# CENTER FOR INFRASTRUCTURE ENGINEERING STUDIES

# Determination and Prioritization of MoDOT Geotechnical Related Problems with Emphasis on Effectiveness of Designs for Bridge Approach Slabs and Pavement Edge Drains Phase I & II

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16. Abstract

To identify, document, and prioritize significant problems having to do with earth materials, such as slope instability, soil erosion, and roadway subgrade instabilities, in Missouri transportation facilities and adjacent rights of way through visits to all MoDOT districts. While all geotechnical related problems will be considered, particular emphasis will be placed on evaluating the effectiveness of recently implemented designs for bridge approach slabs and pavement edge drains. A report documenting and prioritizing geotechnical problems, and evaluating the effectiveness of recently implemented designs, will be provided to MoDOT state and district level personnel, along with recommendations for approaches to research which could be applied to solve problems identified.

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The guidance, suggestions and perseverance of our project technical liaison, Thomas Fennessey, Senior Materials Engineer MoDOT, have been especially valuable throughout this undertaking.

## EXECUTIVE SUMMARY

The objective of this effort was to identify, document, and prioritize geotechnical problems; i.e., those having to do with earth materials, such as slope instability, soil erosion, and roadway sub-grade instabilities, in Missouri highways and adjacent rights-of-way. A written survey was distributed to all District Geologists, Area Engineers, Resident Engineers and several Operations Engineers and Construction Inspectors. Interview trips and subsequent field verification trips were made to each District to document site conditions. While all geotechnical related problems were considered, particular emphasis was placed on evaluating the effectiveness of recently implemented designs for bridge approach slabs and pavement edge drains. The results of the survey are documented in this report. The geotechnical problems are prioritized and an evaluation of the effectiveness of recently implemented designs is provided along with recommendations for approaches which can be applied to solve the identified problems.

Four issues rose to the top of the list of geotechnical related challenges facing the Districts. The issues are slope stability (soil), pavement (in terms of stability, sub-base support, and drainage), erosion control (both on new construction and long-term facilities) and bridge approach slabs. Half of all the issues cited involve excess or uncontrolled water. Every District reported soil slope instability as a major issue, typically in the top three concerns for the District. Field visits revealed the slopes to be too steep and of marginal strength materials. Erosion challenges observed included steep slopes, concentrated drainage or inappropriate materials being placed where in areas of concentrated drainage. Pavement problems were extensive across the state; i.e., poor quality surface and failure of pavement before the end of design life. The causes include: poor subsurface drainage, inadequate sub-base support, expansive soils and settlement, among others; however, this study was not designed to isolate causes for individual locations. All Districts cited bridge approach slabs as problematic. The redesign (c. 1993) is not alleviating the “bump at the end of the bridge.” Causes varied from design of the approach slab to construction/inspection practices.

Three general recommendations, if enacted, will lead to a substantial reduction in geotechnical-related problems, reduced life-cycle costs and improved performance of MoDOT infrastructure.

The general recommendations are:

- Further increase involvement of MoDOT's geotechnical specialists in all phases of operations.
- The Research Unit should institute long-term performance monitoring programs.
- Specific research needs of high priority.

Increase the level of involvement off MoDOT's geotechnical specialists must be included throughout the entire design-build-maintenance spectrum of the Department. This must include actively participating in the iterative process of the structural designs for bridges, walls and pavements; educating inspectors on the requirements for competent construction of geotechnical features in the transportation system; and collaborating with the maintenance forces to identify recurring problems that can be solved at the source rather than being continuously maintained.

Design, construction and maintenance changes should be "evidence-based." In order to do so, moderate- to long-term performance monitoring and subsequent data analyses must be on-going in order to provide the "evidence" on which to base changes. The Department's Research Unit should initiate and support long-term performance monitoring and data analysis in order to provide a sound, rational basis for improving designs, construction and maintenance practices, and ultimately reducing the lifecycle costs for the State's transportation infrastructure.

The findings from this survey indicate that specific research programs should be established to address these high priority geotechnical issues: soil slopes, pavement (subsurface drainage and support systems), soil erosion and bridge approach slabs. These issues were dominant across the State's Highway Districts.

A detailed database on the costs of both initial construction and maintenance of soil slopes is paramount to the effective reduction of effort and cost for failures of these slopes. Moisture conditions through the life of slopes should be documented and key variables and their impacts determined. A systematic evaluation of specific slope repair methods should be conducted.

It is critical to develop a spatial comparison of pavement ratings and maintenance/repair intervals and this must be correlated with pavement types, subsurface drainage systems and subsoil types among other parameters. The database should be analyzed and a network of pavement test sections established including performance monitoring of the subbase, base and drainage systems. The current pavement edge drains appear to be working where they were installed as new construction. Those placed in remedial applications seemed to not work well. This is likely to be the result of construction process as much as or more than of the design. A careful, well-instrumented study of edge drains in new and remedial construction should be incorporated into the test sections.

The goals of erosion control are to keep soil in place and out of waterways. Missouri needs laboratory and field evaluations to identify the key parameters and field demonstrations to show what erosion control measures work and under what conditions.

The consensus from the survey is that bridge approach slabs are not performing well. The causes vary and are certainly construction procedure related. It is entirely possible that the new (1993) design is also insufficient in some applications. A detailed study to isolate key variables and pinpoint the sources leading to poor performance is warranted.

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## INTRODUCTION

Every municipal, state and federal transportation agency must deal with the challenges and consequences of constructing and maintaining infrastructure founded on geologic media. This media (soil and rock) is heterogeneous, has time-dependent properties, and is often the only available alternative. These are not ideal conditions for founding long-term, high-performance infrastructure; and subsequently, numerous geotechnical engineering issues, from highly visible acute landslides/slope failures to chronically deteriorating pavements, are evident across the US including Missouri.

During research meetings between MoDOT personnel and civil engineering faculty from the Columbia and Rolla campuses of the University of Missouri, it was decided to attempt to make an accurate documentation of the extent, distribution, frequency and importance of the problems and how they relate to each other with respect to soil and problem type. Since this documentation is not yet available, maintenance and research efforts are often scheduled on a "problem of the moment" basis rather than through more objective means based on knowledge of the nature, extent, and importance of the problem.

Gathering and analyzing data on existing conditions is known as establishing a baseline. Baselining is mandatory before the effectiveness of any changes in a system can be evaluated (Walton, 1986). The overall goal of this project was to initiate the development of a baseline for the geotechnical facilities of Missouri's State Highway Infrastructure.

## OBJECTIVES

The overall objective of the project was to provide a report, documenting and prioritizing geotechnical problems and evaluating the effectiveness of recently implemented designs, to MoDOT state and District level personnel, along with recommendations for approaches to research which could be applied to solve the problems identified. Tasks involved in acquiring the data, analysis and preparation of the report included: identifying, documenting, and prioritizing significant problems having to do with earth materials, in Missouri transportation facilities and adjacent rights of way through visits to all MoDOT Districts. All geotechnical related problems were considered; however, particular emphasis was placed on evaluating the effectiveness of recently implemented designs for bridge approach slabs (BAS) and pavement edge drains (PED).

## PRESENT TECHNICAL CONDITIONS

During research meetings between MoDOT personnel and civil engineering faculty from both the Columbia (UMC) and Rolla (UMR) campuses of the University of Missouri, held by the Research, Development and Technology Division (RD&T) of MoDOT and at MoDOT District engineers' offices, it became clear that problems with slope stability, erosion, and pavement base instability are extensive. What is not available is accurate knowledge or documentation of the extent and distribution of the problems across the state or how problems relate to each other with respect to soil and problem type. As a result, maintenance and research efforts are often scheduled on a "problem of the moment" basis rather than through more objective means based on knowledge of the nature, extent, and importance of the problem.

In addition, recent design changes have been implemented for bridge approach slabs (BAS) and pavement edge drains (PED) in the past few years. The degree to which these changes have improved performance can now be studied, as sufficient time has passed since their implementation to provide some level of performance evaluation. It was logical to include the evaluation of these two recently implemented designs in this current study as the effort can be efficiently conducted in parallel with the survey of geotechnical problems.

The aim of this project was to identify, observe, document, and prioritize geotechnical related problem situations that are present across the state. The project was a collaborative effort among UMC, UMR, and MoDOT personnel.

### Action Plan:

This project included the following specific activities as illustrated in Figure 1:

1. An initial "kickoff" meeting in Jefferson City with representatives of MoDOT Soils and Geology, MoDOT RD&T, and key District personnel to discuss what is already known, and to finalize a strategy and approach for the project.

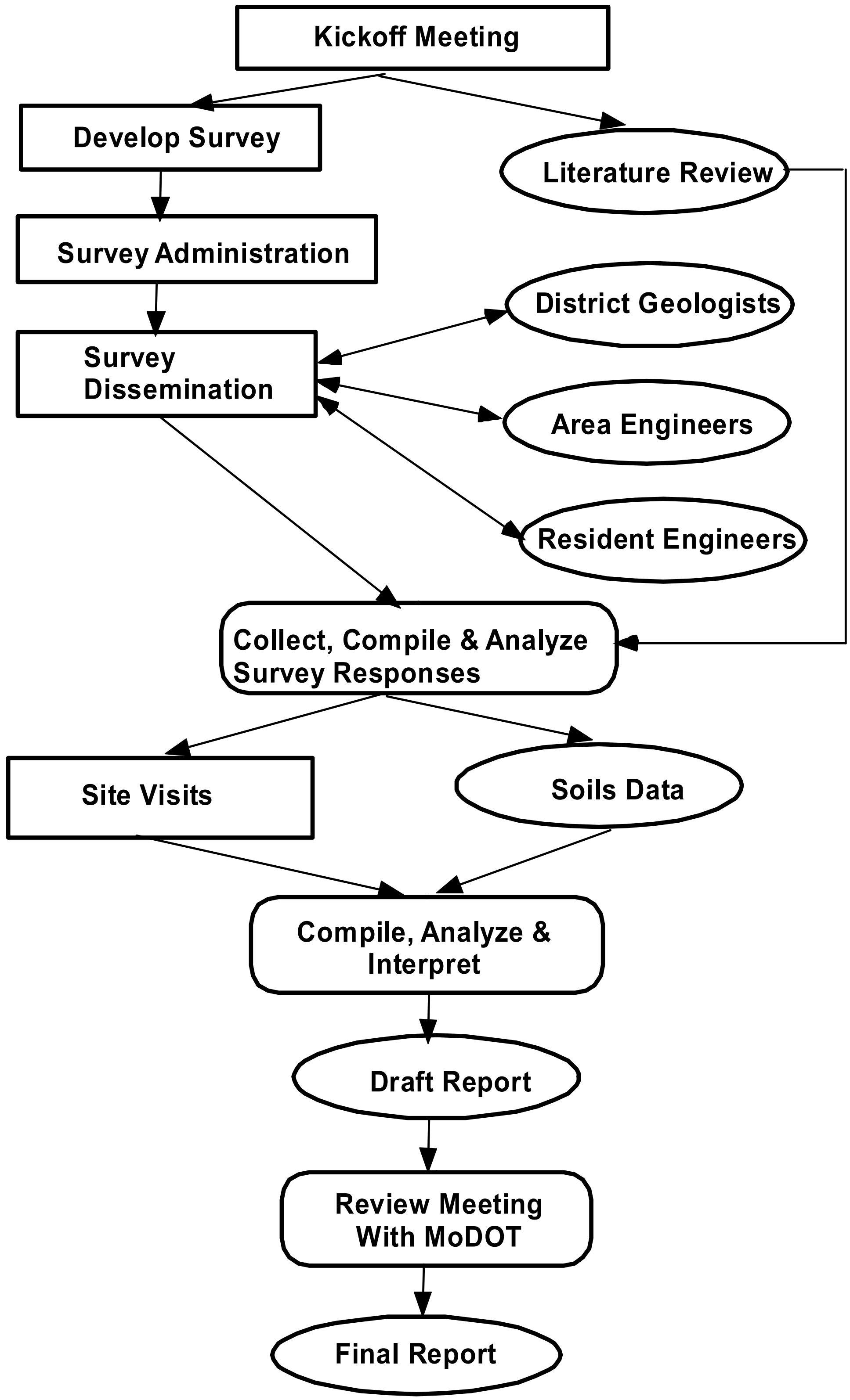



Figure 1 – Flowchart of the project showing major activities.

2. Dissemination of project information to MoDOT District personnel to facilitate collection of problem conditions and monitoring implemented designs within each District. The investigators developed a document (Appendix A) describing the project and a list of the types of information requested for distribution to District and area personnel.

3. Visits by the principal investigators (PIs) of each university to District offices to discuss situations with MoDOT District personnel. UMC visited Districts 1 through 5, and UMR visited Districts 6 through 10.

4. A tour of each District to visit typical sites demonstrating geotechnical problems and sites where recently implemented designs for bridge approach slabs and pavement edge drains have been constructed. The visited sites were documented with field notes and photographs for the purpose of classification and subsequent reference.

5. Compilation, analysis, and interpretation of collected data to develop quantitative measures on the extent of specific problems, correlations of problems with geographic location, and measures of the effectiveness of recently implemented designs.

6. Development and submittal of a draft report that documents the findings of the principal investigators and provides a series of recommendations for future action.

7. A final meeting to be held in Jefferson City with MoDOT personnel to discuss the findings and determine how research could proceed in an optimal way to solve the problems identified.

8. Submittal of the final report – following receipt and incorporation of comments by MoDOT personnel.

## TECHNICAL APPROACH

### General

The aim of this project was to identify, observe, document, and prioritize geotechnical related problem situations that are present across the state. The “Kickoff” meeting was held at MoDOT in January 2000. Following dissemination, collection, and analysis of the survey, the principal investigators met to discuss findings from geographic areas across the state and develop a "consensus" report documenting the results of the survey and providing recommendations for future action. The program for arriving at the final consensus report is outlined in Figure 1.

### Literature Review

A literature review focusing on Bridge Approach Slabs (BAS) (Appendix C) and Pavement Edge Drains (PED) (Appendix D) was initiated about the time of the kickoff meeting. UMR focused on BAS while UMC focused on PED.

### Development of Survey

The draft survey was prepared and modifications suggested during the kickoff meeting. The final version (Appendix A) was prepared and distributed.

### Survey Administration

The survey was initially distributed electronically to all District geologists. It was decided to include area engineers in the distribution, also electronically. Finally, the research teams visited with the respective Districts to present the research program and hardcopies of the survey to the resident engineers, those area engineers that missed the electronic version, and some operations personnel. All surveys were return-posted to the UMR team.

The continuing program, shown in Figure 1, involved collection and compilation of the survey responses, visits to each of the Districts to assess some of the problems noted in the surveys and to examine field sites of the most recent designs for BAS and PED. As much information about the performance of BAS and PED was collected from MoDOT District personnel as practicable during the site visits and through subsequent communications.

The information gathered through the surveys, site visits, communications with District personnel and through the literature review was compiled, analyzed and interpreted with the goal of identifying and prioritizing geotechnical related problems in Missouri’s highway system.

## DATA DEVELOPMENT

### Data Entry and Compilation of Geotechnical Survey

After developing the Geotechnical Survey, target audiences were selected to receive the survey. The target audiences were District Geologist (DG) first, followed by Area Engineer (AE), and then Resident Engineer (RE). Copies of the survey were distributed during meetings held by MoDOT with their DG, AE, RE, and some Operations Engineers, OE. The survey was distributed in paper and electronic formats. The responses were received at UMR in paper form. Once the surveys were received, they were transcribed verbatim into an Excel® workbook. The original paper formats were kept at UMR and copies of the completed surveys in electronic form were distributed for review.

