76	SALT CREEK	3
25-36 X0100	N	S 76	RUSH CREEK	3
25-36 X0100	S	S 76	RUSH CREEK	3
25-36 X0936	N	S 76	WASHITA RIVER	3
25-36 X0936	S	S 76	WASHITA RIVER	3
25-46 EX2022	N	I 35	WASHITA RIVER	3
25-46 EX2022	S	I 35	WASHITA RIVER	3
25-46 WX2022	N	I 35	WASHITA RIVER	3
25-46 WX2022	S	I 35	WASHITA RIVER	3
25-53 X0087	E	S 17A	WASHITA RIVER	3
25-53 X0087	W	S 17A	WASHITA RIVER	3
** COUNTY GRADY				
26-002 NX1120	E	US 62	WASHITA RIVER	7
26-002 NX1120	W	US 62	WASHITA RIVER	7
26-002 SX1120	E	US 62	WASHITA RIVER	7
26-002 SX1120	W	US 62	WASHITA RIVER	7
26-012 X2159	N	US 81	S. CANADIAN RIVER	7
26-012 X2159	S	US 81	S. CANADIAN RIVER	7
26-02 X1566	E	US 62	BITTER CREEK	7
26-02 X1566	W	S 62	BITTER CREEK	7
26-02 X1585	E	S 62	BITTER CREEK	7
26-02 X1585	W	US 62	BITTER CREEK	7
26-12 X0170	N	US 81		7
26-12 X0170	S	US 81	WASHITA RIVER	7
** COUNTY GRANT				
27-002 X0109	N	US 60	SAND CREEK	4
27-002 X0109	S	US 60	SAND CREEK	4
27-04 X1366	E	US 60	POND CREEK	4
27-04 X1366	W	US 60	POND CREEK	4
** COUNTY GREER				
28-02 X1701	N	US 283	ELM FK. OF RED RI	5
28-02 X1701	S	US 283	ELM FK. OF RED RI	5
28-06 X0220	N	S 6	ELM FK. OF RED RI	5
28-06 X0220	S	S 6	ELM FK. OF RED RI	5
28-14 X1020	N	S 34	SALT FK. OF RED RI	5

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
28-14 X1020	S	S 34	SALT FK. OF RED RI	5
COUNTY BRIDGE1	N	COUNTY ROAD	ELM FK. OF RED RI	5
COUNTY BRIDGE1	S	COUNTY ROAD	ELM FK. OF RED RI	5
** COUNTY HARMON				
29-04 X0284	E	US 62	SANDY CREEK	5
29-04 X0284	W	US 62	SANDY CREEK	5
29-08 X0339	N	S 30	SANDY CREEK	5
29-08 X0339	S	S 30	SANDY CREEK	5
29-08 X1114	N	S 30	SALT FK. OF RED RI	5
29-08 X1114	S	S 30	SALT FK. OF RED RI	5
COUNTY BRIDGE1	N	COUNTY ROAD	BITTER CREEK	5
COUNTY BRIDGE1	S	COUNTY ROAD	BITTER CREEK	5
** COUNTY HARPER				
30-004 X1825	E	US 64	CIMMARON	6
30-004 X1825	W	US 64	CIMMARON RIVER	6
30-02 X1821	E	US 64	DRY BUFFALO CREEK	6
30-02 X1821	W	US 64	DRY BUFFALO CREEK	6
30-029 X0244	E	S 149	BEAVER RIVER	6
30-04 X0135	E	US 64	BUFFALO CREEK	6
30-04 X0135	W	US 64	BUFFALO CREEK	6
30-12 X0849	E	US 270	CLEAR CREEK	6
30-12 X0849	W	US 270	CLEAR CREEK	6
30-16 X0193	N	US 283	SPRING CREEK	6
30-16 X0193	S	US 283	SPRING CREEK	6
CL/ML/SM30-029	W	S 149	BEAVER RIVER	6
** COUNTY HASKELL				
31-008 X1536	E	S 9	SAN BOIS CREEK	1
31-008 X1536	W	S 9	SAN BOIS CREEK	1
31-019 X0010	N	S 82	TURKEY CREEK	1
31-019 X0010	S	S 82	TURKEY CREEK	1
COUNTY BRIDGE1	N	COUNTY ROAD	TALOKA CREEK	1
COUNTY BRIDGE1	S	COUNTY ROAD	TALOKA CREEK	1
** COUNTY HUGHES				
32-04 X0056	N	U 75	S. CAND. RI. & CO. RD.	3
32-04 X0056	S	U 75	S. CAND. RI. & CO. RD.	3
32-04 X1578	N	U 75	WEWOKA CREEK	3
32-04 X1578	S	U 75	WEWOKA CREEK	3
32-04 X2190	N	US 75	N. CANADIAN RIVER	3
32-04 X2190	S	US 75	N. CANADIAN RIVER	3
32-10 X1040	E	US 270	COAL CREEK	3
32-10 X1040	W	US 270	COAL CREEK	3
32-26 X0324	N	S 48	S. CAND. RI. & R.R	3
32-26 X0324	S	S 48	S. CAND. RI. & R.R	3
32-30 X0431	N	S 48	WEWOKA CREEK	3
32-30 X0431	S	S 48	WEWOKA CREEK	3

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
** COUNTY JACKSON				
33-04 NX0061	E	US 62	SALT FK. OF RED RI	5
33-04 NX0061	W	US 62	SALT FK. OF RED RI	5
33-04 NX0211	E	US 62	BITTER CREEK	5
33-04 NX0211	W	US 62	BITTER CREEK	5
33-04 SX0061	E	US 62	SALT FK. OF RED RI	5
33-04 SX0061	W	US 62	SALT FK. OF RED RI	5
33-04 SX0211	E	US 62	BITTER CREEK	5
33-04 SX0211	W	US 62	BITTER CREEK	5
COUNTY BRIDGE1	E	COUNTY ROAD		5
COUNTY BRIDGE1	W	COUNTY ROAD		5
COUNTY BRIDGE2	E	COUNTY ROAD		5
COUNTY BRIDGE2	W	COUNTY ROAD		5
** COUNTY JEFFERSON				
34-004 X0795	E	US 70	W. MUD CREEK	7
34-004 X0795	W	US 70	W. MUD CREEK	7
34-018 X0157	N	S 89	MUD CREEK	7
34-018 X0157	S	S 89	MUD CREEK	7
** COUNTY JOHNSTON				
35-06 X0250	E	S 7	BLUE RIVER	3
35-06 X0250	W	S 7	BLUE RIVER	3
35-16 X0691	E	S 22	BIG SANDY CREEK	3
35-16 X0691	W	S 22	BIG SANDY CREEK	3
35-20 X0218	N	S 48	DELAWARE CREEK	3
35-20 X0218	S	S 48	DELAWARE CREEK	3
35-22 X0070	N	S 48A	BLUE RIVER	3
35-22 X0070	S	S 48A	BLUE RIVER	3
35-32 X0658	N	S 99	BLUE RIVER	3
35-32 X0658	S	S 99	BLUE RIVER	3
** COUNTY KAY				
36-02 X0466	E	US 60	DEER CREEK	4
36-02 X0466	W	US 60	DEER CREEK	4
36-022 X0592	E	S 11	DUCK CREEK	4
36-022 X0592	W	S 11	DUCK CREEK	4
36-25 X0245E	N	I 35	CREEK	4
36-25 X0245E	S	I 35	CREEK	4
36-25 X1241E	N	I 35	CREEK	4
36-25 X1241E	S	I 35	CREEK	4
COUNTY BRIDGE	E	COUNTY ROAD	CHIKASKIA RIVER	4
COUNTY BRIDGE	W	COUNTY ROAD	CHIKASKIA RIVER	4
** COUNTY KINGFISHER				
37-04 X0680W	N	US 81	CIMMARON RIVER	4
37-04 X0680W	S	US 81	CIMMARON RIVER	4
37-06 X1327	E	S 3	DEAD INDIAN CREEK	4
37-06 X1327	W	S 3	DEAD INDIAN CREEK	4
COUNTY BRIDGE	E	COUNTY ROAD	TURKEY CREEK	4

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
COUNTY BRIDGE	W	COUNTY ROAD	TURKEY CREEK	4
** COUNTY KIOWA				
38-003 X0213	N	US 62	OVER US 183	5
38-003 X0213	S	US 62	OVER US 183	5
38-018 X0000	N	S 44	N. FK. OF RED RI	5
38-018 X0000	S	S 44	N. FK. OF RED RI	5
38-10 X0000	E	S 9	N. FK. OF RED RI	5
38-10 X0000	W	S 9	N. FK. OF RED RI	5
38-44 X0342	E	S 115	SADDLE MT. CREEK	5
38-44 X0342	W	S 115	SADDLE MT. CREEK	5
** COUNTY LATIMER				
39-02 X0470	E	US 270	GAINES CREEK	2
39-02 X0470	W	US 270	GAINES CREEK	2
39-04 X1925	E	US 270	TURKEY CREEK	2
39-04 X1925	W	US 270	TURKEY CREEK	2
COUNTY BRIDGE	E	COUNTY ROAD	BEAVER CREEK	2
COUNTY BRIDGE	W	COUNTY ROAD	BEAVER CREEK	2
** COUNTY LEFLORE				
40-010 X0629	E	US 270	CASTON CREEK	2
40-010 X0629	W	US 270	CASTON CREEK	2
40-04 X0490	N	US 59	R.R & ST	2
40-04 X0490	S	US 59	R.R & ST	2
** COUNTY LINCOLN				
41-20 X0611	N	US 177	BELLCOW CREEK	4
41-20 X0611	S	US 177	BELLCOW CREEK	4
41-38 X1250	N	S 102	CAPTAIN CREEK	4
41-38 X1250	S	S 102	CAPTAIN CREEK	4
** COUNTY LOGAN				
42-04 X1287	N	US 77	BEAVER CREEK	4
42-04 X1287	S	US 77	BEARER CREEK	4
42-06 X0860	E	S 33	GAR CREEK	4
42-06 X0860	W	S 33	GAR CREEK	4
** COUNTY LOVE				
43-004 X0702	N	US 77	HICKORY CREEK	7
43-004 X0702	S	US 77	HICKORY CREEK	7
43-006 X1460	E	S 32	WALNUT BAYOU CREEK	7
43-006 X1460	W	S 32	WALNUT BAYOU CREEK	7
43-006 X2013	E	S 32	ROCK CREEK	7
43-006 X2013	W	S 32	ROCK CREEK	7
43-010 X0874	E	S 32	HICKORY CREEK	7
43-010 X0874	W	S 32	HICKORY CREEK	7
** COUNTY MAJOR				
47-04 X0652	N	US 60	ELM CREEK	6