The workbook used to retain the survey information in electronic format was designed to separate each question and each type of MoDOT Representative responding to the survey. In this design, a separate spreadsheet was used for each of the eight questions. Another sheet was used to enter the MoDOT personnel contact information (Name, District Number, Title, Address, Phone Number, Email) of each respondent. Bar charts were created to display the quantitative data contained in questions 1, 6 and 7. On each spreadsheet, three separate tables were created; one for each MODOT Representative Category. The table included their written or quantitative responses to the particular question (Appendix B).

Each of the ten (10) DG returned the survey to UMR by May of 2000. The information from those surveys was entered and plotted in the workbook. We received responses from 17 AE, 14 RE, 2 OE and 3 Construction Inspectors (CI). The survey responses from all of the respondents were entered and plotted in the workbook.

### Data Reduction and Analysis

There are numerous approaches to analyze the quantitive data from questions 1, 6 and 7. Several methods were evaluated. The methods selected and used are described below.

Question 1: "What geotechnical problems do you believe apply to your District?" All problems identified were listed (a through u) (Table 1). Each participant's response was weighted. The weighting system gave weights inversely proportional to the number of personnel at the given position. For example, there are 10 DG's and the weighting factor for their responses is 1/10 or

0.10. The weighting factor for OE's is 1/20 or 0.05. The complete scheme is shown in appendix B. The percentage of occurrence by District was calculated by dividing the sum of weights for a District by the sum of all weights for the State for a specific geotechnical issue.

Question 6: "Rank the following maintenance by frequency of their occurrence." For each geotechnical issue, responders ranked from 0 (no maintenance) to 5 (high frequency of maintenance), the perceived level of maintenance. The rank was multiplied by the weighting factor of the particular responder. The weighted–rankings were added for all responders within a District. The sum for the District was then divided by the sum of all weight factors for the District, resulting in the "Frequency" of maintenance for the specific geotechnical issue for a specific District.

Question 7: "Rank the following maintenance by severity of their occurrence." For each geotechnical issue responders ranked from 0 (no severity) to 5 (high severity) the perceived level of severity. The rank was then multiplied by the weighting factor of the particular responder. The weighted–rankings were added for all responders within a District. The sum for the District was then divided by the sum of all weight factors for the District, resulting in the "Severity" of maintenance for the specific geotechnical issue for a specific District.

"Impact" was calculated by multiplying the "Frequency" by the "Severity" for each geotechnical issue in each District. The "impact" represents the relative importance of specific geotechnical issues. For example, issues with high frequency and high severity resulted in high impact and those are the issues that should be given first priority in consideration for further investigation.

## RESULTS

The results are presented in this section. The geotechnical issues identified through the survey are listed in Table 1. Each issue is described separately. The pavement edge drains and bridge approach slabs are described specifically. This section is followed by a general discussion of the cited problems.

Table 1 – Geotechnical issues for the Missouri State DOT reported and documented in this project.

a. Soil Slope Instability
b. Rock Slope Instability
c. Unstable Pavement Subgrades
d. Bridge Foundation Problems
e. Earthquake Foundation Problems
f. Scour under Bridges and River Banks
g. Bridge Approach Embankment and Slab Problems
h. Pavement Subsurface Drainage
i. Erosion on Embankments Slopes or Stream Banks
j. Bridge Abutments or Earth Retaining Structure
k. Settlement
l. Sinkholes/Mines
m. Inferior grade rock in pavements
n. Freeze/thaw over culverts
o. Gley, loess and other problematic soils
p. Natural springs
q. High plasticity backfills
r. Shrink-swell/shales
s. Box-culverts beneath high fills
t. Mud seams in rock cuts

Each issue is presented in detail in the following section; however, it is informative to first take a broader look at the findings from the survey. The occurrence of a specific geotechnical issue per highway District is given in Table 2. The following issues are present in all ten Districts: soil slope instability, unstable pavement subgrades, scour/erosion, and bridge approach slab problems. Problems with pavement subsurface drainage, settlement and sinkholes/mines are present in eight to nine of the ten Districts. All of the above issues should be considered as state-wide concerns.

Rock slope instability, bridge foundations, earthquake foundations and bridge abutments/retaining walls were reported issues in four to six of the ten Districts. These should be considered regional issues. Inferior rock, freeze-thaw, problem soils, natural springs, culverts beneath high fills and mud-filled seams in rock cuts were reported in a single District.

Table 2 – Number of Districts in which a specific geotechnical issue occurred.

| **No. of Districts Reporting out of 10** | **Geotechnical Issue** |
|---|---|
| 10 | a. Soil slope instability<br>c. Unstable pavement subgrades<br>f, i. Scour/erosion<br>g. BAS |
| 8 to 9 | h. Pavement subsurface drainage<br>k. Settlement problems<br>l. Sinkholes/mines |
| 4 to 6 | b. Rock slope instability<br>d. Bridge foundations<br>e. Earthquake foundations<br>j. Bridge abutments/retaining walls |
| 1 | m. Inferior rock<br>n. Freeze thaw<br>o, q, r Problem soils<br>p. Natural springs<br>s. Culverts/high fills<br>t. Mud seams in rock cuts |

While some of these might be considered local or single District issues, subsequent discussions with District personnel revealed many of these to be present in other Districts; however, the specific issue might have been less prevalent or far outweighed by other geotechnical issues.

Some observations on the location trends for the regional geotechnical issues (reported by 4 to 6 Districts) can be made. Consider rock slope instability (Figure 2). A general trend of rock instabilities extends from northeast to southwest across the state. The trend follows the significant rock outcrops and cuts within the Department's highway system. The locations of the bridge foundation problems are shown in Figure 3. These extend in a band trending from northwest to southeast across the State. Part of the band follows the Missouri River. The occurrence of earthquake foundations issues is shown in Figure 4. These sites are clustered in the southeastern quadrant of the State. This is the area impacted by the New Madrid and extended fault system. The percentage of the total reported bridge abutment and retaining wall issues are shown by District in Figure 5. These are generally located in the middle and eastern portions of the State. The data shown in Figures 2-5 have been normalized for the number of respondents in each District and provides a reasonable geographic location of the geotechnical issues cited in each figure.

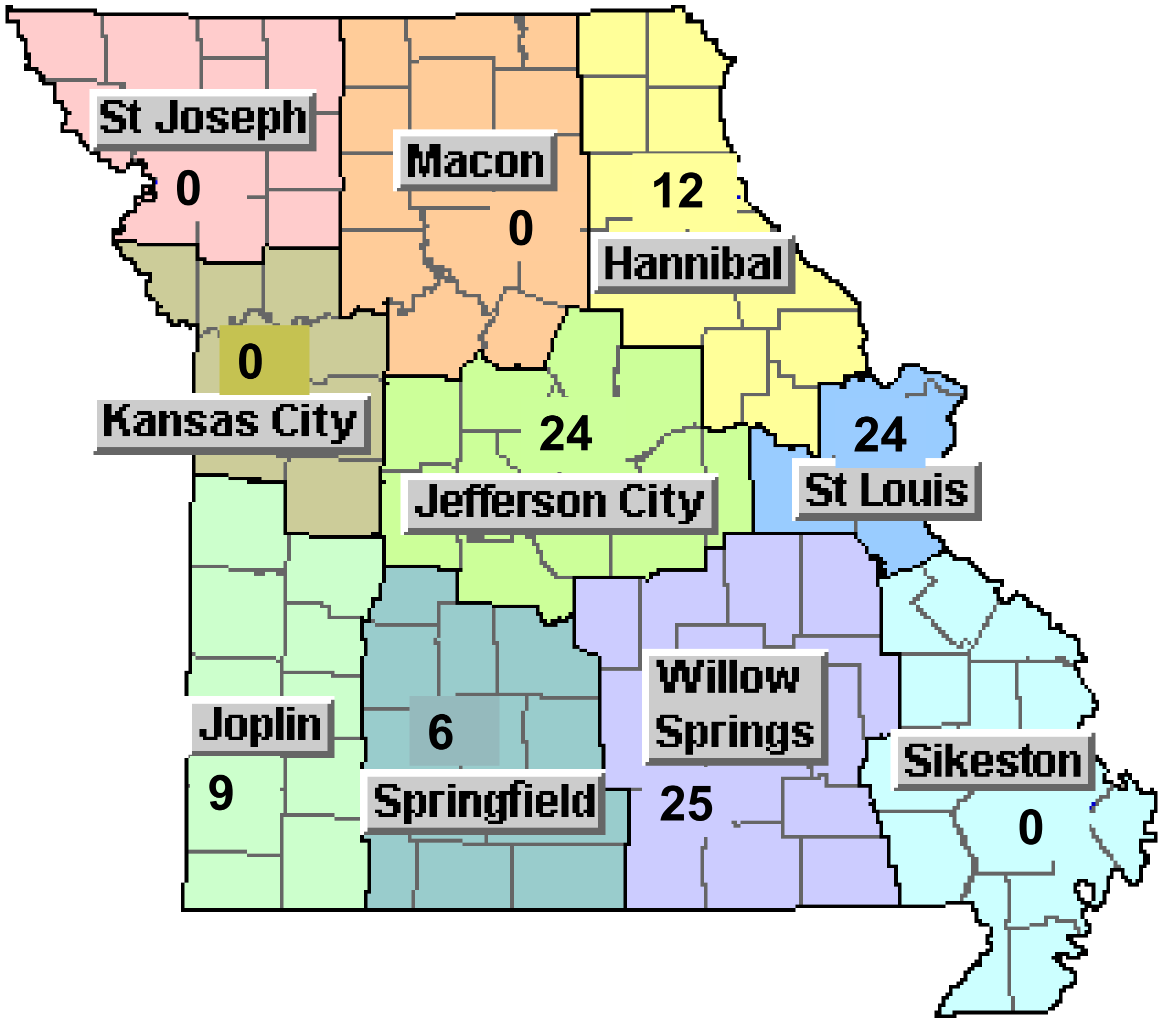



Figure 2 – Percentage of the Total Rock Slope Instability issues reported by District. Number is the percentage of statewide reported rock slope instabilities lying within the specific District.

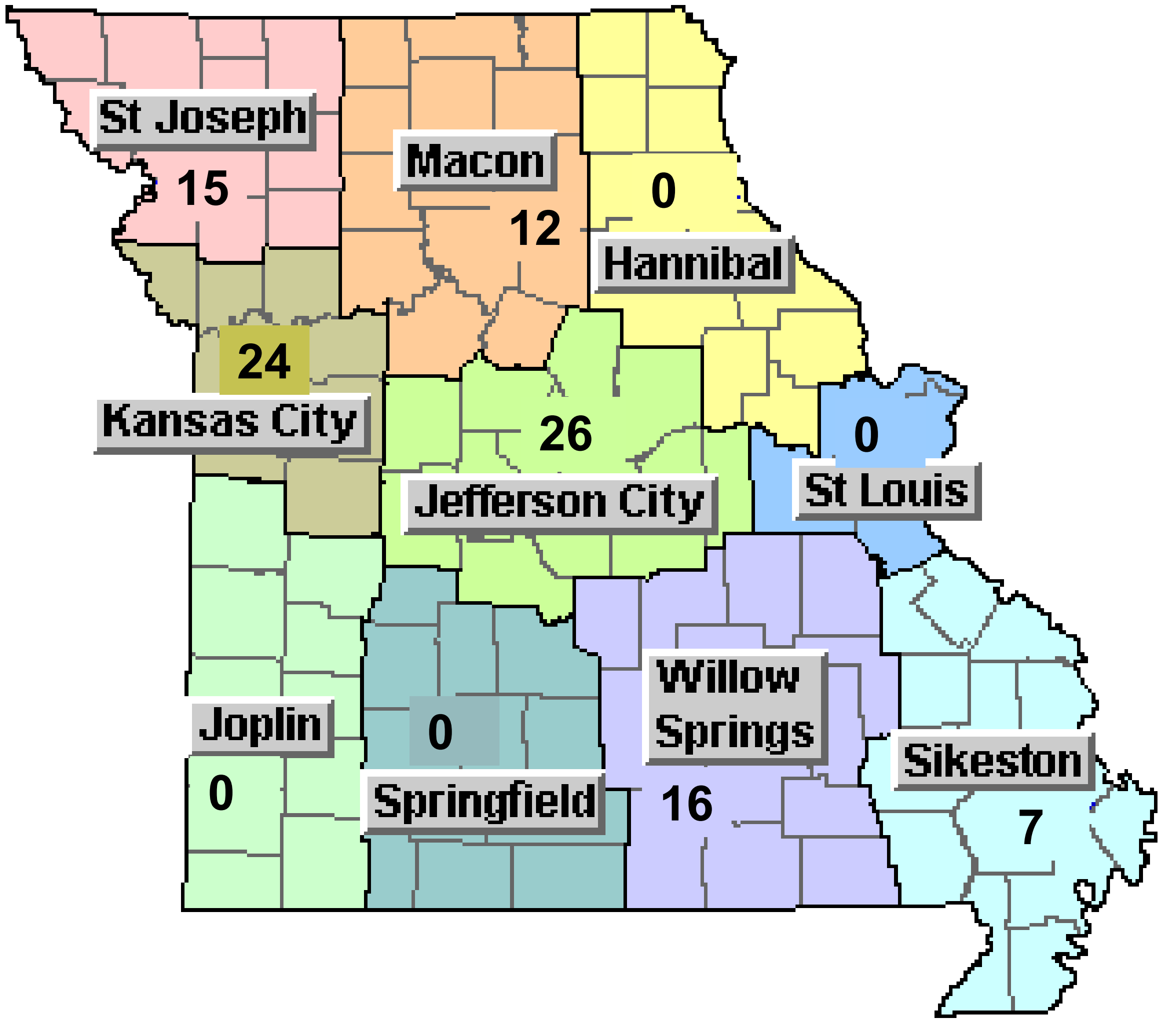



Figure 3. – Percentage of the Total Bridge Foundation issues reported by District. Number is the percentage of statewide reported bridge foundation issues lying within the specific District.


Figure 4. – Percentage of the Earthquake Foundation issues reported by District. Number is the percentage of statewide reported earthquake foundation issues lying within the specific District.

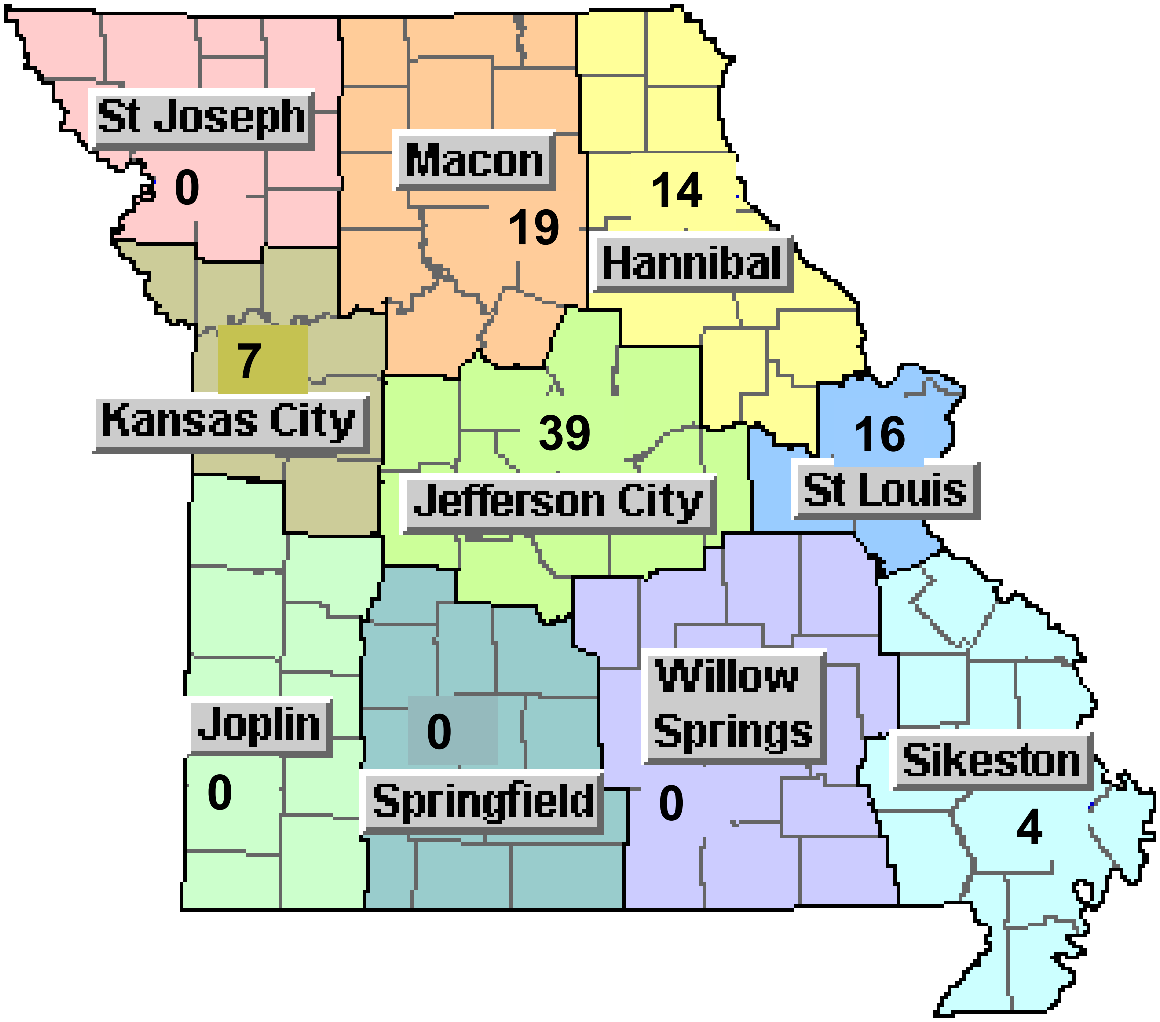



Figure 5. – Percentage of the Bridge Abutment and Retaining Wall issues reported by District. Number is the percentage of statewide reported bridge abutment and retaining wall issues lying within the specific District.

## Characteristics of Geotechnical Problems

In this section each geotechnical issue is characterized through a brief description of the situation, a summary of the positive points and concerns, locations, typical soils or rock involved and, when appropriate, a representative example. The descriptions also include a summary of the results of the survey of MoDOT personnel

## Soil Slope Instability

### General Characteristics

Slope stability problems (instabilities) are typically triggered when human activities or nature has disrupted the balance of forces within the soil mass. These stability problems can be induced by changes in slope geometry, surface loading, soil strength parameters, and/or groundwater. The failures can be presented as a slip surface that is shallow, within the slope itself, or deep seated into the foundation soil (bearing capacity type). Slopes that have been stable for many years also may suddenly fail because of changes in previously mentioned conditions (Abramson, et al. 2002). Sometimes erosion on the face of a slope may worsen to the point of causing a stability problem on the face of the slope.

### General Locations and Geology/Soils

Most of southern Missouri is characterized by the Ozark uplift, which in geologic time exposed rock formations at the surface. These rocks have weathered with time to form residual soils (considered competent in the short-term) and their typical behavior is that of an over-consolidated soil deposit. Over-consolidated soils tend to be stable in the short-term; however, in the long-term they may loose strength, which can affect the long-term performance of soil, and landslides are common in residual soils, particularly during periods of intense rainfall. However, the stability of slopes in residual soils is difficult to predict on the basis of field or laboratory tests because their properties can vary considerably both laterally and with depth due to differential weathering patterns.

In the southeastern portion of Missouri (District 10) near the Mississippi Embayment there are large valleys of soft, fine-grained soils that eventually become the material source for embankments. These fine-grained soils are often high plasticity with significant swelling potential and perform poorly under wet weather conditions. Often slopes of embankments constructed from these soils require some form of stabilization for repair, which was the subject of a recent study at MoDOT (Petry, 2001).

In the northwestern part of Missouri, large deposits of loess exist. Loess is a windblown deposit of mainly silt-sized particles derived from quartz. In its natural, undisturbed form, it is typically lightly cemented (although there is little agreement on the nature of the cementations bonds) and is capable of maintaining vertical faces as long as the soil does not become inundated. In the latter case, the loess loses its cementations bonding and behaves as a cohesion less soil. Loess can be, and is, used in embankments in a remolded form. In these applications, much less is known about the strength properties; however, several recent efforts have been reported in this area (Bowders et al. 2000, Owen, et al. 2002).

Throughout the north and central part of the State, glacial till deposits exist. These deposits consist of medium to high plasticity soils which exhibit low drained (long-term strengths both in cut-slopes and in embankment fill slopes.

**Problem/Situation/Issues**

Slope stability problems are predominantly found within the embankment fill slope (shallow) of roadways. This is likely due to the almost exclusive use of a simplified design chart for these slopes. Few observations of foundation type failures (deep seated) were found. Again, this is attributed to the fact that any potential deep-seated failures are analyzed in the geotechnical design phase. Local soils are typically used in the embankment fills, and they consist predominantly of fine-grained soils with high plasticity; for example, on I-270 southbound lane (S.B.L) just north of MO 100 in St. Louis County, as shown in Figure 6a. The cause of failure was infiltration of water at the low point of a vertical curve into a less compact top lean clay layer, and drainage was impeded by deeper, less permeable layers of weathered shale and lean clays. Hydrostatic pressure built up in the soil resulting in a loss of strength in the clay-shale to lean clay interface (Knobbe, 1988). Similar behavior was found in embankments in District 1 (US 36), District 4 (I-435) and District 5 (I-70). In addition, if slopes for cuts or fills are too steep, they also exhibit slide problems. Typical slopes up to 2H:1V are employed throughout the State. Long-term (drained) stability of the moderate to high plasticity soils in these slopes often show instability at slopes 3H:1V, 4H:1V or lower. An example is the embankment at Emma, Missouri (Loehr et al., 1999).

Additionally, some cut slopes experienced slope stability problems, particularly the slopes in residual soils that lost strength with time and were exposed to high groundwater. An example of this condition was found in District 8 along US 65 between Springfield and Branson (Figure 6b).

**Survey Results**

Soil slope instability was reported as an issue in all ten Districts. The percentage of occurrence was approximately ten percent in each District with the exception of District 8 which reported less than five percent of the soil slope issues in the State (Figure 7).

The frequency and severity for soil slope instability in each District are shown in Table 3. Districts 1, 2, 4 and 6 showed the highest frequency of soil slope instability occurrences. Districts 5 and 8 showed the lowest frequency. Districts 1, 2, 4 and 6 also showed the highest severity for soil slope instability occurrences. Districts 5, 8, and 9 showed the lowest severities.

Table 3 – Frequency and severity for soil slope instability problems in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 4.31 | 4.19 |
| 2 | 4.83 | 4.30 |
| 3 | 3.50 | 3.50 |
| 4 | 4.34 | 4.34 |
| 5 | 2.42 | 2.42 |
| 6 | 3.92 | 3.77 |
| 7 | 3.20 | 3.40 |
| 8 | 1.22 | 0.86 |
| 9 | 3.13 | 1.64 |
| 10 | 2.74 | 3.19 |

(a)  (b) 

Figure 6 – (a) Repair embankment slide along I-270 and (b) Slide in a cut slope along US-65

In conclusion, slope stability is a critical geotechnical problem in the State of Missouri. These slope failures range from minor in nature to million-plus dollar repairs. Taken collectively, the smaller failures in their own right represent a significant, continually recurring maintenance problem.

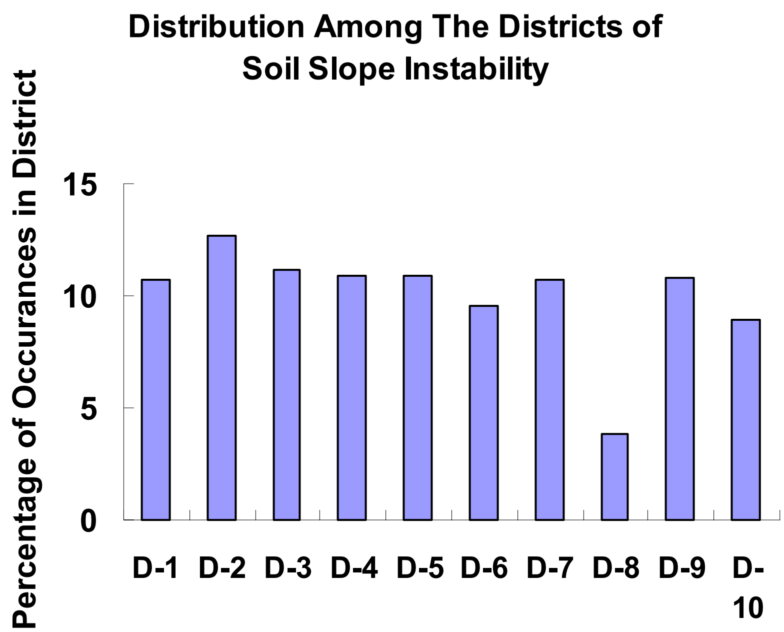



Figure 7 – Percentage of occurrences for Soil Slope Instability by District, normalized by the sum of the weights for all responders in the District. Each District receives the same weight although the number of responders is not the same for each District

## Rock Slope Instability

### General Characteristics

Many terms exist to classify rock slope movements including flows, slides, topples and falls. Relative to Missouri, most rock instabilities can be termed rock falls or rock slides. Rock falls are primarily found in the southern portion of the state (Figure 2) and are most often associated with road cuts or excavations. Rock falls may be associated with recent cuts leaving steep-faced rock walls or over a longer term with weathered portions of the rock cut. In either event, rock falls near transportation facilities can be sudden, incorporate large energies and can be catastrophic. (Fleming and Varnes 1991)

**General Locations and Geology/Soils**

Rock slopes can be found throughout the state with the principal exceptions of the northwest, north central and southeast portions of the states. The greatest number of rock slopes are found in the southwest and central areas of the state. However, the most problematic sites are found in the areas of highest population including District 6 (St Louis) and District 5 (Jefferson City). Other problematic sites are located in the northeast, District 3 (Hannibal). These are mainly situated along the Mississippi river area. Districts 7, 8 and 9 also reported concern with rock slopes.

The principal rock types are limestone and dolomite. They are found in varying degrees of weathering and solutioning leaving many areas of karst. Often the solution channels are in-filled with chert or other earthen materials and when exposed through road cuts, these areas deteriorate at differential rates; e.g., the chert in-filled areas are slow to weather, while the soil in-filled areas weather quickly.

**Problem/Situation/Issues**

Rock fall problems are limited to a small portion of the state. Problem areas are well recognized by District Geologists in the impacted Districts. The Department has used a variety of methods for short-term and long-term stabilization of unstable rock slopes.

Rock slope instabilities have the tendency to occur suddenly, have a great deal of energy and when located near populated areas can be catastrophic. The major issue in Missouri with rock slopes (vertical or near vertical faces) is the tendency for the material to weather in relatively short periods (predominantly limestone), become weak and break free especially during periods of freeze-thaw. Predicting the relative stability (or instability) of rock slopes is difficult at best. Repair, or rather stabilization, is typically expensive, especially in urban areas where flattening or removing the slope may not be viable options. In Missouri, rock slope designs typically use rock fallout zones or catchment areas. These appear to be minimal; i.e., not wide enough, but are often dictated by limited rights-of-way or other constrictions. One possible solution is to use pre-split blast to reduce damage behind the face of the slope and to create slower weathering rock slopes. This technique may show varying benefits ranging on the existing level of weathering/karst already present in the rock mass.

**Survey Results**

Six of the ten Districts reported rock slope instabilities as an issue (Figure 8) making this a regional concern. Districts 5, 6, and 9 accounted for 75 percent of the reported rock slope problems in the State. This stems from the presence of rock cuts and the extensive population base in at least two of the Districts.

The frequency and severity of rock slope instability in each District are shown in Table 4. Districts 6 and 9 show the highest frequency of occurrence. Districts 6 and 7 show the highest severity.

The results from the rock slope instability category show that problems can be high frequency but low severity or high severity and low frequency, both leading to significant issues for a District.

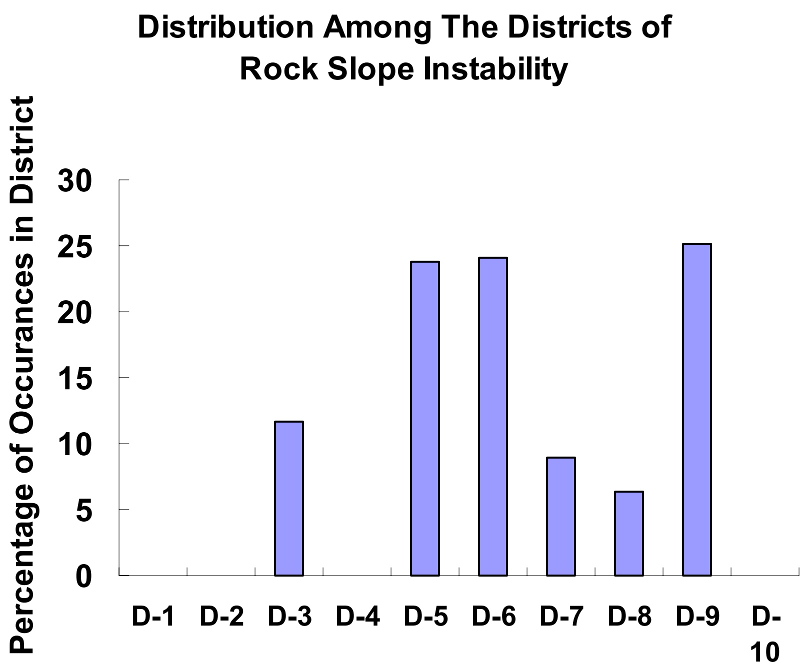



Figure 8 – Percentage of occurrences for Rock Slope Instability by District, normalized by the sum of the weights for all responders in the District. In this manner, each District receives the same weight although the number of responders is not the same in each District

Table 4 – Frequency and severity for rock slope instability problems in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 0.00 | 0.00 |
| 2 | 0.83 | 0.00 |
| 3 | 0.50 | 0.50 |
| 4 | 0.00 | 0.00 |
| 5 | 0.53 | 0.53 |
| 6 | 1.81 | 1.92 |
| 7 | 1.40 | 1.60 |
| 8 | 0.80 | 0.65 |
| 9 | 2.06 | 0.38 |
| 10 | 0.52 | 0.52 |

## Unstable Pavement Subgrades

### General Characteristics

Subgrades are the portion of the pavement system that is prepared as a foundation for the base or surface course. It lies below the base and extends to such a depth as may affect the structural design or long term performance of the pavement (Missouri State Highway Commission, Geology and Soils Manual 1962). Pavement subgrades dominate the performance of overlying pavement systems. Weak subgrades deform under high or cyclic loading situations thereby reducing support of the overlying pavement structure. Weak or deteriorated subgrades result in settlement of the pavement, instability (rutting), cracked pavements, and lead to greater infiltration of surface water into the pavement base and subgrade. These process, initiated by unstable subgrades, lead to premature pavement deterioration and higher frequency of maintenance and replacement.

It is typical to determine the suitability of a subgrade prior to construction of the pavement system. If the subgrade is weak, mechanical or chemical stabilization as well as replacement may be used to improve the strength. However, initially competent subgrades may become weakened after the pavement system is constructed if excess water accumulates in the subgrade or in the pavement base. This later point is addressed in the section entitled "Pavement Subsurface Drainage".