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
47-04 X0652	S	US 60	ELM CREEK	6
47-06 X1084N	E	US 60	INDIAN CREEK	6
47-06 X1084N	W	US 60	INDIAN CREEK	6
47-06 X1084S	E	US 60	INDIAN CREEK	6
47-06 X1084S	W	US 60	INDIAN CREEK	6
47-18 X1505	E	S 8	SAND CREEK	6
47-18 X1505	W	S 8	SAND CREEK	6
47-24 X0241	E	S 15	MAIN CREEK	6
47-24 X0241	W	S 15	MAIN CREEK	6
47-26 X0590	E	S 15	GRIEVER CREEK	6
47-26 X0590	W	S 15	GRIEVER CREEK	6
COUNTY BRIDGE1	E	COUNTY ROAD	MUD CREEK	6
COUNTY BRIDGE1	W	COUNTY ROAD	MUD CREEK	6
** COUNTY MARSHALL				
48-004 X0054	N	US 70	WHISKEY CREEK	2
48-004 X0054	S	US 70	WHISKEY CREEK	2
48-006 X0176	E	S 32	HAUANI CREEK	2
48-006 X0176	W	S 32	HAUANI CREEK	2
COUNTY BRIDGE1	N	COUNTY ROAD		2
COUNTY BRIDGE1	S	COUNTY ROAD	CREEK	2
** COUNTY MAYES				
49-002 EX0539	N	US 69	BRUSH CREEK	8
49-002 EX0539	S	US 69	BRUSH CREEK	8
49-002 WX0539	N	US 69	BRUSH CREEK	8
49-002 WX0539	S	US 69	BRUSH CREEK	8
49-016 X0734	E	S 28	BIG CABIN CREEK	8
49-016 X0734	W	S 28	BIG CABIN CREEK	8
49-032 X0273	N	S 82	GRAND RIVER	8
49-032 X0273	S	S 82	GRAND RIVER	8
49-08 X0902	E	S 20	GRAND RIVER	8
49-08 X0902	W	S 20	GRAND RIVER	8
49-22 X0383	E	S 33	GRAND RIVER	8
49-22 X0383	W	S 33	GRAND RIVER	8
COUNTY BRIDGE1	N	CLARK'S LANE	CREEK	8
COUNTY BRIDGE1	S	CLARK'S LANE	CREEK	8
** COUNTY MCCLAIN				
44-04 EX1131	N	S 77	WALNUT CREEK	3
44-04 EX1131	S	S 77	WALNUT CREEK	3
44-04 WX1131	N	S 77	WALNUT CREEK	3
44-04 WX1131	S	S 77	WALNUT CREEK	3
44-05 EX1101	N	I 35	WALNUT CREEK	3
44-05 EX1101	S	I 35	WALNUT CREEK	3
44-05 NX0928	E	I 35		3
44-05 NX0928	W	I 35		3
44-05 WX1101	N	I 35	WALNUT CREEK	3
44-05 WX1101	S	I 35	WALNUT CREEK	3
44-05 X0305	E	I 35		3

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
44-05 X0305	W	I 35		3
44-05 X1982	E	I 35		3
44-05 X1982	W	I 35		3
44-05 X2520	W	I 35	OVERPASS I 35	3
44-06 X2520	E	I 35	OVERPASS I 35	3
44-28 X1682	E	S 59		3
44-28 X1682	W	S 59		3
44-56 X0110	E	S 24	FINN CREEK	3
44-56 X0110	W	S 24	FINN CREEK	3
** COUNTY MCCURTAIN				
45-032 X0720	E	S 98	HORSEPEN CREEK	2
45-032 X0720	W	S 98	HORSEPEN CREEK	2
45-04 X0578W	N	US 70	LITTLE RIVER	2
45-04 X0578W	S	US 70	LITTLE RIVER	2
** COUNTY MCINTOSH				
46-003 X0000	N	US 69	S. CANADIAN RIVER	1
46-003 X0000	S	US 69	S. CANADIAN RIVER	1
46-003 X0527E	N	US 69	S 9	1
46-003 X0527E	S	US 69	S 9	1
46-003 X0527W	N	US 69	S 9	1
46-003 X0527W	S	US 69	S 9	1
46-003 X0795	N	US 69	N. CANADIAN RIVER	1
46-003 X0795	S	US 69	N. CANADIAN RIVER	1
** COUNTY MURRAY				
50-02 X0642	N	U 77	WASHTIA RIVER	3
50-02 X0642	S	U 77	WASHTIA RIVER	3
50-08 NX0244	E	S 7	WASHITA RIVER	3
50-08 NX0244	W	S 7	WASHITA RIVER	3
50-08 SX0244	E	S 7	WASHITA RIVER	3
50-08 SX0244	W	S 7	WASHITA RIVER	3
50-12 NX0490	E	S 7	GUY SANDY CREEK	3
50-12 NX0490	W	S 7	GUY SANDY CREEK	3
50-12 SX0490	E	S 7	GUY SANDY CREEK	3
50-12 SX0490	W	S 7	GUY SANDY CREEK	3
50-24 X0032	N	US 177	ROCK CREEK	3
50-24 X0032	S	US 177	ROCK CREEK	3
** COUNTY MUSKOGEE				
51-06 X0300N	E	US 62	S.T. & R.R	1
51-06 X0300N	W	US 62	S.T. & R.R	1
51-06 X0300S	E	US 62	S.T. & R.R.	1
51-06 X0300S	W	US 62	S.T. & R.R	1
51-06 X0437N	E	US 62	ROSS LAKE	1
51-06 X0437N	W	US 62	ROSS LAKE	1
51-06 X0437S	E	US 62	ROSS LAKE	1
51-06 X0437S	W	US 62	ROSS LAKE	1
51-15 X0225S	E	I 40	SH 2	1

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
51-15 X0225S	W	I 40	SH 2	1
COUNTY BRIDGE1	E	COUNTY ROAD	PECAN CREEK	1
COUNTY BRIDGE1	W	COUNTY ROAD	PECAN CREEK	1
** COUNTY NOBLE				
52-04 X1619	E	US 64	LONG BRANCH CREEK	4
52-04 X1619	W	US 64	LONG BRANCH CREEK	4
52-24 X0641	N	US 177	TURNPIKE	4
52-24 X0641	S	US 177	TURNPIKE	4
52-33 X1310E	N	I 35	BLACK BEAR CREEK	4
52-33 X1310E	S	I 35	BLACK BEAR CREEK	4
** COUNTY NOWATA				
53-004 X0382	E	US 60	VERDIGRIS RIVER	8
53-004 X0382	W	US 60	VERDIGRIS RIVER	8
53-008 X0328E	N	US 169	CALIFORNIA CREEK	8
53-008 X0328E	S	US 169	CALIFORNIA CREEK	8
53-008 X0328W	N	US 169	CALIFORNIA CREEK	8
53-008 X0328W	S	US 169	CALIFORNIA CREEK	8
53-010 X1048	E	S 10	VERDIGRIS RIVER	8
53-010 X1048	W	S 10	VERDIGRIS RIVER	8
53-12 X0091	E	S 28	VERDIGRIS RIVER	8
53-12 X0091	W	S 28	VERDIGRIS RIVER	8
56-008 X1323	N	US 169	HICKORY CREEK	8
56-008 X1323	S	US 169	HICKORY CREEK	8
** COUNTY OKFUSKEE				
54-06 X0374	NE	U 75	ALABAMA CREEK	3
54-06 X0374	SW	U 75	ALABAMA CREEK	3
54-14 X0233	E	S 56	N. CANADIAN RIVER	3
54-14 X0233	W	S 56	N. CANADIAN RIVER	3
54-18 X1578	E	S 56	NUYAKA CREEK	3
54-18 X1578	W	S 56	NUYAKA CREEK	3
54-20 X0162	N	S 84	N. CANADIAN RIVER	3
54-20 X0162	S	S 84	N. CANADIAN RIVER	3
54-22 NX0233	E	I 40	N. CANADIAN RIVER	3
54-22 NX0233	W	I 40	N. CANADIAN RIVER	3
54-22 SX0233	E	I 40	N. CANADIAN RIVER	3
54-22 SX0233	W	I 40	N. CANADIAN RIVER	3
** COUNTY OKLAHOMA				
55-005 X0148W	N	I 44	SH 3 RAMP UNDER	4
55-005 X0148W	S	I 44	SH 3 RAMP UNDER	4
55-007 X0025E	N	I 44	RENO AVENUE	4
55-007 X0025E	S	I 44	RENO AVENUE	4
55-009 X0250E	N	I 35	HARRISON CREEK	4
55-009 X0250E	S	I 35	HARRISON CREEK	4
55-009 X0250W	N	I 35	HARRISON CREEK	4
55-009 X0250W	S	I 35	HARRISON CREEK	4
55-009 X0398	E	I-35	122 STREET	4

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
55-009 X0398	W	I 35	122 STREET	4
COUNTY BRIDGE1	E	MEMORIAL ROAD	ARCADIA LAKE	4
COUNTY BRIDGE1	W	MEMORIAL ROAD	ARCADIA LAKE	4
COUNTY BRIDGE2	E	DANFORTH ROAD	BLUFF CREEK	4
COUNTY BRIDGE2	W	DANFORTH ROAD	BLUFF CREEK	4
COUNTY BRIDGE3	N	MERIDIAN ROAD	DEER CREEK	4
COUNTY BRIDGE3	S	MERIDAIN ROAD	DEER CREEK	4
** COUNTY OKMULGEE				
56-003 X0980S	E	I 40	WOLF CREEK	1
56-003 X0980S	W	I 40	WOLF CREEK	1
56-004 X0113E	N	US 75	KO & G R.R.	1
56-004 X0113E	S	US 75	KO & G R.R.	1
56-004 X0113W	N	US 75	KO & G R.R.	1
56-004 X0113W	S	US 75	KO & G R.R.	1
56-27 X0196	E	US 62	CASSETAH CREEK	1
56-27 X01961	W	US 62	CASSETAH CREEK	1
COUNTY BRIDGE1	N	COUNTY ROAD	CREEK	1
COUNTY BRIDGE1	S	COUNTY ROAD	CREEK	1
** COUNTY OSAGE				
57-002 X0000	E	US 60	ARKANSAS RIVER	8
57-002 X0000	W	US 60	ARKANSAS RIVER	8
57-012 X0539	N	S 18	SALT CREEK	8
57-012 X0539	S	S 18	SALT CREEK	8
57-016 X0651	N	S 18	SALT CREEK	8
57-016 X0651	S	S 18	SALT CREEK	8
57-020 X1297	E	S 20	HOMINY CREEK	8
57-020 X1297	W	S 20	HOMINY CREEK	8
57-030 X0420	N	S 99	HOMINY CREEK	8
57-030 X0420	S	S 99	HOMINY CREEK	8
** COUNTY OTTAWA				
58-010 X1125	E	US 60	NEOSHA RIVER	8
58-010 X1125	W	US 60	NEOSHA RIVER	8
58-014 X0126	E	US 69	NEOSHO RIVER	8
58-014 X0126	W	US 69	NEOSHO RIVER	8
58-020 X0817	N	S 10	SYCAMORE CREEK	8
58-020 X0817	S	S 10	SYCAMORE CREEK	8
58-035 X0942	N	S 125	NEOSHO RIVER	8
58-035 X0942	S	S 125	NEOSHO RIVER	8
58-24 X0831	E	S 10	SPRING RIVER	8
58-24 X0831	W	S 10	SPRING RIVER	8
58-24 X1287	E	S 10	TURNPIKE	8
58-24 X1287	W	S 10	TURNPIKE	8
** COUNTY PAWNEE				
59-002 X0485	E	US 64	PEPPER CREEK	8
59-002 X0485	W	US 64	PEPPER CREEK	8
59-004 X1230	E	US 64	RANCH CREEK	8