### General Locations and Geology/Soils

In the survey, unstable subgrades were reported by all ten Districts (Figure 9). The seemingly widespread issue may be partially skewed by the fact that problems evidenced by failing pavements can often be attributed to several factors, unstable subgrades being just one. As previously noted, initially stable, supportive subgrades can become unstable and provide little support of the pavement section when the subgrade becomes saturated with water for extended periods and under repetitive loadings as from traffic. In such cases, it may have been failure of the subsurface drainage system that leads to failure of the subgrade and ultimately poor performance of the pavement. Thus, it is difficult to make any definitive determination as to the actual number of unstable subgrades versus other contributing factors. One consideration regarding location is that subgrades in the northern half of the state are almost exclusively soils, some with high plasticities, while many of the roads in the southern (southcentral and southwestern) portion of the state are constructed on rock subgrades. However, in the southeastern portion of the state (District 10), unstable subgrades are a problem in the Mississippi embayment area with high plasticity soils. With the noted exception of expansive shales, few of the rock subgrades are problematic.

### Problems/Situations/Issues

Weak subgrade soils can be stabilized during original construction but they must be recognized as such and then appropriate engineering analysis, design and construction must be brought to bear on the issue.

Subgrade issues are extensive across the state. They can be found in every District. Particularly problematic are the moderate to high plasticity soils in the northwest, north central and southeast portions of the state. The problem of expansive shales is for the most part limited to District 4. District 10 also reported some problems with silt or silty subgrades and instability in high water content environments. The subgrade conditions ultimately control the fate of the long-term performance of the pavement. The importance of proper identification and applicable analysis of the subgrade during pavement design can not be understated.

### Survey Results

Unstable subgrades are present across the state (Figure 9). All Districts showed approximately the same level of occurrence. Districts 2, 4, 5 and 6 reported the highest frequency of occurrence (Table 5). Districts 4, 5, 6 and 7 reported the highest severity of occurrence.

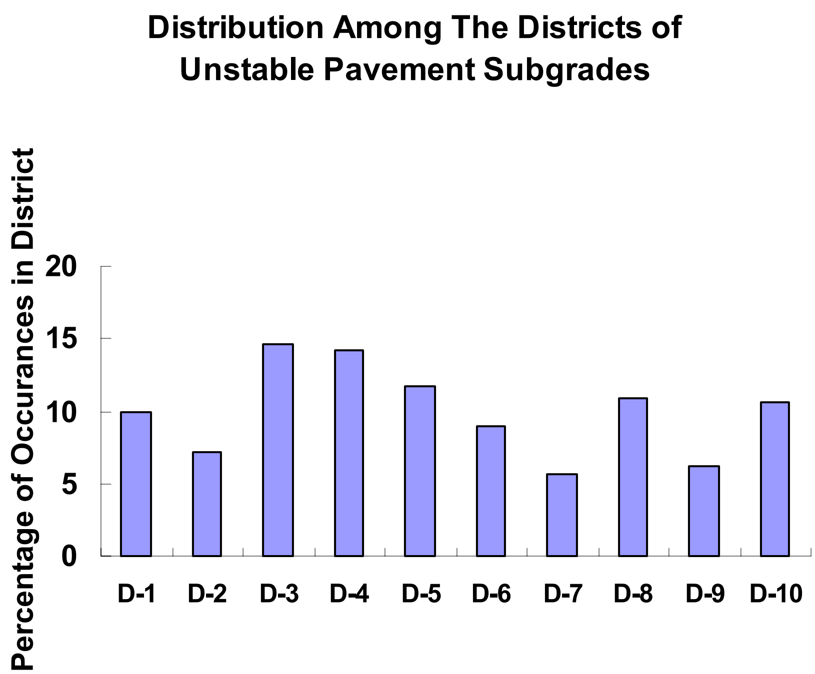



Figure 9 - Percentage of Occurrences of Unstable Pavement Subgrade by District, normalized by the sum of the weights for all responders in the District. In this manner, each District receives the same weight although the number of responders is not the same in each District.

Table 5 – Frequency and severity of unstable pavement subgrades in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 2.33 | 2.93 |
| 2 | 3.67 | 2.59 |
| 3 | 2.50 | 2.50 |
| 4 | 3.06 | 3.06 |
| 5 | 4.00 | 4.00 |
| 6 | 3.31 | 2.97 |
| 7 | 2.80 | 3.00 |
| 8 | 2.43 | 0.21 |
| 9 | 1.38 | 1.38 |
| 10 | 2.67 | 2.78 |

## Bridge Foundation Problems

### General Characteristics

Bridge foundation problems primarily consist of sites with poor foundation materials -- either deep deposits of soft, low strength soils or poor quality (pinnacled or karst) rock. In these cases, deep foundations (piles or drilled shafts), the dominant founding means for bridges in Missouri, can be difficult to design. Often, construction conditions are dramatically different from the conditions on which designs were based.

### General Locations and Geology/Soils

Overall, there were few citations of bridge foundation problems. District 5 cites a problem with a rock-socketed pier and District 10 cites the issues with founding piles in karst.

### Problem/Situation/Issues

Most bridges in Missouri are founded on deep foundations to rock. There are few mentions of problems with settlement of bridges.

There are substantial portions of the state underlain by karst (solutioned carbonate rock). Design and construction of deep foundations in these areas is highly dependent on the quantity and quality of subsurface information available. The standard level of drilling and sampling has been insufficient for these areas; however, additional efforts for subsurface exploration in suspected karst regions are being used presently. Another issue is the tendency to over-design foundations. The result is safe but uneconomical solutions. Even though the design process of deep foundations was not investigated, based on conversations with MoDOT personnel these foundation systems tend to be over-designed; i.e., piles deeper than necessary, drilled shafts larger diameter than required, and a greater number of piles than necessary. Special consideration has been given to drilling programs in areas of variable rock surface; however, no amount of drilling is likely to be adequate in some cases. Therefore, increased reliance on geophysical (or other techniques) in these areas may be warranted.

## Survey Results

Six of the ten Districts reported bridge foundation problems (Figure 10). The problems were few and only tied to specifics in two instances (District 10 – karst and District 5 – rock socket). Overall, the level of frequency and severity of bridge foundation issues is quite low relative to other issues within the Districts (Table 6). This is a special issue, one that is not faced routinely with the exception of a few locations in some Districts; however, when the problem occurs, it can create lengthy construction or design delays and substantial cost increases.

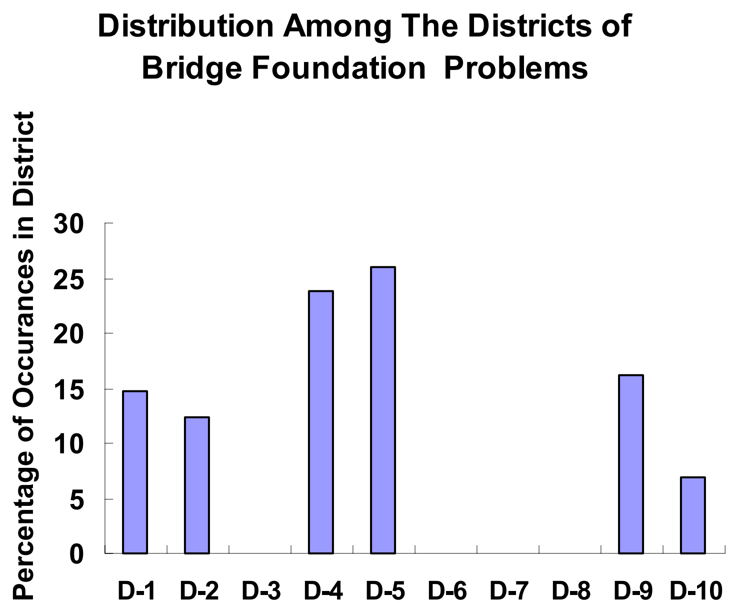



Figure 10 - Percentage of occurrences of Bridge Foundation Problems by District, normalized by the sum of the weights for all responders in the District. In this manner, each District receives the same weight although the number of responders is not the same in each District.

Table 6 – Frequency and severity of bridge foundation problems in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 0.81 | 0.81 |
| 2 | 1.33 | 0.81 |
| 3 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 |
| 5 | 1.23 | 1.23 |
| 6 | 0.59 | 0.72 |
| 7 | 0.60 | 1.20 |
| 8 | 0.21 | 0.21 |
| 9 | 1.32 | 0.51 |
| 10 | 0.41 | 0.63 |

## Earthquake Foundation Problems

### General Characteristics

The southeast portion of the State of Missouri is considered an earthquake area due to its proximity to the New Madrid Seismic Zone (NMSZ). The NMSZ system of faults is located in a very unique setting with respect to hazards related to soil deposits. The areal extent of liquefiable soil deposits in the Mississippi Embayment is the largest in the North American continent. Additionally, these soil deposits are very deep and the anticipated behavior during dynamic loading is not well understood. Much is still to be learned about this high consequence seismic zone given that strong ground motion data is not available in recorded history. The paleoliquefaction features of this seismically active area are the evidence that strong ground motions occurred in the past, as well as the anecdotal data from the 1811 and 1812 earthquake events. Seismicity is currently being monitored by the USGS via a network of seismographs and records of small magnitude earthquakes are helping in defining the systems of faults. The Mississippi Embayment, seismicity events and Missouri roadways are shown in Figure 11. The awareness of earthquake problems in the MoDOT Districts near the NMSZ was evident in the survey responses

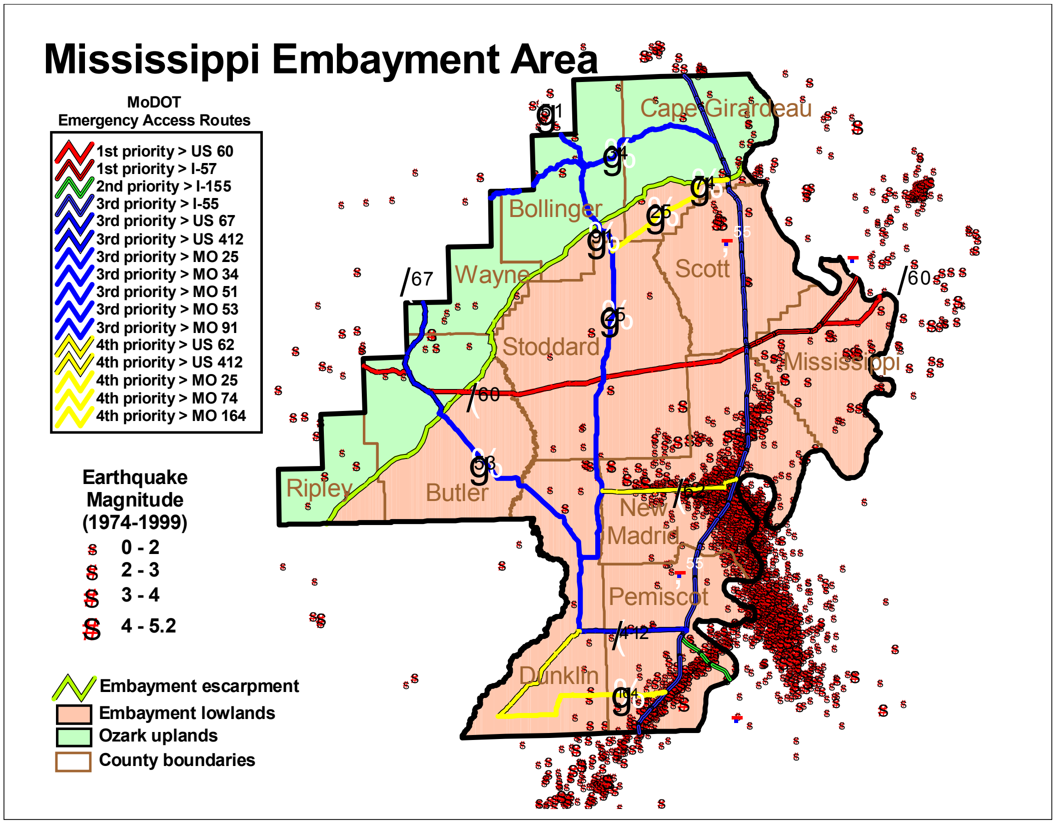



Figure 11 – The 1974-1999 earthquake epicenters and magnitudes (source: St. Louis University).

**General Locations and Geology/Soils**

The current MoDOT standard method of bridge design for earthquakes uses the American Association of State Highway and Transportation Officials (AASHTO) specifications. The AASHTO design acceleration map values for the St. Louis area range from 0.075g to 0.12g and for the Embayment area of southeast Missouri range from 0.15g to 0.36g (Figure 12). Then, the acceleration values are modified considering the soil profile type. The NCHRP 472 (2002) recommends some changes to this process. AASHTO will consider adoption of the changes in 2002. The classic geotechnical earthquake hazards consist of: liquefaction, ground motion amplification and seismic induced slope instability. The effective ground acceleration can increase due to ground motion amplification based on the soil profile type. The MoDOT Districts near the NMSZ are Districts: 10, 9 and 6. District 10 is a large District of varied geology and the only one containing the Mississippi Embayment deep unconsolidated soil sediments (> 2,000 feet) near the NMSZ. Further north and west District 10 has the Ozark escarpment where the elevation starts rising and firmer ground is present including rock outcrops (Figure 11). St. Louis, MO (District 6) is surrounded by three rivers (Mississippi, Missouri and Meramec), with alluvium deposits at bridge river crossings susceptible to liquefaction. Even though District 6 is somewhat north of the NMSZ, there are other faults in Illinois along the Wabash faulting system that add to the hazard of this highly populated city. District 9 is in close proximity to the NMSZ but with less geotechnical earthquake hazards, except for some potential slope instabilities.

**Problem/Situation/Issues**

The earthquake issue in the state of Missouri is bound by the fact that the last strong ground motion was in the series of events in 1811 and 1812 estimated to have been a magnitude 8 earthquake. The rock geology in the mid-continent is more sound that the younger geology in California, causing the propagation of waves to be more widespread and affect a larger area. However, the long return period of these events has resulted in a hazard that is infrequent but of high consequence. The biggest hazard for the Missouri state roads and interstates is the fact that most of the bridges were built with aseismic design, making them vulnerable to earthquake loading. For the most part, the earthquake foundation problem is perceived to be a design problem and obviously there has been no significant events to serve as evidence for this problem. Earthquake research projects (sponsored by MoDOT and FHWA) are currently (2002) underway at UMR and will start addressing some of these issues. The main concern is the lack of fundamental knowledge and lack of familiarity regarding geotechnical earthquake engineering by MoDOT personnel at all levels. Training courses can be used to partly remedy this situation.

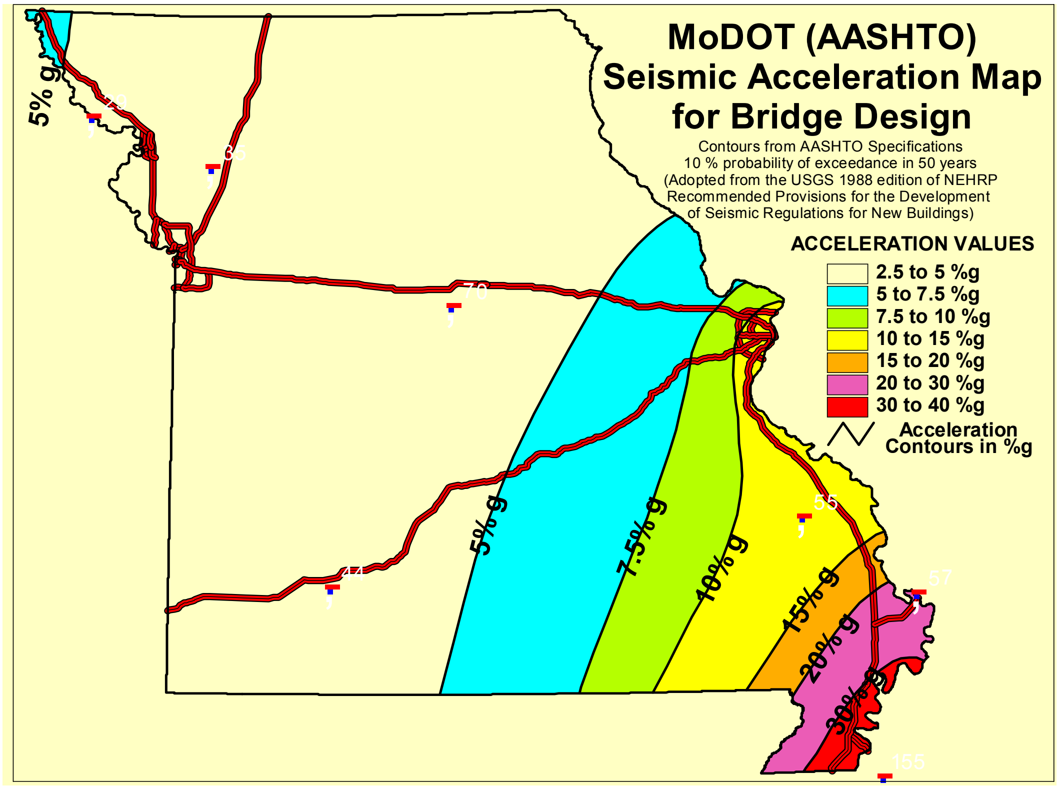



Figure 12 – AASHTO Seismic Accelerations based on USGS/National Earthquake Reduction Program Recommended 1988 Provisions.

**Survey Results**

Only the Districts in the southeastern quarter of the state showed earthquake foundation problems as an issue. This finding relies on the geographic location with respect to the NMSZ and the awareness of MoDOT personnel to the design issues faced by the Department. The distribution shown in Figure 13 is in agreement with the general trend anticipated. The frequency and severity for each District are shown in Table 7. Districts 1, 3, 5 and 8 show no earthquake issues while Districts 6, 7, 9 and 10 show the greatest frequency and severity for earthquake issues.

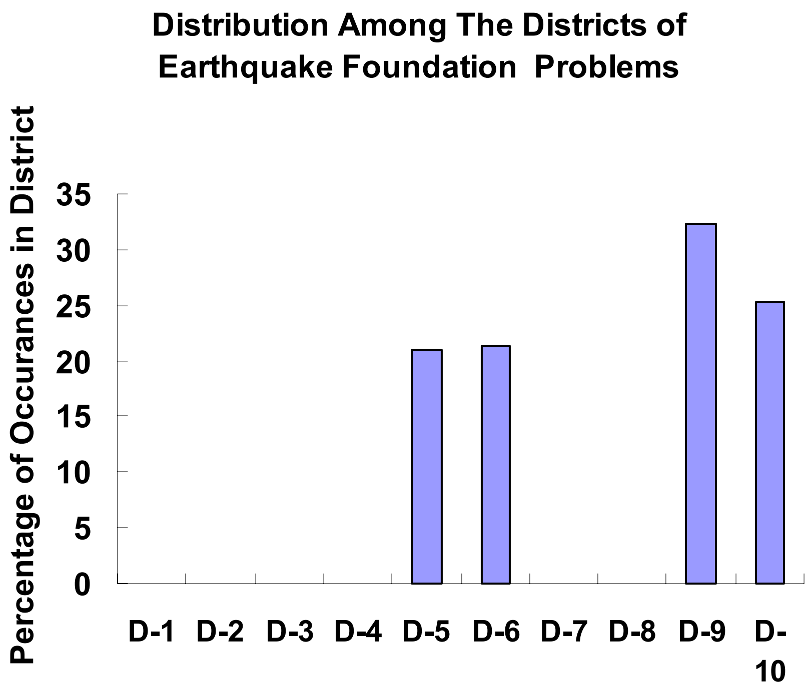



Figure 13 - Percentage of occurrences of Earthquake Foundation Problems by District, normalized by the sum of the weights for all responders in the District. In this manner, each District receives the same weight although the number of responders is not the same in each District.

Table 7 – Frequency and severity of earthquake foundation problems in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 0.00 | 0.00 |
| 2 | 0.67 | 0.00 |
| 3 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 |
| 5 | 0.53 | 0.53 |
| 6 | 0.77 | 0.82 |
| 7 | 0.60 | 1.20 |
| 8 | 0.00 | 0.00 |
| 9 | 2.01 | 1.31 |
| 10 | 0.93 | 0.56 |

## Scour under Bridges and River Banks

### General Characteristics

Channel scour around bridge foundations is the leading cause of bridge failure in the United States, exceeding all other causes combined (Landers & Mueller, 1995). Placing any object in a river or stream bed that creates a disturbance to the natural flow pattern, will result in increased flow velocity around the object and accelerated erosion (scour) in the vicinity of the object. This is a common occurrence for bridge piers placed in mid-stream and for bridge abutments which encroach into the flow path. The resulting flow pattern is complex making prediction of the depth of scour difficult at best. Variables in the process include: water velocity and turbidity, river width and depth, pier width, geometry and orientation, stratigraphy, and soil or rock properties, among others. There are as many methods of predicting scour as there are Departments of Transportation. In 1984 Koerner wrote that in a survey of organizations the most frequently noted method of predicting scour was given as "experience." In 2002, the most common method uses the HEC software; however, major efforts are underway to improve scour prediction techniques (Briaud, et al. 2001 a, b).

### General Locations and Geology/Soils

All ten Districts cited scour under bridges and river banks to be an issue (Figure 14). Districts 1, 2, 4, 5 and 10 reported the highest incidence of scour.

### Problem/Situation/Issues

Most bridges are placed on deep foundations; so, scour is not typically an issue for bridge footings. However, scour depth predictions are so poor and typically very conservative (predicted depths are many times deeper than actual depths) so that foundations are over-designed incurring excessive costs. The Transportation Research Board's National Cooperative Highway Research Program has a current project (No. 24-20, FY 2002), to look at prediction of scour at bridge abutments. The objective is to develop more accurate and comprehensive methodologies for predicting scour.

Much of the surface of the state is covered by easily erodible soils. The state is located in a humid climate averaging 40 inches of precipitation per year. Many of these storms are high intensity, low duration. This creates rapid, high velocity flows in streams and rivers (flash floods). Such conditions combine to maximize the erosion (scour) around obstacles in and near the stream channels. In addition, rapid urbanization (Kansas City, St Louis, Columbia, Springfield) has also contributed to increased surface runoff and increased flooding and rapid response of stream flows to even minor precipitation events. The impact of urbanization will continue to increase at a rapid pace further exacerbating the situation. Improved methods of handling increasing peak flows from storms and more accurate techniques for scour depth estimation are urgently needed.

**Survey Results**

The distribution of occurrence of scour under bridges and river banks among the Districts is shown in Figure 14. While scour issues are present in all ten districts, a higher percentage is evident in Districts 1, 2, 4, 5 and 10. Districts 1, 2, and 10 may rank higher due to the presence of highly erodible soils covering large areas within these Districts. In Districts 4, 5 and 6, the presence of erodible soils coupled with the impact of urbanization on the drainage patterns, rates and volumes of flow may be a contributing factor.

The frequency and severity for scour under bridges and river banks in each District are listed in Table B. Districts 1 and 2 rank far above the other Districts in frequency and severity. Again, this can be attributed to the wide expanse of erodible soils in these Districts. Districts 4, 6, and 8 rank lowest in both frequency and severity.

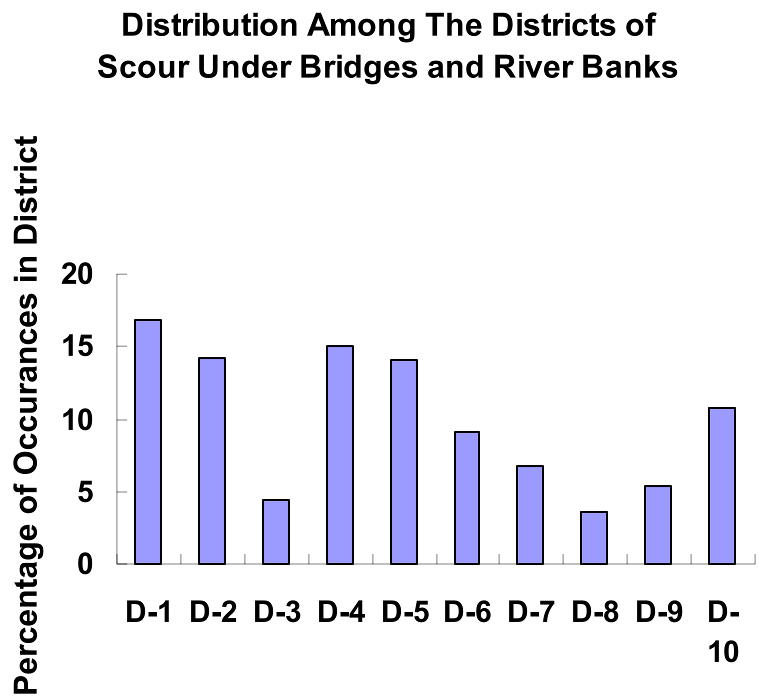



Figure 14 - Percentage of Occurrences of Scour Under Bridge and River Bank by District, normalized by the sum of the weights for all responders in the District. In this manner, each District receives the same weight although the number of responders is not the same in each District.

Table 8 – Frequency and severity of scour under bridges and river banks in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 4.70 | 4.11 |
| 2 | 2.33 | 4.33 |
| 3 | 1.25 | 1.25 |
| 4 | 0.70 | 0.70 |
| 5 | 1.94 | 1.94 |
| 6 | 0.73 | 0.87 |
| 7 | 1.20 | 2.20 |
| 8 | 0.64 | 0.64 |
| 9 | 1.44 | 1.57 |
| 10 | 1.77 | 1.77 |

## Erosion

### General Characteristics

Soil erosion is a naturally occurring process on all land surfaces that have a surface soil horizon. Naturally occurring geologic formations are continuously being degraded with time by physical and chemical weathering. So, the agents of soil erosion are water and wind, each contributing a significant amount of soil loss (Arnold, J.B. et al. 1987). Freezing and thawing may also be a contributor to erosion depending on the soil composition. When the natural environment is transformed to a built environment, such as building roadways, the erosion patterns are affected. Along roadways soil erosion is a problem on embankment fills, road cuts, splash areas for surface water run-off and natural slopes. In Missouri, the major causes of erosion are the effects of surface water as it flows across the soil surfaces.

### General Locations and Geology/Soils

Soil erosion generally occurs after heavy rain, before seeded areas have established growth. This is a common problem throughout the State of Missouri. Particularly, in areas that have many embankments or bridge approach embankments constructed of soil. In the southern portion of Missouri (Ozarks) the karst geology is conducive to the formation of vertical "clay seams" due to infilling of solution channels or weathered seams in the limestone that, when cut (near vertical) for a roadway, present a problem of erosion of the soil located in the weathered seams and solution channels.

### Problem/Situation/Issues

One of the soil erosion problem areas is District 6 where the number of man-made embankments is quite large and it has stretched the capabilities of maintenance operations. For example, this type of problem is located at the edge of a concrete shoulder on the Spencer Road ramp on to Mo-370. Surface water has eroded and continues to erode the soil (which appeared to be a loess soil) and exposed the pavement section and subbase. A 4-ft hole (gulley) is present immediately adjacent to the pavement section, as shown in Figure 15. The erosion control issue is regulated by the US Environmental Protection Agency, which limits the level of suspended solids in water courses. The increased regulations and enforcement have forced MoDOT and construction contractors to increase efforts to control erosion from construction sites. Less attention is paid to existing facilities; however, erosion of soil adjacent to and beneath MoDOT infrastructure continues to result in significant damage to structures and acceleration of potential slope instabilities; i.e., it is not significant or there are not enough resources to address it until it affects the roadway.

(a)  (b) 

Figure 15 – (a) Erosion at the edge of shoulder concrete on Spencer road ramp on to Mo-370.
(b) Erosion problem near I-170 and I-70 intersection.

**Survey Results**

All ten Districts reported erosion problems (Figure 16). Districts 1, 2, 4, 5, 6, 9 and 10 indicated slightly higher occurances than Districts 3, 7 and 8. The frequency and severity for erosion issues in each District are listed in Table 9. Districts 1, 2, 6 and 9 reported the highest frequency and severity. All other Districts reported a modest frequency and severity.

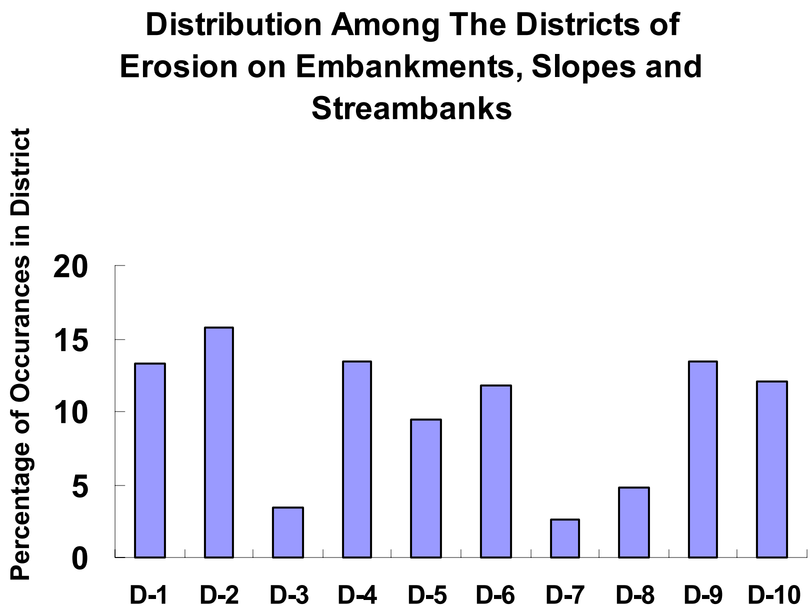



Figure 16 – Percentage of ocurrences of Erosion on Embankment, Slope and Stream Bank by District, normalized by the sum of the weights for all responders in the District. n this manner, each District receives the same weight although the number of responders is not the same in each District.

Table 9 – Frequency and severity of Erosion on Embankments, Slopes and/or Stream Banks in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 2.93 | 3.39 |
| 2 | 5.17 | 3.72 |
| 3 | 1.75 | 1.75 |
| 4 | 1.77 | 1.77 |
| 5 | 2.35 | 2.35 |
| 6 | 4.11 | 3.68 |
| 7 | 1.40 | 2.20 |
| 8 | 1.08 | 0.43 |
| 9 | 4.31 | 3.31 |
| 10 | 1.67 | 1.70 |

## Bridge Approach Slab Problems

### General Characteristics

Bridge approach slabs are intended to provide a smooth grade transition between the bridge and the pavement. They are an extension of the bridge structure onto the earth approach embankment. They normally consist of a 30-foot long concrete structural slab supported at one end by the bridge abutment (typically pile supported) and at the other end on a sleeper slab-on-grade (the embankment soil fill). The difference in the types of supports can result in differential settlements that affect the ride quality over the bridge. The current design of the bridge approach slabs includes a grid of holes (cast-in-place) for the purpose of pressure grouting (mudjacking) the slab post-construction for support and to some extent to maintain grade. Apparently, the design makes allowances for the possibility of settlement and provides a means to remediate the differential settlement. An older design (c.1993 and before) did not include the sleeper slab nor the cast-in-place grout holes. One of the objectives in this project was to get an idea of how the new design is performing.

### General Locations and Geology/Soils

The location of these problems is pretty well defined as they correspond to the bridge locations where the new design was implemented. Since the BAS structural components are supported partially on the bridge and the embankment soils, the subgrade soils consist of the imported material used for the embankment approach fill. The materials can vary from very competent crushed rock to a poor fine-grained soil (loess, clay or even an expansive soil).