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
59-004 X1230	W	US 64	RANCH CREEK	8
59-006 X2183	E	US 64	ARKANSAS RIVER	8
59-006 X2183	W	US 64	ARKANSAS RIVER	8
59-14 X1566	E	S 18	ARKANSAS RIVER	8
59-14 X1566	W	S 18	ARKANSAS RIVER	8
59-24 X0182	N	S 99	ARKANSAS RIVER	8
59-24 X0182	S	S 99	ARKANSAS RIVER	8
COUNTY BRIDGE	N	COUNTY ROAD	CAMP CREEK	8
COUNTY BRIDGE	N	COUNTY ROAD	CAMP CREEK	8
** COUNTY PAYNE				
60-006 X1280	E	S 33	LOST CREEK	4
60-006 X1280	W	S 33	LOST CREEK	4
60-010 X0493S	E	S 33	EUCHEE CREEK	4
60-010 X0493S	W	S 33	EUCHEE CREEK	4
60-06 X1810	E	S 33	CIMMARON RIVER	4
60-06 X1810	W	S 33	CIMMARON RIVER	4
60-27 X0254	N	S 108	CIM. RI & CO. RD.	4
60-27 X0254	S	S 108	CIM. RI & CO. RD.	4
** COUNTY PITTSBURG				
61-029 X0339	N	S 113	COAL CREEK	2
61-029 X0339	S	S 113	COAL CREEK	2
61-08 X1629	N	US 270	RR	2
61-08 X1629	S	US 270	RR	2
COUNTY BRIDGE	N	COUNTY ROAD	CREEK	2
COUNTY BRIDGE	S	COUNTY ROAD	CREEK	2
** COUNTY PONTOTOC				
62-10 X1151	E	S 1	UNDERPASS SH 3	3
62-10 X1151	W	S 1	UNDERPASS SH 3	3
62-12 X0000	E/S	S 3W	S. CANADIAN RIVER	3
62-12 X0000	W/N	S 3W	S. CANADIAN RIVER	3
62-16 NX1289	E	S 19	BIG SANDY CREEK	3
62-16 NX1289	W/N	S 19	BIG SANDY CREEK	3
62-16 SX1289	E/S	S 19	BIG SANDY CREEK	3
62-16 SX1289	W/N	S 19	BIG SANDY CREEK	3
62-20 X0031	N	S 48	LEADER CREEK	3
62-20 X0031	S	S 48	LEADER CREEK	3
62-40 X1559	N	S 99	UNDERPASS SH 3	3
62-40 X1559	S	S 99	UNDERPASS SH 3	3
** COUNTY POTTAWATOMIE				
63-02 X0726	E	US 270	N. CANADIAN RIVER	3
63-02 X0726	W	US 270	N. CANADIAN RIVER	3
63-04 X0227	E	S 3E	N. CANADIAN RIVER	3
63-04 X0227	W	S 3E	N. CANADIAN RIVER	3
63-14 X0731	N	S 9A	LITTLE RIVER	3
63-14 X0731	S	S 9A	LITTLE RIVER	3
63-20 X0802	N	US 177	SALT CREEK	3

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
63-20 X0802	S	US 177	SALT CREEK	3
63-20 X1425	N	US 177	LITTLE RIVER	3
63-20 X1425	S	US 177	LITTLE RIVER	3
63-23 EX0465	N	US 270	R.R & ST UNDER	3
63-23 EX0465	S	US 270	R.R & ST UNDER	3
63-23 WX0465	N	US 270	R.R & ST UNDER	3
63-23 WX0465	S	US 270	R.R & ST UNDER	3
63-23 X0620	N	US 270	N. CANADIAN RIVER	3
63-23 X0620	S	US 270	N. CANADIAN RIVER	3
63-34 X0693	E	S 59	SALT CREEK	3
63-34 X0693	W	S 59	SALT CREEK	3
63-47 X1257	N	S 102	LITTLE RIVER	3
63-47 X1257	S	S 102	LITTLE RIVER	3
63-56 X0070	N	S 102	N. CANADIAN RIVER	3
63-56 X0070	S	S 102	N. CANADIAN RIVER	3
** COUNTY PUSHMATAHA				
64-012 X0735	E	S 3	TURNPIKE	2
64-012 X0735	W	S 3	TURNPIKE	2
64-016 X0886	E	S 3	MILL CREEK	2
64-016 X0886	W	S 3	MILL CREEK	2
COUNTY BRIDGE	N	COUNTY ROAD		2
COUNTY BRIDGE	S	COUNTY ROAD		2
** COUNTY ROGER MILLS				
65-004 X0083	N	US 283	WASHITA RIVER	5
65-004 X0083	S	US 283	WASHITA RIVER	5
65-012 X1133	E	S 33	NINE MILE CREEK	5
65-012 X1133	W	S 33	NINE MILE CREEK	5
65-012 X1450	E	S 33	WASHITA RIVER	5
65-012 X1450	W	S 33	WASHITA RIVER	5
65-024 X1314	E	S 47	SARGENT MAJOR CREEK	5
65-024 X1314	W	S 47	SARGENT MAJOR CREEK	5
** COUNTY ROGERS				
66-002 EX0386	N	S 66	VERDIGRIS RIVER	8
66-002 EX0386	S	S 66	VERDIGRIS RIVER	8
66-002 WX0386	N	S 66	VERDIGRIS RIVER	8
66-002 WX0386	S	S 66	VERDIGRIS RIVER	8
66-008 X0674	E	S 20	VERDIGRIS RIVER	8
66-008 X0674	W	S 20	VERDIGRIS RIVER	8
66-018 NX0709	E	S 33	VERDIGRIS RIVER	8
66-018 NX0709	W	S 33	VERDIGRIS RIVER	8
66-018 SX0709	E	S 33	VERDIGRIS RIVER	8
66-018 SX0709	W	S 33	VERDIGRIS RIVER	8
66-028 X0715	E	S 88	OOLOGAH DAM SPILLWAY	8
66-028 X0715	W	S 88	OOLOGAH DAM SPILLWAY	8
** COUNTY SEMINOLE				
67-02 X0894	N	US 270	WEWOKA CREEK	3

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
67-02 X0894	S	US 270	WEWOKA CREEK	3
67-22 X0058	N	S 56	WEWOKA CREEK	3
67-22 X0058	S	S 56	WEWOKA CREEK	3
67-26 X0271	E	S 59	LITTLE RIVER	3
67-26 X0271	W	S 59	LITTLE RIVER	3
67-26 X0294	E	S 59	LITTLE RIVER	3
67-26 X0294	W	S 59	LITTLE RIVER	3
67-32 X0778	N	S 99	TURKEY CREEK	3
67-32 X0778	S	S 99	TURKEY CREEK	3
67-37 NX0782	E	I 40	TURKEY CREEK	3
67-37 NX0782	W	I 40	TURKEY CREEK	3
67-37 SX0782	E	I 40	TURKEY CREEK	3
67-37 SX0782	W	I 40	TURKEY CREEK	3
67-37 X1804	N	I 35	OVERPASS S 56	3
67-37 X1804	S	I 35	OVERPASS S 56	3
67-42 X0043	N	S 3E	WEWOKA CREEK	3
67-42 X0043	S	S 3E	WEWOKA CREEK	3
67-42 X0683	N	S 3E	LITTLE RIVER	3
67-42 X0683	S	S 3E	LITTLE RIVER	3
67-42 X1176	N	S 3E	SALT CREEK	3
67-42 X1176	S	S 3E	SALT CREEK	3
67-52 X0285	E	S 3E	TURKEY CREEK	3
67-52 X0285	W	S 3E	TURKEY CREEK	3
** COUNTY SEQUOYAH				
68-002 X0000	E	I 40	ARKANSAS RIVER	1
68-002 X0000	WE	I 40	ARKANSAS RIVER	1
68-029 X0200	E	S 10	DEEP BRANCH CREEK	1
68-029 X0200	W	S 10	DEEP BRANCH CREEK	1
68-029 X0224	E	S 10	ILLINOIS RIVER	1
68-029 X0224	W	S 10	ILLINOIS RIVER	1
68-06 X0746	E	US 64	LITTLE VIAN CREEK	1
68-06 X0746	W	US 64	LITTLE VIAN CREEK	1
68-22 X0735N	E	I 40	SH 82	1
68-22 X0735N	W	I 40	SH 82	1
68-22 X0735S	E	I 40	SH 82	1
68-22 X0735S	W	I 40	SH 82	1
68-23 X0233N	E	I 40	HOG CREEK	1
68-23 X0233N	W	I 40	HOG CREEK	1
COUNTY BRIDGE1	N	COUNTY ROAD	CREEK	1
COUNTY BRIDGE1	S	COUNTY ROAD	CREEK	1
** COUNTY STEPHENS				
69-006 X0545	E	S 7	LITTLE BEAVER CREEK	7
69-006 X0545	W	S 7	LITTLE BEAVER CREEK	7
69-012 X0642	E	S 29	CLEAR CREEK	7
69-012 X0642	W	S 29	CLEAR CREEK	7
69-02 X0821	N	US 81	COUNTY ROAD	7
69-02 X0821	S	US 81	COUNTY ROAD	7
69-02 X1278	N	US 81	CLARIDY CREEK	7

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
69-02 X1278	S	US 81	CLARIDY CREEK	7
69-025 NX0073	E	S 7	R.R & 7 ST. UNDER	7
69-025 NX0073	W	S 7	R.R & 7 ST. UNDER	7
69-025 SX0073	E	S 7	R.R. & 7 St. UNDER	7
69-025 SX0073	W	S 7	R.R. & 7 St. UNDER	7
** COUNTY TEXAS				
70-004 X0610	N	US 54	BEAVER CREEK	6
70-004 X0610	S	US 54	BEAVER CREEK	6
70-04 X1100	N	US 54	PONY CREEK	6
70-04 X1100	S	US 54	PONY CREEK	6
70-10 X1255	E	US 64	LITTLE GOFF CREEK	6
70-10 X1255	W	US 64	LITTLE GOFF CREEK	6
70-24 X0049	E	S 03	COLDWATER CREEK	6
70-24 X0049	W	S 03	COLDWATER CREEK	6
70-26 X0307	N	S 94	BEAVER RIVER	6
70-26 X0307	S	S 94	BEAVER RIVER	6
70-30 X0541	N	US 95	BEAVER RIVER	6
70-30 X0541	S	US 95	BEAVER RIVER	6
COUNTY BRIDGE1	N	COUNTY ROAD	BEAVER RIVER	6
COUNTY BRIDGE1	S	COUNTY ROAD	BEAVER RIVER	6
** COUNTY TILLMAN				
71-012 X0000	E	S 5	N. FK. OF RED RI	5
71-012 X0000	W	S 5	N. FK. OF RED RI	5
71-014 X1057	E	S 5	DEEP RED CREEK	5
71-014 X1057	W	S 5	DEEP RED CREEK	5
COUNTY BRIDGE1	E	COUNTY ROAD	OVER RAILROAD	5
COUNTY BRIDGE1	W	COUNTY ROAD	OVER RAILROAD	5
COUNTY BRIDGE2	E	COUNTY ROAD	COFFIN CREEK	5
COUNTY BRIDGE2	W	COUNTY ROAD	COFFIN CREEK	5
** COUNTY TULSA				
72-018 X0300E	N	US 75	S 117	8
72-018 X0300E	S	US 75	S 117	8
72-018 X0300W	N	US 75	S 117	8
72-018 X0300W	S	US 75	S 117	8
72-85 X0997	E	S 51	FISHER CREEK	8
72-85 X0997	W	S 51	FISHER CREEK	8
72-86 X0264N	E	US 64	COUNTY ROAD	8
72-86 X0264N	W	US 64	COUNTY ROAD	8
72-86 X0264S	E	US 64	COUNTY ROAD	8
72-86 X0264S	W	US 64	COUNTY ROAD	8
COUNTY BRIDGE1	W	E 96TH STREET	ARKANSAS RIVER	8
COUNTY BRIDGE1	W	E 96TH STREET	ARKANSAS RIVER	8
COUNTY BRIDGE2	E	COUNTY ROAD	BIRD CREEK	8
COUNTY BRIDGE2	W	COUNTY ROAD	BIRD CREEK	8
COUNTY BRIDGE3	N	N. MINGO ROAD	RANCH CREEK	8
COUNTY BRIDGE3	S	N. MINGO ROAD	RANCH CREEK	8
COUNTY BRIDGE4	N	N. MINGO ROAD	BIRD CREEK	8

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
COUNTY BRIDGE4	S	N. MINGO ROAD	BIRD CREEK	8
COUNTY BRIDGE5N	E	COUNTY ROAD	CREEK	8
COUNTY BRIDGE5N	W	COUNTY ROAD	CREEK	8
COUNTY BRIDGE5S	E	COUNTY ROAD	CREEK	8
COUNTY BRIDGE5S	W	COUNTY ROAD	CREEK	8
** COUNTY WAGONER				
73-06 X0500E	N	US 69	VERDIGRIS RIVER	1
73-06 X0500E	S	US 69	VERDIGRIS RIVER	1
73-23 X0184	E	S 16	VERDIGRIS RIVER	1
73-23 X0184	W	S 16	VERDIGRIS RIVER	1
** COUNTY WASHINGTON				
74-002 X0623	E	US 60	HOGSHOOTER CREEK	8
74-002 X0623	W	US 60	HOGSHOOTER CREEK	8
74-008 EX1461	N	US 75	COTTON CREEK	8
74-008 EX1461	S	US 75	COTTON CREEK	8
74-008 WX1461	N	US 75	COTTON CREEK	8
74-008 WX1461	S	US 75	COTTON CREEK	8
74-008 X0372	N	US 75	COON CREEK	8
74-008 X0372	S	US 75	COON CREEK	8
74-021 EX1492	N	US 75	CANEY RIVER	8
74-021 EX1492	S	US 75	CANEY RIVER	8
74-021 WX1492	N	US 75	CANEY RIVER	8
74-021 WX1492	S	US 75	CANEY RIVER	8
74-021 X0780	N	US 75	AT & SF R.R UNDER	8
74-021 X0780	S	US 75	AT & SF R.R UNDER	8
** COUNTY WASHITA				
75-010 X0849	E	S 152	WASHITA RIVER	5
75-010 X0849	W	S 152	WASHITA RIVER	5
75-06 X0501	N	US 183	BOGGY CREEK	5
75-06 X0501	S	US 183	BOGGY CREEK	5
75-08 X2077	E	S 152	CALVARY CREEK	5
75-08 X2077	W	S 152	CALVARY CREEK	5
** COUNTY WOODS				
76-02 X0841	E	US 64	EAST MOCASSIN CREEK	6
76-02 X0841	W	US 64	EAST MOCASSIN CREEK	6
76-06 X0545	E	US 64	LITTLE EAGLE CHIEF CRE	6
76-06 X0545	W	US 64	LITTLE EAGLE CHIEF CRE	6
76-06 X0983	E	US 64	A.T & SF R.R	6
76-06 X0983	W	US 64	A.T & SF R.R	6
76-12 X0958	N	US 281	EAGLE CHIEF CREEK	6
76-12 X0958	S	US 281	EAGLE CHIEF CREEK	6
76-26 X0330	N	S 50	HOUSTON CREEK	6
76-26 X0330	S	S 50	HOUSTON CREEK	6
** COUNTY WOODWARD				
77-004 X0951	E	US 183	SAND CREEK	6

ODOT BRIDGE SURVEY - TABLE #1

BRIDGE NO	BRIDGE END	HIGHWAY	CROSSING	DIV
77-004 X0951	W	US 183	SAND CREEK	6
77-004 X1724	E	US 183	WOLF CREEK	6
77-004 X1724	W	US 183	WOLF CREEK	6
77-012 X0622	E	S 15	N. CANADIAN RIVER	6
77-012 X0622	W	S 15	N. CANADIAN RIVER	6
77-017 X0079	N	S 50	SAND CREEK	6
77-017 X0079	S	S 50	SAND CREEK	6
77-017 X0537	N	S 50	N. CANADIAN RIVER	6
77-017 X0537	S	S 50	N. CANADIAN RIVER	6
COUNTY BRIDGE1	W	COUNTY ROAD	N. CANADIAN RIVER	6
COUNTY BRIDGE1	W	COUNTY ROAD	N. CANADIAN RIVER	6

APPENDIX IV

DESCRIPTION OF GEOLOGIC UNITS

GEOLOGICAL UNITS

DESCRIPTION	ABBREVIATION	GROUP
1) ALLUVIUM: Gravel, sand, silt, and clay. Yields large amounts of water of good quality along the Arkansas River and probably will yield moderate to large amounts along the Canadian River.	ALM	4
2) TERRACE DEPOSITS: Gravel, sand, silt, and clay. Yield moderate to large amounts of water of good quality locally along the Arkansas River; smaller amounts elsewhere.	TRD	4
3) SEMINOLE FORMATION: Sandy shale, sandstone, and thin coal seams. Probably will yield only limited amounts of water of poor quality.	SMF	4
4) HOLDENVILLE SHALE: Shale, thin sandstones, and minor limestones. Probably will yield only limited amounts of water of poor quality.	HDS	1
5) WEWOKA FORMATION: Shale, sandstone, and minor limestones. Probably will yield only limited amounts of water of poor quality.	WKF	1&2
6) WETUMKA SHALE: Shale, minor sandstones, and minor limestones. Probably will yield only limited amounts of water of poor quality.	WTS	1
7) CALVIN SANDSTONE: Shale and sandstone. Yields limited amounts of water of fair to poor quality.	CNS	2
8) SENORA FORMATION: Shale, sandstone, and thin coal seams. Yields limited amounts of water of poor quality.	SRF	2
9) STUART SHALE: Shale and minor sandstones. Probably will yield only limited amounts of water of poor quality.	STS	1
10) THURMAN SANDSTONE: Sandstone and shale. Probably will yield only limited amounts of water of poor quality.	TUS	2

11) BOGGY FORMATION: Shale, sandstone, and coal; includes Bluejacket Sandstone Member at base. Yields limited amounts of water of poor quality.	BGF	1
12) SAVANNA, McALESTER, AND HARTSHORNE FORMATIONS: Savanna Formation, shale, sandstone, and coal. Yields limited amounts of water of poor quality. McAlester and Hartshorne Formations (undifferentiated), shale, sandstone, and coal. Yield limited amounts of water of poor quality. Savanna and McAlester Formations (undifferentiated), shale and minor sandstones. Yields limited amounts of water of poor quality.	SMF MHF	1
13) ATOKA, BLOYD AND HALE FORMATIONS: Undifferentiated. Atoka formation, shale and sandstone. Yields limited amounts of water of poor quality. Bloyd Formation, shale and limestone; and Hale Formation, limestone and sandstone. Probably will yield only small amounts of water of fair to poor quality.	ABH	2
14) MISSISSIPPIAN ROCKS ABOVE CHATTANOOGA SHALE: Undifferentiated. Pitkin Formation, limestone; Fayetteville Formation, shale and limestone; Hindsville Formation, limestone and shale; and Moorefield Formation, limestone. Keokuk Formation, chert; Reeds Spring Formation, chert and limestone; and St. Joe "Group", limestone and marlstone. Yield small to moderate amounts of water of fair to good quality.	MRC	3
15) MISSISSIPPIAN, DEVONIAN, SILURIAN, AND ORDOVICEAN ROCKS: Undifferentiated. Mississippian and Devonian, Chattanooga shale, shale; Devonian, Sallisaw Formation, limestone, sandstone, and chert; and Frisco Formation, limestone. Silurian, Quarry Mountain Formation, limestone; Tenkiller Formation, limestone; and Blackgum Formation, limestone and dolomite. Ordovicean, Sylvan Shale, shale; Fornvale Limestone,limestone; Fite Limestone, limestone; Tyner Formation, shale, sandstone, dolomite, and limestone; Burgen Sandstone, sandstone and minor shales and limestone; and Cotter Dolomite, dolomite. Limestone, dolomite, and sandstone units may yield small to moderate amounts of water of fair to good quality; shale units probably will yield only limited amounts of water of poor to fair quality.	MDS	3
16) DOXEY FORMATION: Red-brown shale and siltstone, with greenish gray calcareous siltstone at base. Exposed thickness is 30 feet, with top eroded.	DYF	2

17) <u>CLOUD CHIEF FORMATION:</u> CCF 3

Red-brown and greenish-gray shale and siltstone with some orange-brown fine-grained sandstone and siltstone. At base are two or more thin, pink to maroon to greenish-gray dolomite beds and (or) gypsum beds (Moccasin CreekBed), eroding into a mappable escarpment: About 25 feet above the base is a white to light-gray dolomite (DayCreek Bed) not mapped. Thickness ranges up to 160 feet, with top eroded in many places.

18) <u>RUSH SPRINGS FORMATION:</u> RSF 2

Orange-brown fine-grained sandstone, commonly cross-bedded, with some interbedded red-brown shale, silty shale, and gypsum beds. In southern part of area, about 30 feet below top is a thin massive gypsum bed (Weatherford or One Horse Bed) not mapped here but mapped by Misor and others (1954) as basal Cloud Chief. About 100 feet lower is another thin gypsum (Old Crow Bed), not mapped here. Thickness is about 190 feet in southern part and 90 feet near Kansas border, with top eroded in many places.