### Problem/Situation/Issues

Differential settlement of bridge approach slabs is a widespread problem in Missouri and represents a significant annual maintenance expense to MoDOT. The settlement of the approach slabs may be due to the selection of fill material, type of foundation soils, drainage, embankment erosion, inadequate compaction of fill, etc. However, it is postulated that the main causes of BAS settlement is typically due to compression of embankment soil and to consolidation of subgrade soils. Some interesting situations were noticed in several bridges in Howell County (District 9) where the BAS experienced heave since they were built with soils from a borrow source that contained expansive soils.

When bridge approach slabs are built on a cut subgrade, rock cut, and/or have a small fill height of embankment, they consistently perform well. Very little to no differential settlement was found on these bridge approach slabs (Figure 17a). In such cases, sleeper slabs and approach slabs may not ever be warranted.

When bridge approach slabs are built on thick fill height embankments and no sleeper slab drainage is provided, they always have differential settlement problems (Figure 17b). However, mudjacking was usually used to raise the settled bridge approach slabs without complete reconstruction. In some cases it involves drilling additional holes through the bridge approach slab and injecting a grout. Another method recently introduced into the market is the use of expanding foams (Uretek® is one proprietary example).

In some instances, differential settlement was noticed at the approach slab/bridge abutment contact. This likely indicates a failure (structural) of the bridge seat for the slab or of the slab itself. Careful analysis (destructive) and monitoring of such cases is required to correctly identify the failure mechanism(s). Additionally, since the presence of differential settlement appears to correlate positively with increasing height of embankment fill, it suggests that the length of the bridge approach slabs should vary according to the fill height in order to minimize the distortion (differential settlement/length of approach) in the approach.


(a) (b)

Figure 17 – (a) No settlement on BAS unused mudjack holes shown and (b) Differential settlement occurs on BAS

**Survey Results**

All ten Districts reported bridge approach embankment  and slab problems (Figure 18).  Districts 2, 3, 4, 9 and 10 reported the highest occurances and were about the same among these Districts.  Districts 1 and 8 were the lowest among the Districts.  The frequency and severity of bridge approach embankments and slab issues are listed in Table 10.  Districts 3, 9 and 10 indicated the highest frequency and severity. District 1 indicted the lowest frequency and severity.

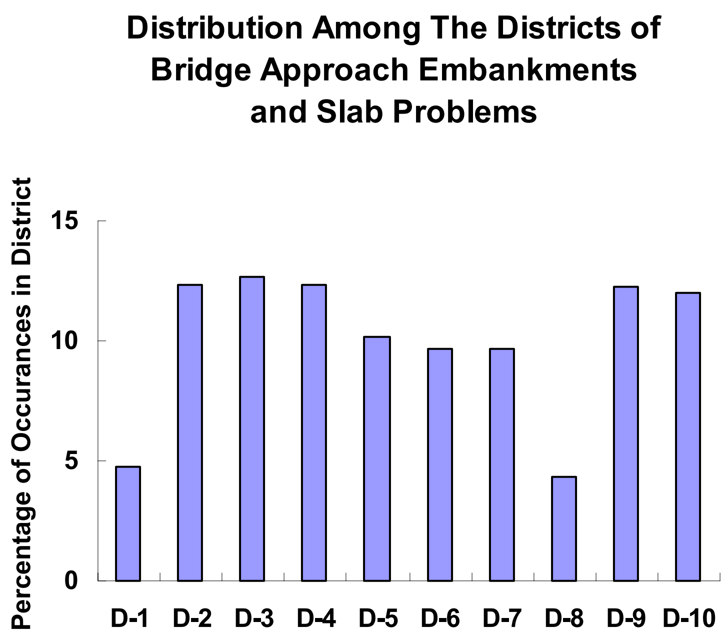



Figure 18 - Percentage of occurrences of Bridge Approach Embankment and Slab Problems by District, normalized by the sum of the weights for all responders in the District. In this manner, each District receives the same weight although the number of responders is not the same in each District.

Table 10 – Frequency and severity of bridge approach embankment and slab problems in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 1.76 | 0.98 |
| 2 | 3.00 | 0.65 |
| 3 | 3.25 | 3.25 |
| 4 | 1.71 | 1.71 |
| 5 | 2.77 | 2.77 |
| 6 | 3.40 | 2.06 |
| 7 | 2.20 | 1.80 |
| 8 | 2.50 | 1.08 |
| 9 | 3.50 | 3.50 |
| 10 | 3.11 | 2.84 |

**Pavement Subsurface Drainage**

**General Characteristics**

All pavements are exposed to inflows from sources of water, including precipitation and/or groundwater. Adequate subsurface drainage must be supplied to drain the water from beneath pavements in a short time period. Over the past four decades, designers of pavements have primarily focused on the idea of making pavements strong, meanwhile ignoring the need for subsurface drainage. This has lead to premature failure of pavements. Cedergren (1989, 1994, 1996) cites data from a long-term study that showed well-drained pavements outlast poorly drained pavements by a minimum of 10 to 40 times. With proper subsurface drainage, effective pavement lifetimes can be 50 years or longer and maintenance funds can be focused on the wearing surface since the pavement's substructure does not require extensive re-construction.

In Missouri, subsurface drainage of pavements is accomplished through use of drainable base courses and pavement edge drains (PED). Missouri DOT uses three standard pavement designs. These include light, medium and heavy-duty pavements (Figure 19). No subsurface drainage is supplied in light-duty pavements. Medium-duty pavements include a Type 5 base with edge drains, and heavy-duty pavements include an asphalt stabilized drainable layer with edge drains. Subsurface drainage is only provided for medium and heavy-duty pavements in the Missouri DOT system.

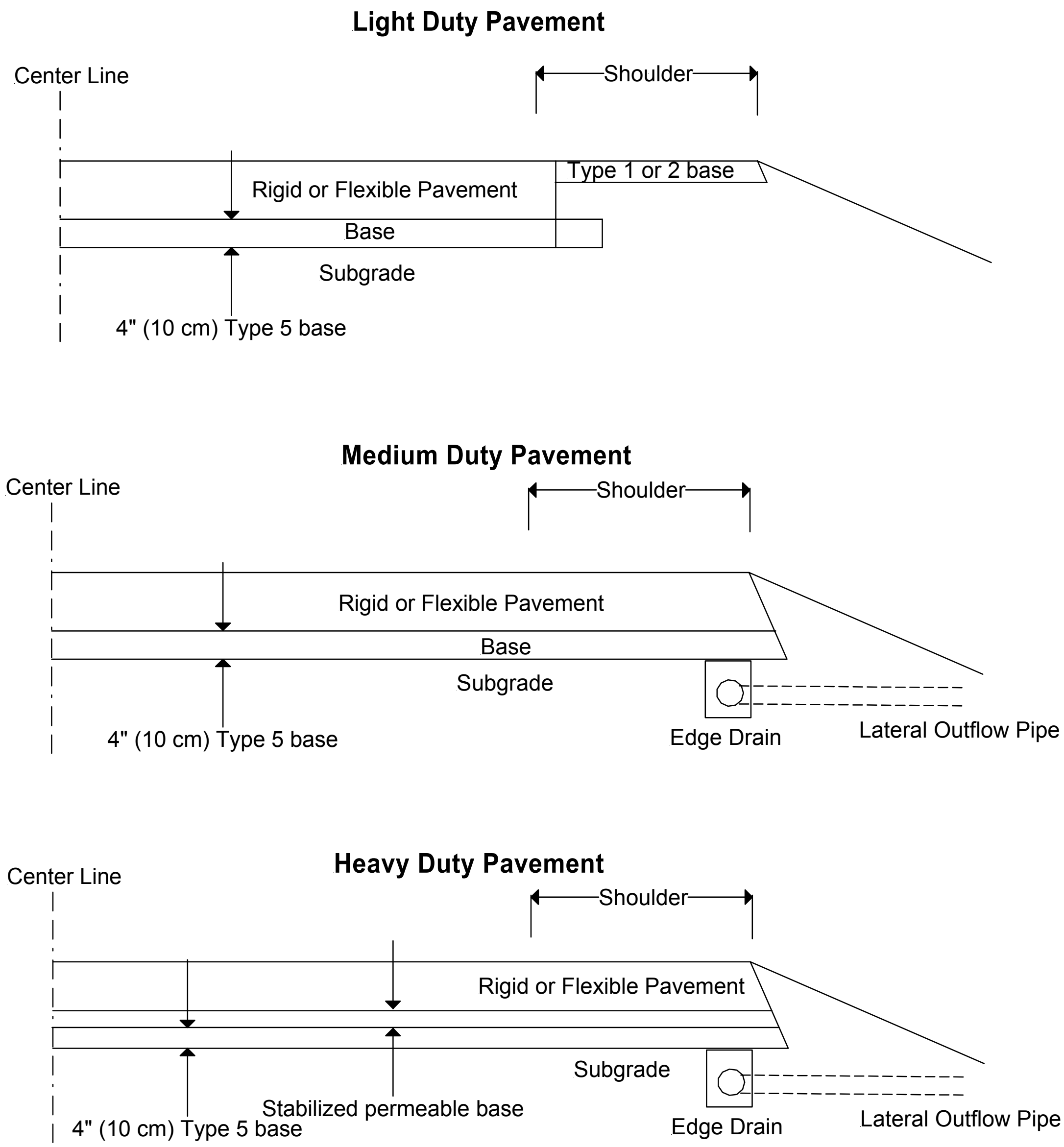



Figure 19 – The three pavement design cross sections used in MoDOT system (a) Heavy-duty, (b) Medium-duty, (3) Light-duty.

### General Locations and Geology/Soils

Subsurface drainage systems were evaluated across the state. Nine of the 10 Districts reported some issues with subsurface drainage (Figure 20). Only District 8 did not report any subsurface drainage issues. However, there was an issue of pavement pumping on I-44 at Phillipsburg. This possibly was related to poor drainage. District 2 reported the highest number of concerns followed closely by Districts 4 and 5. Districts 3, 6 and 10 indicated a moderate concern with subsurface drainage. Subsurface drainage can be difficult to de-couple from the unstable subgrade issue. When not transported by adequate subsurface drainage systems, excess water, can aggravate or accelerate the degradation of the subbase, the base course(s) and even the wearing surface. All of the Districts have marginal soils within their boundaries, i.e., soils excessive strength loss with the exposure to excess water (high plasticity clays and silts, especially loess). In addition to problematic soils, District 4 cited expansive shales. These strata when allowed free access to water expand and cause pavement heaving, e.g., I-435. Lack of subsurface drainage or poorly functioning drainage can contribute greatly to the degradation of the pavement is supporting layers whether they are soil or rock.

**Problem/Situation/Issues**

Undrained or poorly drained substructures of pavements loose their strength, deform easily and do not provide adequate long-term support of the overlying pavement structure. This can lead to premature failure of pavements. In Missouri, much of the subsurface beneath pavements consists of weak, marginal or readily degraded soils (and in places shales). Poor subsurface drainage systems accelerates their degradation and subsequent loss of support and failure of the pavement. In addition, undrained substructures facilitate extremely high pore water pressures during traffic loading which also accelerates pavement failure.

State DOT's are again beginning to realize the extreme importance and the lifecycle value of providing effective subsurface drainage for their pavement systems. There are more alternatives than ever before for providing effective subsurface drainage, e.g.'s, aggregate blends, geosynthetics, open-graded courses, cement and asphalt stabilized courses, etc. Missouri DOT can and should borrow on some of the effective drainage designs that other state DOTs have been using.

Many of the soils (and shales) beneath Missouri pavements are marginal materials in terms of supporting overlying pavements. Effective subsurface drainage is the key to long lasting pavements. Few of the Missouri's roads are designed and constructed with adequate, long-term drainage. Base and subbase failures are common and lead to high frequency, but temporary, repairs to the wearing surface. The drainage aspects of the failures are not sufficiently repaired.

## Survey Results

All Districts reported some occurrence of subsurface drainage issues; however, District 8 did not specifically note this issue on Question 1 of the survey. Districts 2, 3, 4 and 5 reported similar occurances and were the highest of the Districts. The frequency and severity of pavement sub-surface drainage issues for each District are listed in Table 11. Districts 4 and 5 report higher frequency and severity for drainage issues than the other Districts. District 10 reports the lowest frequency and severity.

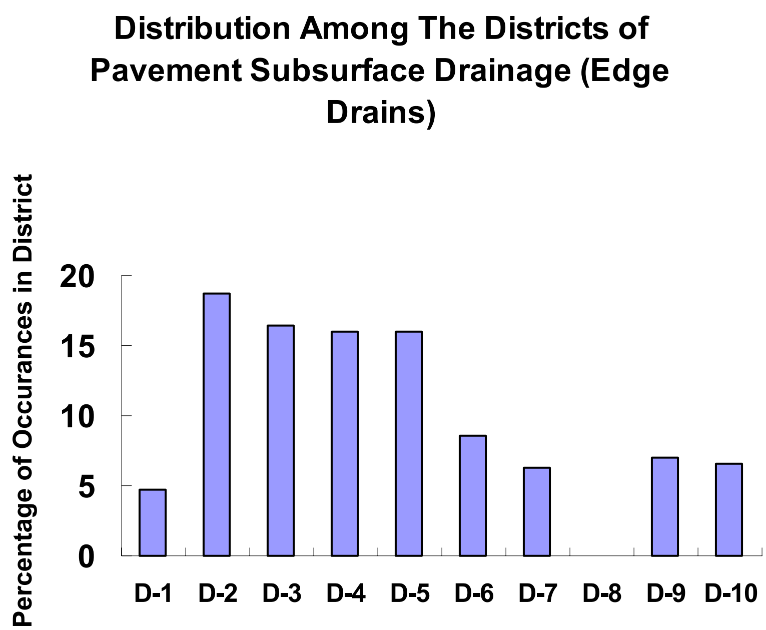



Figure 20 – Percentage of occurrences of Pavement Subsurface Drainage Problems by District, normalized by the sum of the weights for all responders in the District. In this manner, each District receives the same weight although the number of responders is not the same in each District.

Table 11 – Frequency and severity of pavement subsurface drainage (edge drains) problems in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 0.98 | 1.17 |
| 2 | 2.67 | 0.94 |
| 3 | 1.00 | 1.00 |
| 4 | 3.52 | 3.52 |
| 5 | 3.35 | 3.35 |
| 6 | 2.51 | 2.56 |
| 7 | 2.40 | 2.40 |
| 8 | 2.14 | 0.21 |
| 9 | 1.64 | 1.32 |
| 10 | 0.74 | 0.93 |

## Bridge Abutments and Earth Retaining Structure

### General Characteristics

Retaining walls and those serving as bridge abutments are critical structures. The tilt of the wall can result in reduced clearance for the superstructure or excessive clearance potentially resulting in a dropped span. The first condition arises from the force exerted by the backfill, active earth pressures. The second condition, the wall moves towards the backfill, can occur when the foundation soils beneath the backfill are compressible and the weight of the backfill causes consolidation of the foundation soils. The base of the abutment can then settle so that the base becomes inclined and the wall tilts toward the fill. So foundations of retaining structures merit careful consideration.

### General Locations and Geology/Soils

Six of the ten Districts reported concerns with retaining walls and abutments (Figure 21). The responses were scattered across the state and did not necessarily correlate with a specific soil type or stratigraphic section.

### Problem/Situation/Issues

Bridge abutments and retaining walls are critical structures since excessive movements can result in damage to other facilities abutting them, such as bridges or pavements. Settling and tilting are the major concerns; however, aesthetics in the case of retaining walls is of some concern, especially in the increasingly prevalent architecturally faced walls.

In general, there were not many problems associated with abutments and retaining walls. New technologies, such as mechanically stabilized earth (MSE) and reinforced earth, can alleviate some of the problems and concerns, such as increasing tolerable settlements.

The principal concern with problematic abutments and retaining walls is that fixes are costly. There is also significant importance and urgency when the wall in question is supporting a bridge or other traffic bearing artery. Although a wall may not collapse, excessive movement, in some cases, can result in structural damage to the superstructure supported by the wall.

**Survey Results**

Only six of the ten Districts reported issues with bridge abutments and earth retaining structures (Figure 21). District 5 reported twice as high of occurrence than any other Districts. The frequency and severity of abutment and earth retaining structure issues for each District are listed in Table 12. District 5 ranks at the top for frequency and severity. Although District 7 did not specifically report abutments as an issue in Question 1, they reported high frequency and severity for this issue. Districts 1, 8, 9 and 10 reported low frequency and severity for these issues.

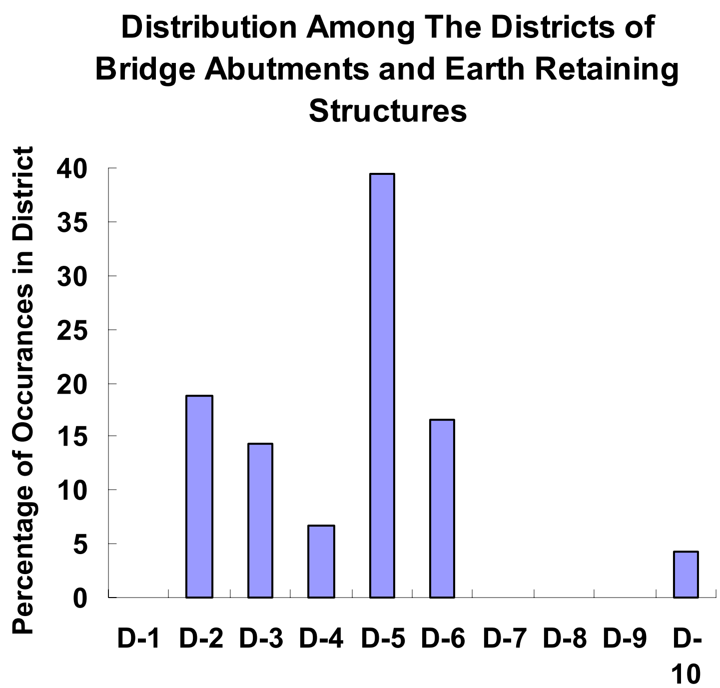



Figure 21 – Percentage of Occurrences of Bridge Abutment, Retaining Structure Problems by District, normalized by the sum of the weights for all responders in the District. In this manner, each District receives the same weight although the number of responders is not the same in each District.

Table 12 – Frequency and severity of bridge abutments and earth retaining structure problems in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 0.59 | 0.00 |
| 2 | 2.50 | 0.00 |
| 3 | 0.75 | 0.75 |
| 4 | 0.71 | 0.71 |
| 5 | 1.58 | 1.58 |
| 6 | 1.16 | 1.33 |
| 7 | 1.20 | 1.20 |
| 8 | 0.21 | 0.21 |
| 9 | 0.13 | 0.13 |
| 10 | 0.41 | 0.41 |

## Settlement Problems

### General Characteristics

When a soil deposit is loaded, the total vertical deformation at the surface is called total settlement. The loading can be an added external load, the self-weight of the soil or a change in effective stress, e.g., lowering of the groundwater table. Total settlement is comprised of the sum of the immediate compression, primary consolidation, and secondary compression. Typically it is the *differential* settlement that is critical in civil engineering structures. Differential settlement is a difference in settlement from one location to another. Along the roadway, it is desired to maintain a horizontal line or a vertical curve designed for smooth driving conditions. If the ground settles at one location on the alignment it may generate a dip in the road, hence driver discomfort and hazards may occur such as water ponding on the roadway. Another typical condition is when an embankment (flexible foundation) joins a bridge abutment (fixed foundation) causing an abrupt differential within the transition from the approach embankment to the bridge (Moulton, 1986).

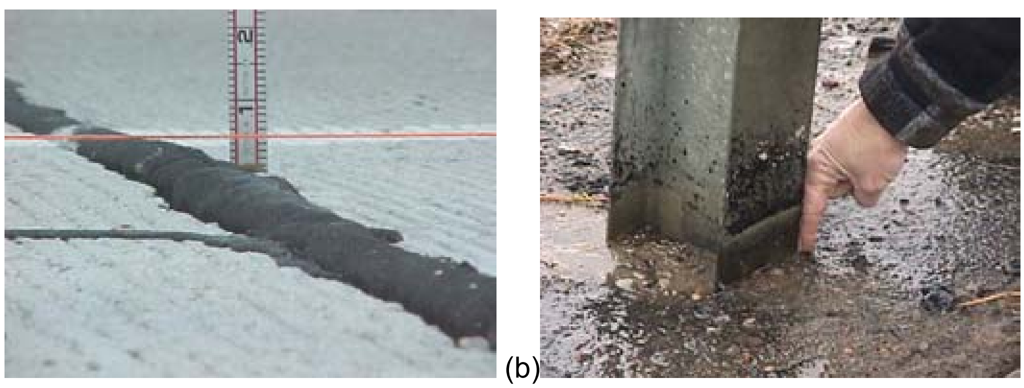
### General Locations and Geology/Soils

The general locations where settlements can occur are varied depending on the loading and soil conditions. Compressible soils are often found in recent geologic settings, for example, aeolian, alluvium or lacustrine deposits. Most of the time these conditions are identified at an early phase of a project and design is undertaken to mitigate the anticipated deformations. However, deformations (settlements) do occur and are reported typically based on surface deformations which may be a result of deformations within the embankment or from compression of the underlying foundation soils or both. Nothing was reported on structural bridge foundation settlement (Moulton 1986), and it is unclear if any bridges are monitored for settlement. This is likely the case since most bridge foundations are extended to rock, or in the case of District 10, to dense sand. Settlement of approach embankments was reported.

### Problem/Situation/Issues

A unique situation was reported in the survey regarding large settlements most probably due to embankment foundation settlement. In District 10, MO 412 (Hayti Bypass, south of Hayti) has a 20- to 25-foot high embankment that was placed on top of a clay filled river channel and has undergone excessive embankment settlement. During the two years of construction, there was six feet of settlement. There has been roughly eight feet of settlement to date (2001). Wick drains were installed down to the sand layer below the clay throughout the project. Pore pressure measuring devices were also installed. It has been two years since the last grading project. There was still about 0.2 feet of settlement for the last three-month period (up to June 2002). This area is not open to traffic. The original recommendation for this area from the Geotechnical Section was to bridge this area and not to attempt to place a fill. This is an example of not fully integrating MoDOT's geotechnical specialists throughout the design of a project, resulting in further geotechnical challenges.

In general, the impact of this problem (roadway settlement) is not fully realized since maintenance personnel often have a program to pave over or otherwise treat the symptoms on a routine basis. Many situations were reported on the bridge approach embankments (Figure 22) and bridge approach slabs (BAS); however, these problems are addressed in the Bridge Approach Slab (BAS) section of this report.



(a) (b)

Figure 22 – (a) Settlement at bridge approach slab and concrete pavement joint (b) Settlement at bridge end illustrated at guard rail post, Bridge A-4811, District 10, Jackson, MO.

**Survey Results**

When the question about settlements was posed in the survey to MoDOT personnel, it was somewhat general. Many situations could have been lumped into one problem – "deformation of the roadway"—including at the abutment of bridges, embankments and foundations. Nine of the ten Districts reported some occurrence of settlement issues (Figure 23). Districts 4, 5 and 6 reported the highest level of occurances. Districts 1, 2 and 10 followed close behind. The frequency and severity of settlement issues for each District are listed in Table 13. Districts 2, 4 and 6 reported the highest frequency and severity.

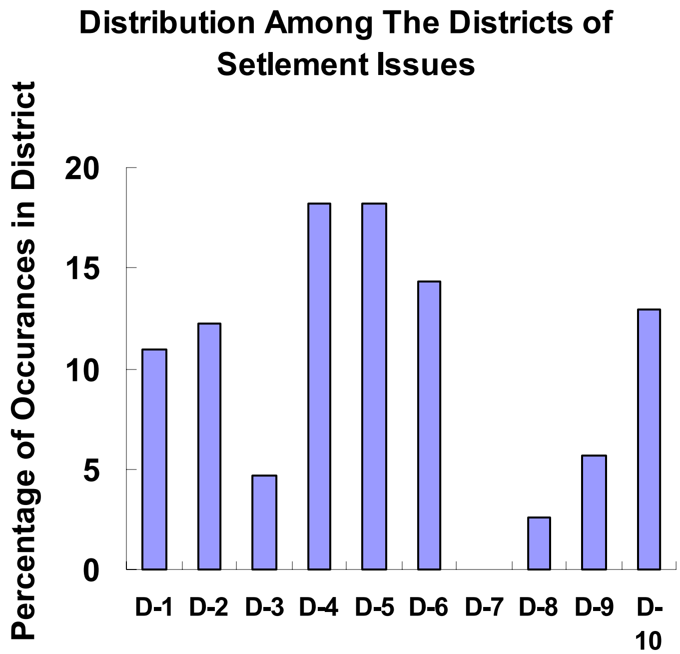



Figure 23 – Percentage of occurrences of Settlement Problems by District, normalized by the sum of the weights for all responders in the District. In this manner, each District receives the same weight although the number of responders is not the same in each District.

Table 13 – Frequency and severity of settlement problems in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 1.52 | 2.33 |
| 2 | 3.00 | 2.00 |
| 3 | 1.50 | 1.50 |
| 4 | 2.47 | 2.47 |
| 5 | 1.94 | 1.94 |
| 6 | 2.39 | 2.26 |
| 7 | 1.20 | 0.60 |
| 8 | 1.64 | 0.36 |
| 9 | 1.25 | 1.19 |
| 10 | 1.59 | 1.59 |

## Sinkholes

### General Characteristics

Sinkholes form when groundwater dissolves the underlying limestone, carbonate rock, salt beds, or rocks. Generally sinkholes can be divided into two types, "induced" and "natural". Induced sinkholes are related to man's activities such as underground mining, decline in the water table due to groundwater withdrawals and diversion of drainage over openings in bedrock from construction. Natural sinkholes are those occurring as a natural process of erosion of the limestone by water (Unklesbay and Vineyard 1992).

### General Locations and Geology/Soils

The occurrence of natural sinkholes is usually related to locations that are within karst geologic environments. Districts 7, 8 and 9, which are in the Ozark uplift formation, have geologic characteristics that develop natural sinkholes. Also, significant portions of Districts 3, 4 and 5 are underlain by limestone and dolomite deposits and are subject to sinkhole formation. The overburden above these natural cavities is typically residual soil. Induced sinkholes due to mine subsidence were found to be the most prevalent in the southwest corner of the state near Joplin and this area extends into the neighboring states. There is some instance of induced sinkholes around District 4 (Kansas City area) related to the extensive underground mining activities of the past; however, these mines are limestone mines and in many cases the cavities remaining after mining ceased are utilized as commercial space. In these instances, the mines are stable and collapse or sinkhole development are not of concern. Sinkhole development in Districts 3 and 4 are generally due to natural processes.

### Problem/Situation/Issues

District 3 ranked sinkholes among their top three geotechnical issues in both frequency of occurrence and in severity. Districts 4 and 5 ranked occurrence and severity of sinkholes within their Districts as eighth or tenth in relative concern compared to other geotechnical concerns.

The problems in District 7 are the collapse of sinkholes due to abandoned underground mining activities, as shown in Figure 24. MoDOT is developing the extension of US 71 in the near vicinity of these sinkholes and recognizes that other mines may exist beneath the ground. Other significant deformation and stability failures could occur due to the presence of abandoned mines, which were very common in this region in the early 1900s. UMR and MoDOT have investigated these sites in 1996-98 using geophysical techniques in an attempt to characterize sinkhole occurrence and frequency for proposed roadway alignments (Shoemaker, et al., 1998).

(a)  (b) 

Figure 24 – (a) Recent and (b) Old sinkholes in District 7 NE of Joplin, MO

**Survey Results**

Eight of the ten Districts listed sinkholes as a geotechnical concern in their District (Figure 25). Districts 1 and 2 did not report any occurances of sinkholes in their areas. Districts 3, 8 and 9 reported the highest occurrence of sinkholes or mines. The frequency and severity of sinkholes and mines for each District are listed in Table 14. Districts 2 and 8 reported the highest frequency and severity. Districts 1 and 2 reported the lowest frequency and severity

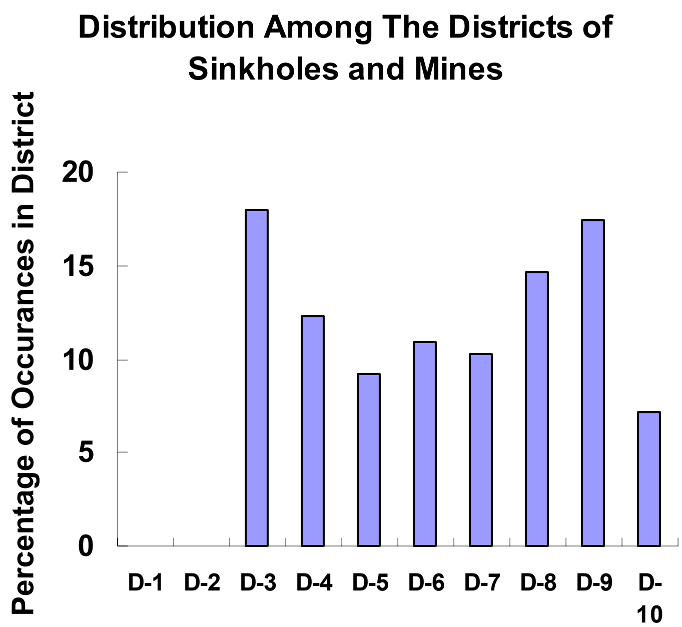



Figure 25 – Percentage of occurrences of Sinkhole and Mines Problems by District, normalized by the sum of the weights for all responders in the District. In this manner, each District receives the same weight although the number of responders is not the same in each District.

Table 14 – Frequency and severity of sinkhole and mines problems in each District.

| District | Frequency | Severity |
|---|---|---|
| 1 | 0.00 | 0.00 |
| 2 | 0.83 | 0.00 |
| 3 | 3.25 | 3.25 |
| 4 | 0.70 | 0.70 |
| 5 | 1.06 | 1.06 |
| 6 | 0.86 | 0.77 |
| 7 | 1.20 | 1.80 |
| 8 | 3.84 | 3.84 |
| 9 | 2.31 | 2.31 |
| 10 | 0.89 | 0.81 |

**Isolated Issues**

A number of issues were cited by a single District. In some cases these were unique, isolated problems or multiple events but occurring within a specific region or locale. In subsequent discussions with District personnel, it was noted that several of these issues are at least regional in extent. The issues are listed below and a brief discussion is presented for each item.

**Issues Noted By a Single District**

| Issue | District |
|---|---|
| ▪ Inferior Grade Rock in Pavement | 1 |
| ▪ Freeze/Thaw Over Culverts | 1 |
| ▪ Gley Soil & Loess | 2 |
| ▪ Natural Springs | 4 |
| ▪ High Plasticity Backfills | 4 |
| ▪ Shrink-Swell Shales | 4 |
| ▪ Box Culverts in High Fills | 7 |
| ▪ Pinnacle Rock | 7 |
| ▪ Mud Seams in Rock Cuts | 8 |

**Inferior Grade Rock in Pavements**

Specific mention was made by personnel in District 1 of inferior rock being used in pavements. The District 4 Geologist mentioned a similar issue in conversation. In general, rock quality in Districts 1, 2 and 4 is poor. Some quarries do a better/worse job of making a final product, but most have poor quality rock to work with from the start. In addition, there are various problems compounded by the presence of shale, chert, deleterious materials and mud seams. While costs and availability drive usage of marginal or poorer materials, design should compensate for poorer quality materials.