19) <u>MARLOW FORMATION:</u> MWF 2

Orange-brown fine-grained sandstone and siltstone, with some interbedded red-brown shale and silty shale in upper part and some thin gypsum beds at base, about 35 feet above base, and at top. The upper two gypsum and (or) dolomite beds are generally pink to maroon and less than 1 foot thick; they may erode into mappable escarpments about 20 feet apart, being named Emanuel Bed at top and Relay Creek Bed 15 to 20 feet below the top. In places the basal Marlow is a greenish-gray medium-grained sandstone. In Woods and Woodward Counties, the Doe Creek Lentil (Pmd) is a coarse-grained calcareous sandstone with algal clumps and invertebrate fossils, ranging up to 70 feet thick from the base of the Marlow to the Relay Creek Bed, cropping out in a narrow band of high hills striking northeast. Thickness is about 120 feet, with top eroded at many places.

20) <u>CEDAR HILLS SANDSTONE:</u> CHS 2

Orange-brown to greenish-gray fine-grained sandstone and siltstone, with some red-brown shale. Thickness ranges up to 180 feet, with more sandstone to the north and more shale to the south.

21) <u>ELK CITY SANDSTONE:</u> ECS 2

Reddish-brown, fine-grained sandstone with minor amounts of silt and clay, weakly cemented by iron oxide, calcium carbonate, and gypsum; maximum thickness 185 feet, top eroded.

22) <u>EL RENO GROUP; FLOWERPOT SHALE:</u> EFS 1
Primarily evaporites and reddish-brown shale, with deltaic clastics to the southeast. Flowerpot Shale, reddish-brown shale containing several salt and gypsum beds in the upper part. Thickness, about 300 to 450 feet; gradations southward and eastward into the Chickasha Formation and Duncan Sandstone.

23) <u>DUNCAN SANDSTONE:</u> DNS 2
Comes under El Reno Group. Light gray and reddish-brown, crossbedded, fine-grained sandstone and mudstone conglomerate with some interbedded yellowish-gray and reddish-brown shales; thickness, about 200 feet; gradational into the Cedar Hills Sandstone northward and into the Flowerpot Shale northward and westward.

24) <u>OSCAR GROUP:</u> OCG 1
Shale, sandstone, and arkose. 300 to 500 feet thick, base covered.

25) <u>DEESE GROUP:</u> DSG 1
Base of Confederate Limestone down to top of Otterville Limestone; thickness, 9700 feet. Probably yields only limited amounts of water of poor to fair quality.

26) <u>GRAYSON MARL AND BENNINGTON LIMESTONE:</u> GBL 1
Grayson Marl, marl, olive-gray, weakly indurated; thickness, about 25 feet. Bennington Limestone at base is moderately indurated, medium bedded; thickness, about 10 feet. Yields only limited amounts of water of poor quality.

27) <u>BOKCHITO FORMATION:</u> BKF 1
Clay, illitic, kaolinitic, with some tan limestones and sandstones. Subdivided into Pawpaw Clay at top, 40 to 60 feet thick; Quarry Limestone, 13 feet thick; Weno Clay, 100 to 135 feet thick; and basal Denton Clay, 50 to 70 feet thick. Yields only limited amounts of water of poor quality.

28) <u>GOODLAND LIMESTONE AND WALNUT CLAY:</u> GLW 3
Goodland Limestone, limestone, gray, dense, nodular to massive; thickness, 20 to 30 feet. At base is Walnut Clay, tan, about 4 feet thick. Yields only limited amounts of water of poor quality.

29) <u>ANTLERS SAND:</u> ARS 2
Sand, white to yellow, medium-grained, weakly indurated, with varicolored clays. Contains arkosic conglomerates near Arbuckle Mountains and Baum Limestone near Mannsville anticline. Thickness 200 to 700 feet. Yields moderate to large amounts of water of good quality.

30) <u>GARBER SANDSTONE:</u> GBS 2
Sandstone, red-brown, fine to coarse-grained; thickness about 110 to 150 feet, including Fairmont Shale west of Elmore City, Garvin County. Yields small to moderate amounts of water of fair quality.

31) <u>WELLINGTON FORMATION:</u> WNF 2
Shale, red-brown, with several 20 to 30 feet bituminous sandstones at base (Ryan); thickness, about 100 to 200 feet, decreasing southeastward. Yields small to moderate amounts of water of fair quality.

32) <u>ADA FORMATION:</u> AAF 1
Shale, red-brown to gray, bituminous sandstone and limestone conglomerate; thickness, 100 to 1400 feet (subsurface), decreasing southward. Probably will yield only limited amounts of water of fair quality.

33) <u>VAMOOSA FORMATION:</u> VMF 1&2
Shale, sandstone, and chert conglomerate; red-brown to buff fine to coarse-grained sandstone. Subdivided into 12 members, each with coarse clastics at base overlain by shale. Thickness, about 125 to 260 feet (to 1000 feet in subsurface), decreasing southward. Yields small to moderate amounts of water of fair quality.

34) <u>ATOKA FORMATIONS:</u> TKF 2
Shale, dark-gray, and sandstone, buff to white, fine to coarse-grained, with some chert conglomerates; thickness, 800 to 3000 feet. Probably yields only limited amounts of water of poor to fair quality.

35) <u>VANOSS GROUP:</u> VSG 1
Shale, maroon, arkose, and limestone conglomerate; thickness, 250 to 900 feet (subsurface), decreasing southward. Yields only limited amounts of water of fair to good quality.

36) <u>TISHOMINGO AND TROY GRANITES:</u> TTG 3
Granite, pink, with much microcline and biotite; Tishomingo is coarse grained. Estimated thickness 10 miles. Probably will yield only limited amounts of water of good quality.

37) <u>FAIRMONT SHALE:</u> FTS 1
Shale, red-brown, blocky; thickness, 40 to 80 feet, decreasing southward. Yields only limited amounts of water of poor quality.

38) <u>WEST SPRING CREEK AND KINDBLADE FORMATIONS:</u> WSK 3
Limestone, gray to tan, fine-grained, cherty, gradational eastward into dolomites and sandstones; thickness, 1500 to 2300 feet, decreasing eastward. Yields moderate to large amounts of water of good quality.

39) <u>BLAINE FORMATION:</u> Mostly thin gypsums with thin dolomites below each gypsum, interbedded with red-brown shale, grades southward into Chickasha Formation. Thickness, 50 to 75 feet.	BLF	3
40) <u>FLOWERPOT SHALE:</u> Mostly red-brown silty clay shale with stringers of gypsum (satin spar and selenite); grades southward into Chickasha Formation. Thickness, 20 to 40 feet.	FPS	1
41) <u>PURCELL SANDSTONE:</u> Red-brown to maroon fine to coarse-grained sandstone, mudstone conglomerate, and red-brown shale. Thickness, 150 feet.	PCS	2
42) <u>BISON FORMATION:</u> Mostly orange-brown to greenish-gray fine-grained sandstone. Thickness ranges up to 120 feet.	BNF	2
43) <u>OGALLALA FORMATION:</u> Gray to light-brown, fine to medium-sand with some clay, silt, gravel, volcanic ash, and caliche beds; locally cemented by calcium carbonate. Thickness ranges from 0 to about 320 feet. The formation thins eastward.	OLF	4
44) <u>EL RENO GROUP: DOG CREEK SHALE:</u> Reddish-brown shale with thin beds of siltstone and dolomite; thickness, about 220 feet; gradational eastward into the Chickasha Formation.	EDS	4
45) <u>NELLY BLY FORMATION AND HOGSHOOTER LIMESTONE:</u> Nelly Bly Formation consists mainly of shale , a few layers of fine to medium-grained sandstone. Thickness ranges from 80 to 550 feet (25 to 170m). Underlying Hogshooter Limestone is massive crinoidal limestone 1 to 50 feet (0.3 to 14m).	NBH	4
46) <u>COFFEYVILLE AND CHECKERBOARD FORMATIONS:</u> Coffeyville Formation is mainly shale interbedded with fine to medium-grained sandstone. Locally formation contains thin coal seams. Thickness ranges from 175 to 470 feet (50 to 140m). Underlying Checkerboard Limestone is crystalline limestone 2 to 15 feet (1 to 5m) thick.	CDF	4
47) <u>McALESTER FORMATION:</u> Shale, gray, illitic, chloritic, with many tan to gray sandstones, fine to coarse-grained, micaceous, quartzose; McAlester and Stigler coals 600 to 800 feet or more below top; thickness, 2000 to 2830 feet, increasing eastward.	MRF	1

48) <u>POST OAK CONGLOMERATE:</u> POC 2

Limestone conglomerate near limestone outcrops contains zeolite-opal (Tepee Creek Formation) locally, near gabbro and anorthosite outcrops; arkosic gravel and cobbles near igneous outcrops. These rock types are interbedded with sands, silt, clay and shale, as much as 500 feet thick at surface but several thousand feet thick in subsurface, extending down section into Pennsylvanian rocks.

49) <u>KEOKUK AND REEDS SPRING FORMATIONS AND ST. JOE GROUP:</u> KSF 3

Keokuk Formation, chert and limestone. Yields small to moderate amounts of good-quality water. Reeds Spring Formation, chert and limestone. Yields small to moderate amounts of good quality water. St. Joe Group, limestone and shale. Yields small to moderate amounts of good quality water.

50) <u>CHATTANOOGA, FERNVALE, FITE, TYNER, BURGEN, AND COTTER FORMATIONS:</u> CFT 3

Chattanooga Formation, shale and minor sandstone. Yields only small amounts of fair to poor quality water.

Fernvale Formation, limestone. Yields only small amounts of fair to poor quality water.

Fite Formation, limestone. Yields only small amounts of fair to poor quality water.

Tyner Formation, shale and dolomite. Yields only small amounts of fair to poor quality water.

Burgen Sandstone, sandstone and minor dolomite and shale. Yields small to moderate amounts of good quality water.

Cotter Formation, dolomite and minor sandstone. Yields only small amounts of fair to poor quality water.

51) <u>BLOYD AND HALE FORMATION:</u> BHF 1&3

Bloyd Formation, limestone and shale. Yields only small amounts of fair to poor quality water. Hale Formation, limestone and sandstone. Yields only small amounts of fair to poor quality water.

52) <u>LENAPAH FORMATION:</u> LPH 3

Limestone and shale. Yields only small amounts of fair to poor quality water.

53) <u>OOLOGAH FORMATION:</u> OGF 3

Thin-bedded limestone and some shale in the southern parts of the area. North of Oologah, in western Rogers County, the map unit includes limestone and minor shale, and shale and thin sandstone. Yields only small amounts of fair to poor quality water.

54) <u>STANLEY SHALE:</u>	SYS	1

Shale, dark-gray, siliceous, with some gray to buff fine-grained sandstones; thickness, 10,000 feet. Yields only limited amounts of water of poor quality.

55) <u>LOESS:</u>	LOS	2

APPENDIX V

SOIL PROFILES AND LABORATORY TEST RESULTS

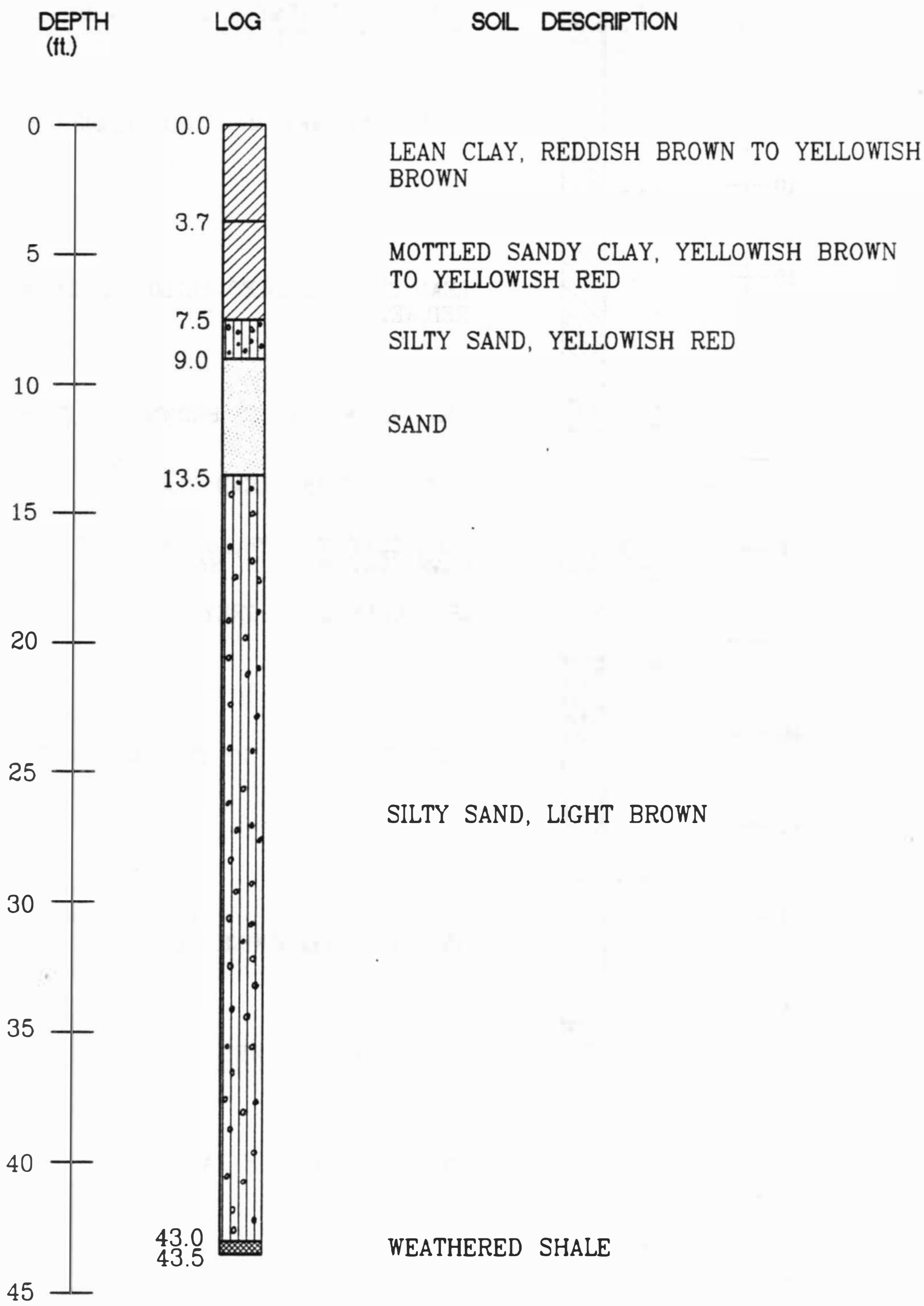

FIGURE V.1 SOIL PROFILE for BOREHOLE #1
at SHAWNEE SITE (US 270 63-23 X0465)

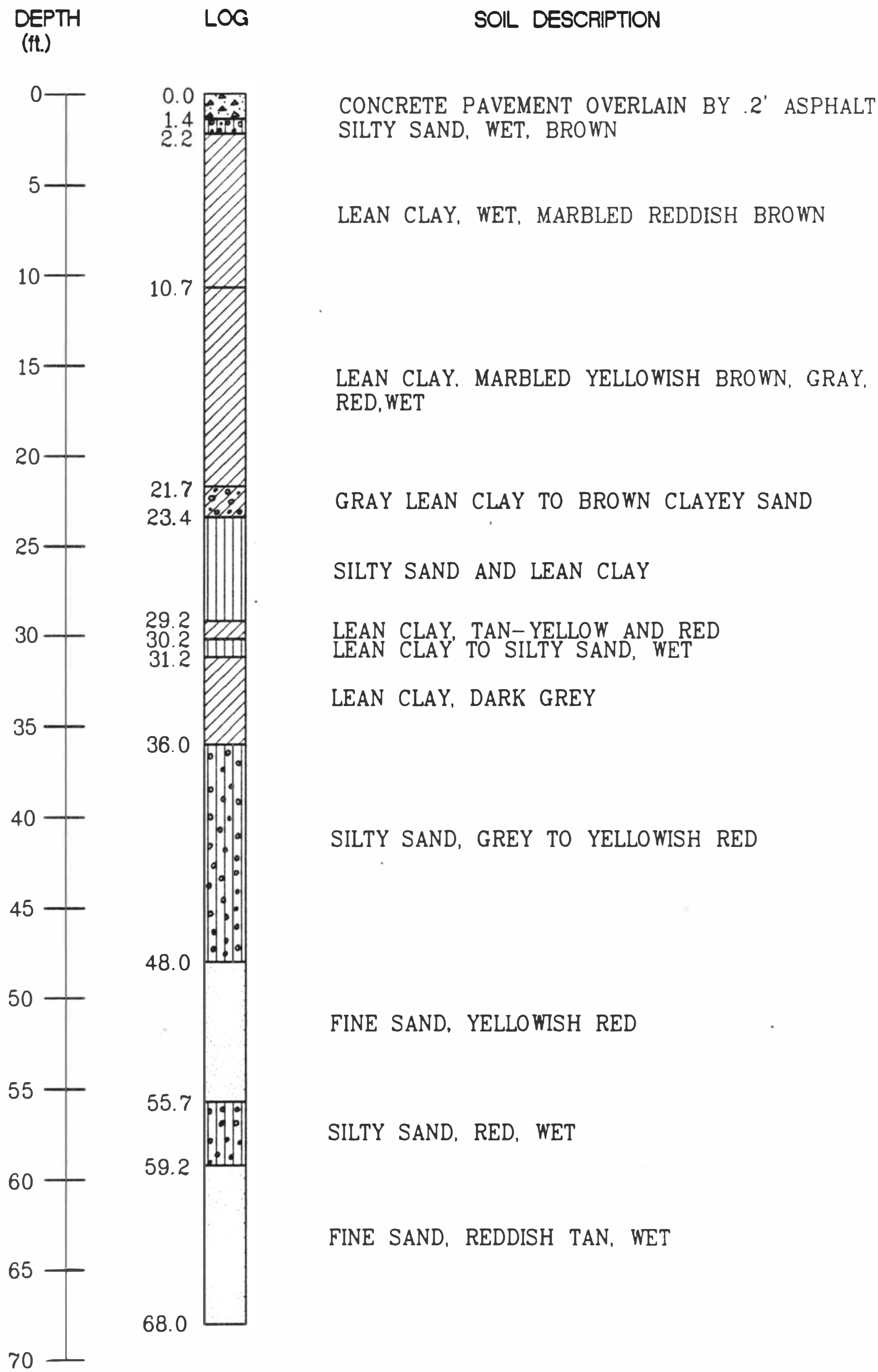

FIGURE V.2 SOIL PROFILE for BOREHOLE #2
at SHAWNEE SITE (US 270 63-23 X0465)

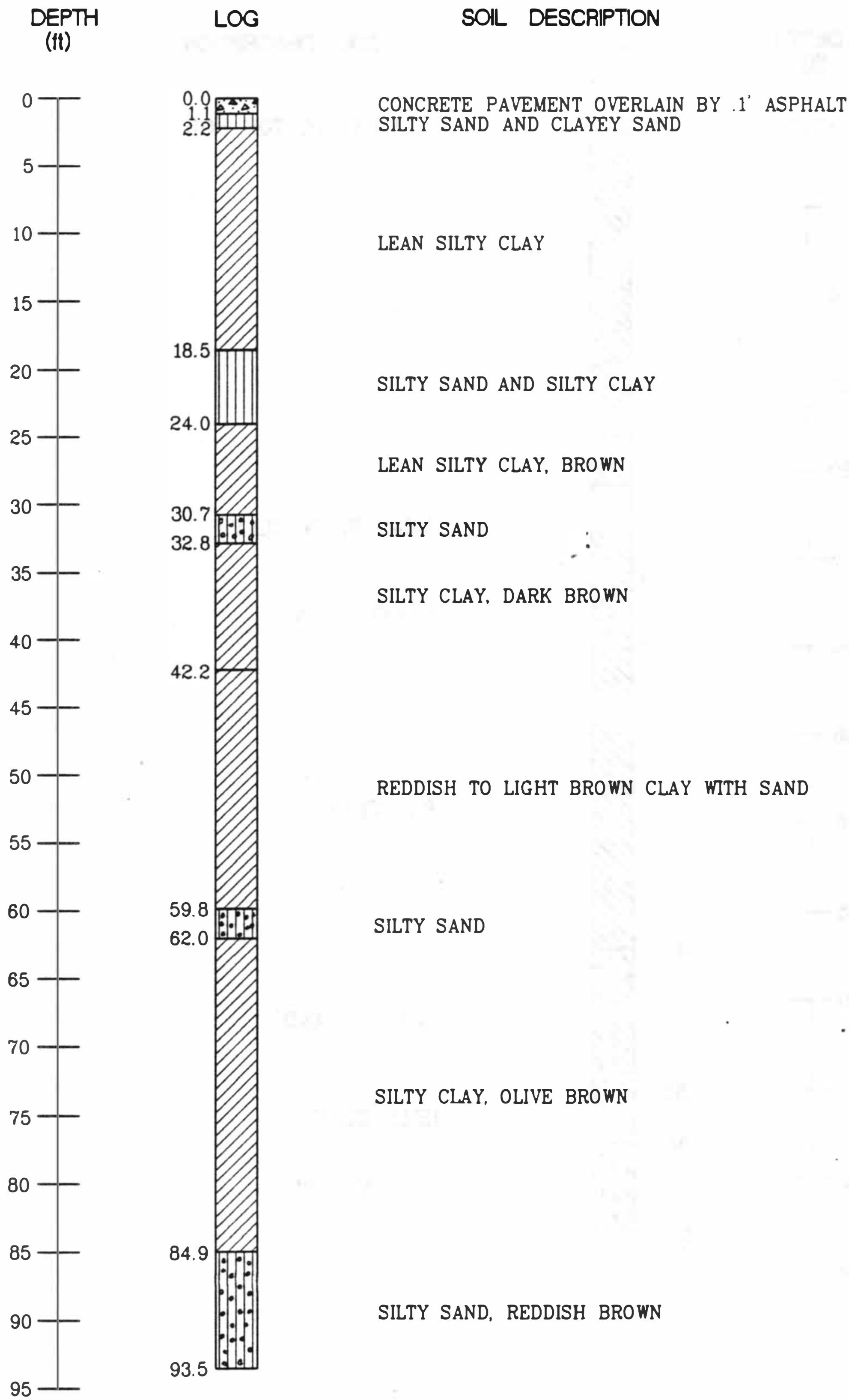

FIGURE V.3 SOIL PROFILE for BOREHOLE #3
at WEWOKA CREEK SITE (US 270 67-02 X0894)

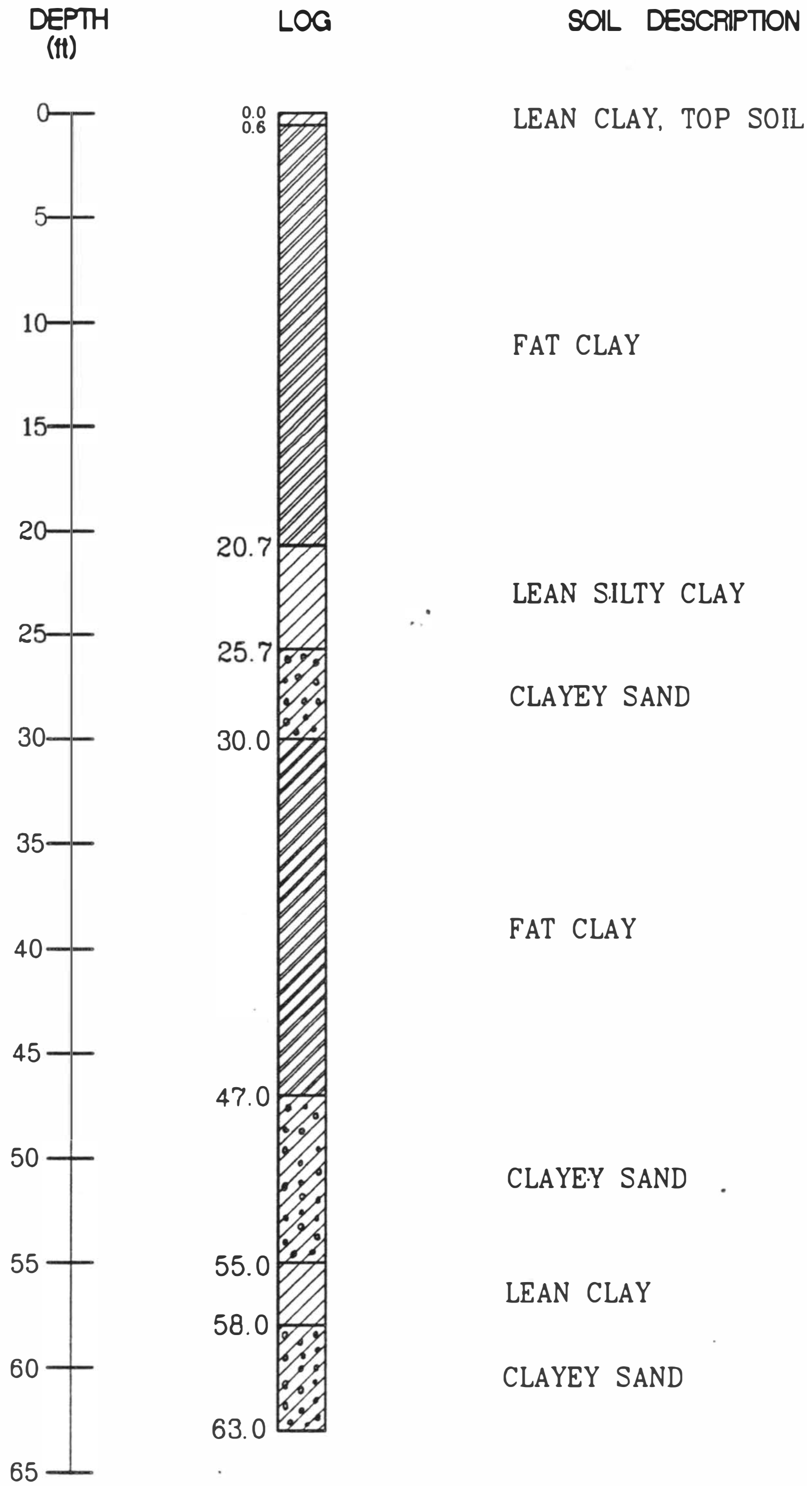

FIGURE V.4 SOIL PROFILE for BOREHOLE #5
at WEWOKA CREEK SITE (US 270 67-02 X0894)

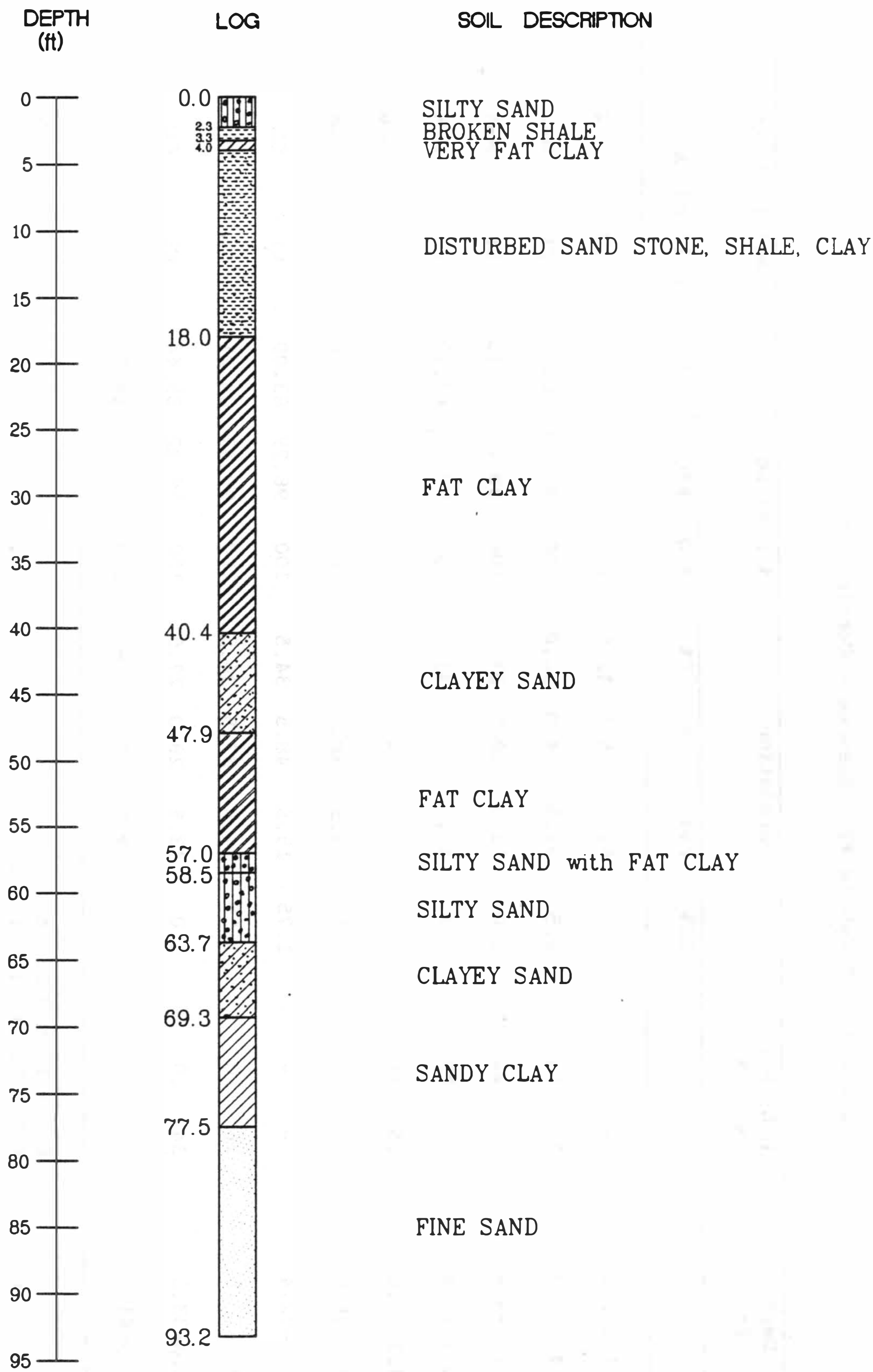

FIGURE V.5 SOIL PROFILE for BOREHOLE #6
at WEWOKA CREEK SITE (US 270 67-02 X0894)

Table V.1 Borehole #2 (Shawnee - Continuous Sampling)

Sample #	Depth Ft.	L.L %	P.I %	Gradation				% Passing			Classification	
				CS%	FS%	S%	C%	#10	#40	#200	Unified	AASHTO
2A	1.3-2.2	-	-	1.5	61.0	25.0	12.5	100	98.20	37.45	SM	A-4
2F	4.8-5.5	30	16	1.5	28.5	44.0	26.0	100	98.58	70.30	CL	A-6
2M	9.2-9.9	35	21	2.0	32.0	38.5	27.5	100	98.22	66.13	CL	A-6
2O	10.7-11.4	48	29	1.0	15.0	47.0	37.0	100	99.14	83.79	CL	A-6
2S	13.3-14.0	25	11	-	-	-	-	-	-	-	CL	A-6
2U	14.3-15.0	34	20	1.5	29.5	38.0	31.0	100	98.57	88.86	CL	A-6
2FF	21.7-22.4	-	-	1.75	15.5	48.5	34.5	100	98.29	83.00	CL	CL
2QQ	29.2-29.9	26	10	1.50	34.5	37.5	26.5	100	98.41	64.21	CL	CL
2WW	32.6-33.3	34	20	1.0	43.5	28.0	27.5	100	99.22	55.44	CL	CL
2JJJ	40.6-41.3	-	-	51.5	39.0	9.5	-	100	99.85	48.52	SM	A-2-4

L.L - Liquid Limit
P.I - Plasticity Index
C.S - Coarse Sand
F.S - Fine Sand
S - Silt
C - Clay

Table V.1 (continued) Borehole #2 (Shawnee - Continuous Sampling)

Sample #	Depth Ft.	F.M.C. %	F.D.D. pcf	D.D. pcf	O.M.C. %	C_v in^2/min	C_c	C_s	P_c t/ft^2	OCR	γsat pcf	Wsat %
2F	4.8-5.5	21.65	-	115.74	14.70	-	-	-	-	-	-	-
2H	6.2-6.9	18.75	110.90	-	-	0.0018	0.218	0.02	2.0	4.65	131.45	18.50
2M	9.2-9.9	22.69	-	110.30	16.00	-	-	-	-	-	-	-
2S	13.3-14.0	16.29	-	115.40	15.60	-	-	-	-	-	-	-
2U	14.3-15.0	19.70	105.10	-	-	-	-	-	-	-	127.84	21.80
2W	15.7-16.4	21.54	101.30	-	-	0.011	0.321	0.02	3.1	3.08	125.47	23.80
2BB	18.9-19.6	20.82	101.80	107.64	17.61	-	-	-	-	-	125.78	23.50
2JJ	24.0-24.7	15.50	-	108.10	17.58	-	-	-	-	-	-	-
2UU	31.2-31.9	18.91	-	107.81	17.15	-	-	-	-	-	-	-
2AAA	34.9-35.6	12.70	-	107.69	17.05	-	-	-	-	-	-	-
2BBB	35.6-36.0	15.72	102.10	-	-	-	-	-	-	-	-	-

F.M.C - Field moisture content
F.D.D - Field dry density
D.D - Dry density
O.M.C - Optimum moisture content
C_v - Coefficient of consolidation
C_c - Compression index
C_s - Swelling index
P_c - Preconsolidation pressure
OCR - Overconsolidation ratio
γsat - Saturated unit weight
Wsat - Water content at saturation

Table V.2 Borehole #3 (Wewoka Creek - West Approach)

Sample #	Depth Ft.	L.L %	P.I %	Gradation				% Passing			Classification	
				CS%	FS%	S%	C%	#10	#40	#200	Unified	AASHTO
3A	1.1-1.6	15	-	6.10	58.2	23.7	12.0	100	93.90	35.70	CL	A-6
3F	4.8-5.6	-	-	1.50	27.5	38.0	33.0	100	98.60	71.40	-	-
3G	5.6-6.3	-	-	0.50	27.5	38.5	33.5	100	99.40	77.20	-	-
3K	8.5-9.2	-	-	0.50	30.0	36.5	33.00	100	99.30	69.30	-	-
3Q	12.7-13.4	31	15	-	-	-	-	-	-	-	CL	A-6
3S	13.5-14.4	-	-	0.50	20.5	49.0	30.00	100	99.80	78.70	-	-
3JJ	24.5-25.2	38	21	0.00	13.5	46.5	40.00	100	99.80	87.00	CL	A-6
3NN	27.2-27.9	35	20	-	-	-	-	-	-	-	CL	A-6
3TT	30.7-31.4	31	14	0.00	28.0	49.0	23.00	100	99.90	71.80	CL	A-6
3ZZ	34.9-35.6	48	30	0.50	11.0	44.5	44.00	100	99.30	88.40	CL	A-6
3HHH	40.1-40.3	-	-	1.50	23.0	23.5	52.00	100	98.70	75.43	-	-
3PPP	44.9-45.6	-	-	0.00	5.5	26.5	68.00	100	99.70	95.00	-	-
3XXX	50.6-51.3	-	-	7.50	31.5	21.0	40.00	100	92.60	61.10	-	-
3EEEE	55.2-55.9	-	-	0.30	27.7	34.0	38.00	100	99.90	72.10	-	-
3VVVV	65.6-66.3	-	-	0.00	1.5	43.5	55.00	100	100.00	98.40	-	-
3BBBBB	69.9-70.6	-	-	0.50	21.0	46.5	32.00	100	99.50	78.50	-	-
3HHHHH	74.0-74.7	-	-	0.00	17.5	48.5	34.00	100	100.00	82.40	-	-
3OOOOO	79.2-79.9	-	-	0.00	20.5	45.5	34.00	100	100.00	79.60	-	-

Table V.2 (continued) Borehole #3 (Wewoka Creek - West Approach)

Sample #	Depth Ft.	FMC %	F.D.D. pcf	D.D. pcf	O.M.C. %	C_v in^2/min	C_c	C_s	Pc t/ft^2	OCR	γsat pcf	Wsat %
3A	1.1-1.6	19.86	-	107.48	17.41	-	-	-	-	-	-	-
3F	4.8-5.6	-	-	107.31	17.28	-	-	-	-	-	-	-
3G	5.6-6.3	19.37	-	-	-	-	-	-	-	-	-	-
3J	7.8-8.5	22.22	-	107.82	17.42	-	-	-	-	-	-	-
3K	8.5-9.2	25.45	-	-	-	-	-	-	-	-	-	-
3L	9.2-9.9	17.49	109.70	-	-	0.0078	0.141	0.00	2.5	4.06	130.70	19.14
3Q	12.7-13.4	18.11	-	107.63	17.24	-	-	-	-	-	-	-
3S	13.5-14.4	16.20	-	107.67	17.31	-	-	-	-	-	-	-
3EE	21.8-22.4	18.60	110.45	-	-	0.00175	0.565	0.05	4.3	2.97	131.70	18.76
3JJ	24.5-25.2	21.53	-	108.93	14.57	-	-	-	-	-	-	-
3KK	25.2-25.9	20.18	-	108.57	17.34	-	-	-	-	-	-	-
3NN	27.2-27.9	19.43	-	109.11	15.11	-	-	-	-	-	-	-
3TT	30.7-31.4	20.91	-	115.60	12.88	-	-	-	-	-	-	-
3ZZ	34.9-35.6	21.98	-	104.60	17.83	-	-	-	-	-	-	-
3AAA	35.6-36.3	33.36	102.35	-	-	0.00135	0.864	0.08	4.9	2.16	126.13	23.23
3HHH	40.1-40.3	18.09	109.60	110.69	15.95	0.0062	0.18	0.02	2.7	1.04	130.64	19.20
3OOO	44.2-44.9	23.45	101.92	-	-	0.00165	0.912	0.12	3.75	1.34	125.86	23.49
3PPP	44.9-45.6	25.19	-	-	-	-	-	-	-	-	-	-
3XXX	50.6-51.3	20.79	-	-	-	-	-	-	-	-	-	-
3ZZZ	52.0-52.7	21.89	104.13	-	-	0.0028	0.133	0.03	2.8	0.84	127.24	22.19
3EEEE	55.2-55.9	20.06	-	-	-	-	-	-	-	-	-	-
3HHHH	57.3-58.0	24.83	101.50	-	-	0.00525	0.116	0.05	3.7	1.01	125.59	23.73
3TTTT	64.3-64.9	28.28	92.38	-	-	0.0075	0.133	0.06	2.75	0.72	119.92	29.81
3VVVV	65.6-66.3	29.07	-	-	-	-	-	-	-	-	-	-
3BBBBB	69.9-70.6	23.39	101.40	-	-	-	-	-	-	-	125.53	23.80
3HHHHH	74.0-74.7	21.99	104.43	-	-	-	-	-	-	-	127.42	22.01
3OOOOO	79.2-79.9	19.73	108.10	-	-	-	-	-	-	-	129.71	19.99

Table V.3 Borehole #5

Sample #	Depth Ft.	L.L %	P.I %	Gradation CS%	FS%	S%	C%	% Passing #10	#40	#200	Classification Unified	AASHTO
5A		-	-	2.00	24.0	24.0	50.0	100	98.2	74.6	-	-
5H		-	-	0.14	13.9	45.0	41.0	100	99.9	86.0	-	-

Table V.4 Borehole #6 (Wewoka Creek - Under the Bridge)

Sample #	Depth Ft.	L.L %	P.I %	Gradation CS%	FS%	S%	C%	% Passing #10	#40	#200	Classification Unified	AASHTO
6B	1.9-2.3	-	-	1.5	70.0	11.0	17.5	100	98.6	28.6	-	-
6C	2.3-3.3	-	-	2.0	26.0	31.0	41.0	100	98.0	71.9	-	-
6D	3.7-4.0	-	-	0.5	7.0	31.5	61.0	100	99.7	92.5	-	-
6J	8.3-8.7	-	-	4.7	15.8	37.0	42.5	100	95.3	79.4	-	-
6AA	19.0-19.7	27	15	-	-	-	-	-	-	-	CL	A-6
6JJ	25.1-25.8	-	-	0.2	11.8	51.5	36.5	100	99.9	88.1	-	-
6RR	29.7-30.4	-	-	5.1	21.8	35.1	38.0	100	94.9	73.1	-	-
6LLL	42.2-42.9	-	-	0.6	8.3	43.6	47.5	100	99.4	91.1	-	-
6UUU	48.7-49.4	-	-	0.4	11.0	36.6	52.0	100	99.6	88.6	-	-
6JJJJ	57.3-57.6	-	-	0.1	36.0	26.9	37.0	100	99.9	63.9	-	-
6ZZZZ	69.3-70.0	-	-	0.1	24.5	44.4	31.0	100	99.9	75.4	-	-
6LLLLL	76.8-77.5	-	-	0.0	10.3	47.7	42.0	100	100.0	89.7	-	-
6UUUUU	85.7-86.7	-	-	0.1	54.3	27.6	18.0	100	99.9	45.6	-	-

Table V.4 (continued) Borehole #6 (Wewoka Creek - Under the Bridge)

Sample #	Depth Ft.	F.M.C. %	F.D.D. pcf	D.D. pcf	O.M.C. %	C_v in^2/min	C_c	C_s	Pc t/ft^2	OCR	γsat pcf	Wsat %
6B	1.9-2.3	14.85	-	-	-	-	-	-	-	-	-	-
6C	2.3-3.3	14.10	-	-	-	-	-	-	-	-	-	-
6D	3.7-4.0	17.63	110.39	-	-	-	-	-	-	-	131.17	18.82
6H	6.8-7.5	14.56	-	115.41	17.33	-	-	-	-	-	-	-
6J	8.3-8.7	14.14	-	-	-	-	-	-	-	-	-	-
6AA	19.0-19.7	18.75	-	115.77	17.64	-	-	-	-	-	-	-
6JJ	25.1-25.8	27.33	-	-	-	-	-	-	-	-	-	-
6RR	29.7-30.4	18.08	-	-	-	-	-	-	-	-	-	-
6LLL	42.2-42.9	26.59	-	-	-	-	-	-	-	-	-	-
6UUU	48.7-49.4	28.06	-	-	-	-	-	-	-	-	-	-
6JJJJ	57.3-57.6	23.98	-	-	-	-	-	-	-	-	-	-
6ZZZZ	69.3-70.0	27.18	-	-	-	-	-	-	-	-	-	-
6LLLLL	76.8-77.5	27.80	-	-	-	-	-	-	-	-	-	-
6UUUUU	85.7-86.7	21.14	-	-	-	-	-	-	-	-	-	-

Table V.5 Borehole #7 (Shawnee - Undisturbed Sample)

Sample #	Depth Ft.	F.M.C. %	F.D.D. pcf	D.D. pcf	O.M.C. %	C_v in^2/min	Cc	C_s	Pc t/ft^2	OCR	γsat pcf	Wsat %
7B	3.8-5.8	-	-	-	-	0.01615	0.15	0.02	3.00	-	-	-
7D	7.8-9.8	-	-	-	-	0.0027	0.14	0.02	-	-	-	-
7G	13.8-15.8	-	-	-	-	0.0052	0.28	0.03	1.85	-	-	-
7I	17.8-19.8	-	-	-	-	0.0038	0.18	0.02	1.40	-	-	-
7K	21.8-23.8	-	-	-	-	0.00185	0.24	0.07	2.40	-	-	-