**Freeze/Thaw Over Culverts**

In District 1, a problem of freeze/thaw and subsequent pavement failure due to heave above culverts was noted. The District evaluated the problem (1998) and isolated the soil types which ranged from low plasticity silts (ML) and clays (CL) to some high plasticity clays (CH). The problem culverts were primarily located along Interstate 29 where it follows the Missouri River floodplain (Iowa State Line roughly to Mound City). The causes of the heaving were attributed to near surface water table, frost (capillary rise) susceptible soils, and temperatures below freezing. A solution was proposed which consisted of removing the existing soils and replacing them with a coarser (more porous) backfill (less susceptible to significant capillary rise). In subsequent discussions with the District Geologist, he indicated that this solution was never implemented, and they continue to do the necessary resurfacing; however, the underlying cause of the heaving has not been alleviated.

**Gley, Loess and Other Problematic Soils**

In District 2, specific mention was made of two problematic soil types that are found extensively across the District – gley and loess. Gley is a high plasticity clay (CH) that presents stability problems for cut slopes, embankments and pavement subgrades. Gley is found in Districts 1, 2, 4 and probably 3, although it was not mentioned by anyone. Gley has low shear strength, high compressibility and is extremely difficult to work with. Stabilization of gley can be attempted through the addition of calcium sources such as lime, cement, or fly ash. It may also be stabilized through the addition of synthetic fibers. In general, it has been found to be easier to waste the gley than to attempt to amend it and alter its properties.

Loess is found in many Districts, including 1, 2, 3, 4, 5, 6 and 10; thus, it is not "isolated" as other geotechnical issues are. Loess, a quartz-derived silt, typically has no or low plasticity (ML) but can contain a significant clay size fraction (<0.002 mm). Loess can have higher effective friction angles than other materials (Owen, 2001), which leads to construction of steeper slopes; however, loess is highly erodable and District personnel make frequent mention of the erosion control problems they have when loess is encountered in their projects. Controlling erosion of loess is an on-going issue in the Districts in which it occurs. Vegetation can be successful in controlling erosion; however, establishing the vegetation on loess in a timely manner has been problematic. Synthetic methods of erosion control, fibers, emulsions, etc., have had varied success. Provisions (using synthetics for channels or energy dissipation at outlets) are not routinely used. No provisions are considered for concentration of runoff from roadway structures; e.g., bridge ends and sags.

A survey of the available soils information indicates that there are many soil series types that contain sufficient clay to be considered expansive or highly active. If the cutoff of a Plastic Index of 25 or more is used, the following listing is found:

a. Western Plains Soil Series: Baxter, Boone, Cherokee, Gerald, Oswego, and Summit.
b. Glacial Plains Soil Series: Grundy, Lindley, Putnam, Shelby, Wabash and Marshall.
c. Ozarks Soil Series: Clarksville, Hagerstown (possibly), and Union (possibly).
d. Southeastern Lowlands: Sharkey.

Those listed with a possibly beside them may have some materials in their total profile that would classify as expansive clays. There are several other soils series that contain clay soils that have Plastic Indexes above 20, in addition. Overall, the potential for volume change happening because of moisture changes in clays affecting transportation facilities is high. The potential problems include, but are not limited to, differential movements of pavement subgrades reflected in pavement roughness and deterioration, slope failures caused by softening of clay soils as they cycle through shrink and swell, and failures of earth retaining structures caused by swelling.

The problems noted during District visits and provided by District personnel indicate the widespread nature of difficulties caused by clays. In Districts 1 and 4 there are problems associated with weathered shales, probably of the Pleasanton geologic group, and soils primarily from the Marshall, Summit and Wabash soils. The problems noted near Kirksville and District 2 are likely because of the Lindley, Grundy and Shelby soils. The Putnam soils are problems for Districts 3 and 5, noted near Mexico and Ashland. Problems with clays are more difficult to map in the District 6 area, but are probably caused by Wabash soils or those weathered from the Pleasanton geologic group materials. District 8 has experienced problems with clays probably from the Clarksville series, especially when they appear as clay seams in limestone cuts. The other reported area of difficulty is located south of Sikeston and near Benton in District 10, where the Sharkey soils are located. High-plasticity clays, some which exhibit signs of shrink-swell and some which do not, are located in many parts of the State. They contribute to shortening of pavement life and failures of earth structures in many places.

Clay soil related problems have been found to happen in most of the Districts of MODOT. Although they are not always apparent as having been caused by clay behavior, the underlying contributions of clays to these problems are present. Pavement roughness results because of the shrink-swell activated reorganization of subgrade elevations in patterns that represent waves longitudinally along the roadway. Also, because of the nature of clay to swell and soften when taking on water, subgrades can have localized loss of support causing severe pavement distress and/or failure. The strength of clays in slopes tends to degrade to its residual (long-term) strength values as shrink-swell cycling takes place. When these weathered slopes gain moisture from rain or flooding, they fail. Most of the time these are smaller surficial slope failures, but they can eventually lead to total slope failure. Clays that are located at depth in slopes can take on moisture, swell and soften, and lead to larger slope failures as well. When placed behind earth retaining structures, especially when inadequate drainage is provided, clays can cause these structures to be overturned or, if in the supporting soils of the wall, can contribute to its failure.

As of a result of the information gathered during this survey, it is apparent that knowledge of the locations of clays during the discovery and design phases of projects is essential. Better knowledge of the locations of problems caused by clay soils could be obtained by a further and more detailed soil survey of their locations. The DG and staff typically perform soil surveys for all future projects. Requiring proper attention required to clay situations during construction is crucial to the performance of the project. Understanding of how to deal with clay problems, as they arise after construction, is important to the success of maintenance operations. What is needed is a cooperative effort of education of all MODOT employees about clays, as well as continual involvement of the Geotechnical Specialists (HQ and Districts) in all phases of every project.

Many of the difficulties that are present when utilizing clays as part of MODOT projects can be minimized by consideration of methodologies of soil stabilization. Through mechanical reworking the soil or addition of agents to improve their behavior, much could be accomplished to overcome the difficulties noted during this survey.

**Natural Springs**

District 4 noted that there are several instances of natural springs (seeps) occurring in the roadway. No known action has been taken but it is recognized that drainage, or lack thereof, is a major contributor to unstable subgrades and to premature failure of pavements.

Designs for drainage systems to remove and re-direct subsurface water from the roadway are available (Moulton 1979, Cedergren 1989). The problem appears to lie in the fact that designs for a roadway are performed on limited subsurface information. Issues like natural springs or seeps within the roadway may not be discovered until construction. In situations like this, it becomes the responsibility of the field personnel to take action for re-design or at least adding a design "on-the-fly" to solve the encountered situations. If the situation is missed or an untrained inspector does not take action, the spring can later cause problems in the roadway.

**High Plasticity Embankments**

District 4 personnel noted that embankments that are constructed using high plasticity soil generally tend to have slope instability associated with them. Often in these situations, the sides of the embankments are graded on a 2H:1V slope (approximately 26 degrees), although this is no longer the practice for embankments of high plasticity soils (2002) . Existing slopes tend to suffer sloughs or slides several years after construction. Explanation of this behavior usually follows the pattern of stable slopes initially partially due to negative porewater pressure in the slope after compaction, followed by increasing porewater pressure (less negative) and decreasing effective stress and shear strength with time until a slide results. This problem is certainly present state-wide, and it can occur in moderate and low plasticity soils as well. These slides fall into the general category of soil slope instability as reported in an earlier section of this report.

**Expansive Shales**

A particular issue facing District 4, not mentioned by other Districts, is that of expansive shales (Figure 26). Several examples of the impact of expansive shales can be seen on I-435 south of Kansas City. The rigid pavement, placed above rock cuts (excavated shale) has been pushed up, cracked and largely destroyed due to action of the expansive shale (Figure 27). Shale is a sedimentary rock formed by the compaction and cementation processes acting on clay, silt and sand particles. Upon unloading of overburden stress and given access to water, shale can rapidly decompose and swell especially when it is composed of swelling clay minerals such as smectite. The swelling or heave can also occur when the shale contains sulfide minerals, i.e., pyrite (Dubbe et al 1984). Heave pressures on the order of 12,000 psf have been suggested for pyritic shales. The process of expansion for the pyrite-laden shale is a function of the pyrite content and its access to oxygen. Fresh cut shale faces will oxidize and expand rapidly. An additional problem from the oxidation of pyritic shales is the production of sulfates which can attack the structure of concrete and accelerate its deterioration.

Figure 26 – Exposed area showing shale that is underlying highway in District 4.

Figure 27 – Heave in I-435 due to underlying expansive shales.

**Box-Culverts Beneath High Fills**

District 7 noted that there was some concern regarding placement of pre-cast box culverts beneath high fills. It is unclear whether this is a concern regarding the structural integrity of the culvert or whether there is some issue with the fill material above the culvert. In general, there were numerous anecdotal references to the difficulties of moisture/density or any control of large fills, especially rock fills.

**Drainage of Rock Fills**

District 7 also noted some problems with drainage of rock fills. In some cases, the rock fill may have been covered with a soil veneer which acts to keep water inside the fill. One solution used has been to "daylight" the rock at the toe of the fill thereby allowing free drainage of water from the fill.

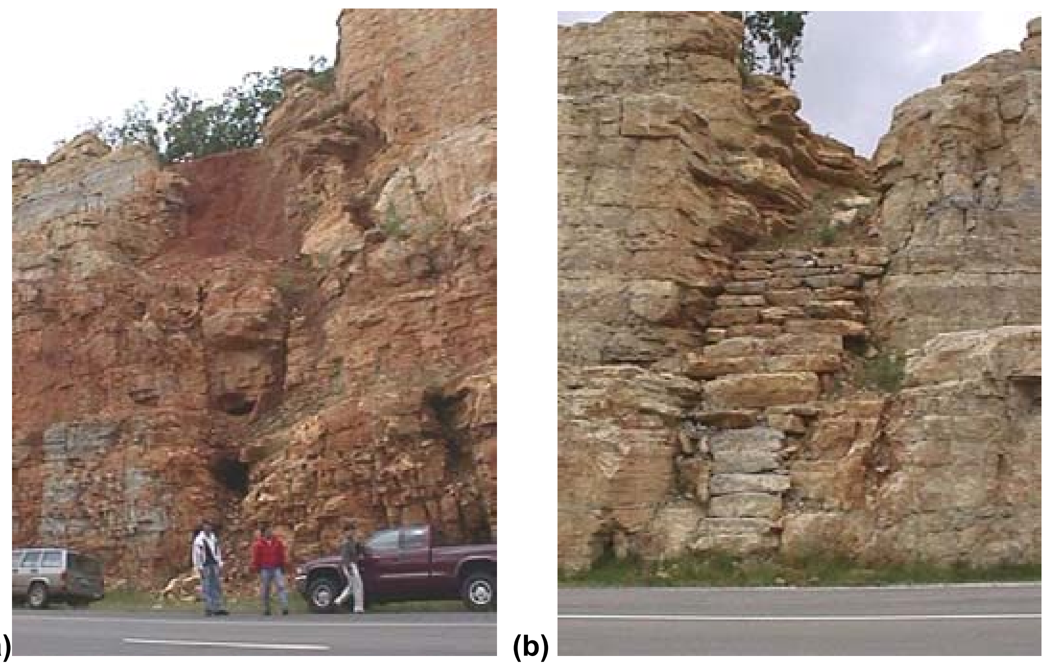
**Pinnacle Rock**

District 7 noted the difficulties presented when working in an area of pinnacled rock. Accurately locating the rock surface through drilling is difficult and subsequent construction can yield dramatically different profiles for top-of-rock than anticipated from the subsurface report.

**Clay Seams in Rock Cuts**

Clay seams in rock cuts occur in karst geologic environments. Weathering is primarily due to the solution of limestone (or other high carbonate rock) forming seams or solution features in the rock structure. There are three effects of limestone solution: 1. denudation or degradation of the rock surface, 2. enlargement of the primary (interparticle) porosity, and 3. enlargement of the secondary (fissure) porosity. Both of these enlarged porosities cause most of the serious structural and hydraulic problems that arise in limestone terrain. Solutioning that is focused in the secondary porosity, the bedding surfaces, and the transverse joint fissures separates the rock mass into partially discontinuous blocks with irregular lenticular or sheet-like gaps or slots between them. Limestone contains variable amounts of insoluble materials. When the soluble carbonates are dissolved and carried away in the groundwater, the insoluble components of the original rock are left behind. These insolubles include sedimentary gravels, sands, silts and clays. They partially fill the slots and cavities and blanket the rock surface with residual soils. (Sowers 1996).

This survey found that clay seams in rock cuts are a problem in District 8, as mentioned by AE, RE and DG. In District 8, high cuts in limestone are common; thus, the presence of the clay seams issue is found there. In other Districts, clay seams were not specifically mentioned in the survey as a significant issue relative to other geotechnical problems. However, deteriorating limestone in exposed faces (whether clay/mud infilled or not) is a potential issue wherever it occurs. Examples include Rte 63 from Rolla to Columbia, District 4 and the general Kansas City area. In District 8, the prevalent problem with clay seams in rock were the vertical clay seams in rock cuts that erode with time and create a cavity in the rock cut resulting in potential instability, as shown in Figure 28. The hazard that these unstable earth structures present require stabilization without much time for an analysis and designed solution. However, stacking of large flat rocks in crevices as shown in Figure 28 and backfilling behind with filter stone and geotextiles are some of the current solutions MoDOT engineers have effectively implemented. But in the long-term period, these areas may fail and result in future erosion or traffic hazards.



**(a)** **(b)**

Figure 28 – (a) A full-scale view of the magnitude of a clay seam on US 65 and (b) A solution to the clay seam problem is the man-made wall of rock to cover the seam.

**Pavement Edge Drains (PED)**

MoDOT instituted new designs and applications of pavement edge drains (PED) for both new and retrofitted roadways in the early 1990's. PED are systems to collect and drain subsurface water from beneath pavements (Figure 29). One objective of this project was to develop a sense of how well the new PED design is performing. A database of all contracts involving PED was established using bid item criteria. Jobs and project sites were located across the state, and field visits were made to locate and inspect the conditions of the pavement and the PED.

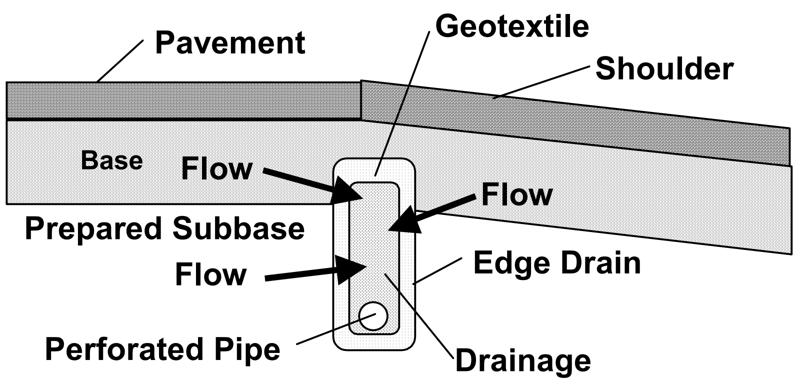



Figure 29 – Typical Pavement Edge Drain. Many variations on the design exist and can include aggregate or geocomposite drains.

The map shown in Figure 30 shows the general locations of the PED sites. Over 122 projects scheduled to use PED were located. Many PED field locations were visited. In some cases there was no evidence of the PED; i.e., no outlet drains could be located and no evidence of them in the pavement was found. Discussions with AE, RE and others indicated that although PED were scheduled for a project, the contractor may have used an alternate two-foot rock fill in lieu of the drains. In general, where drains (outlets) were located, the pavements appeared to be in good condition. It could entirely be that these pavements were reasonably new. Several MoDOT personnel indicated that the PED tend to work "for a while." This comment may be related or have a basis in the condition of the outlets of the PED.

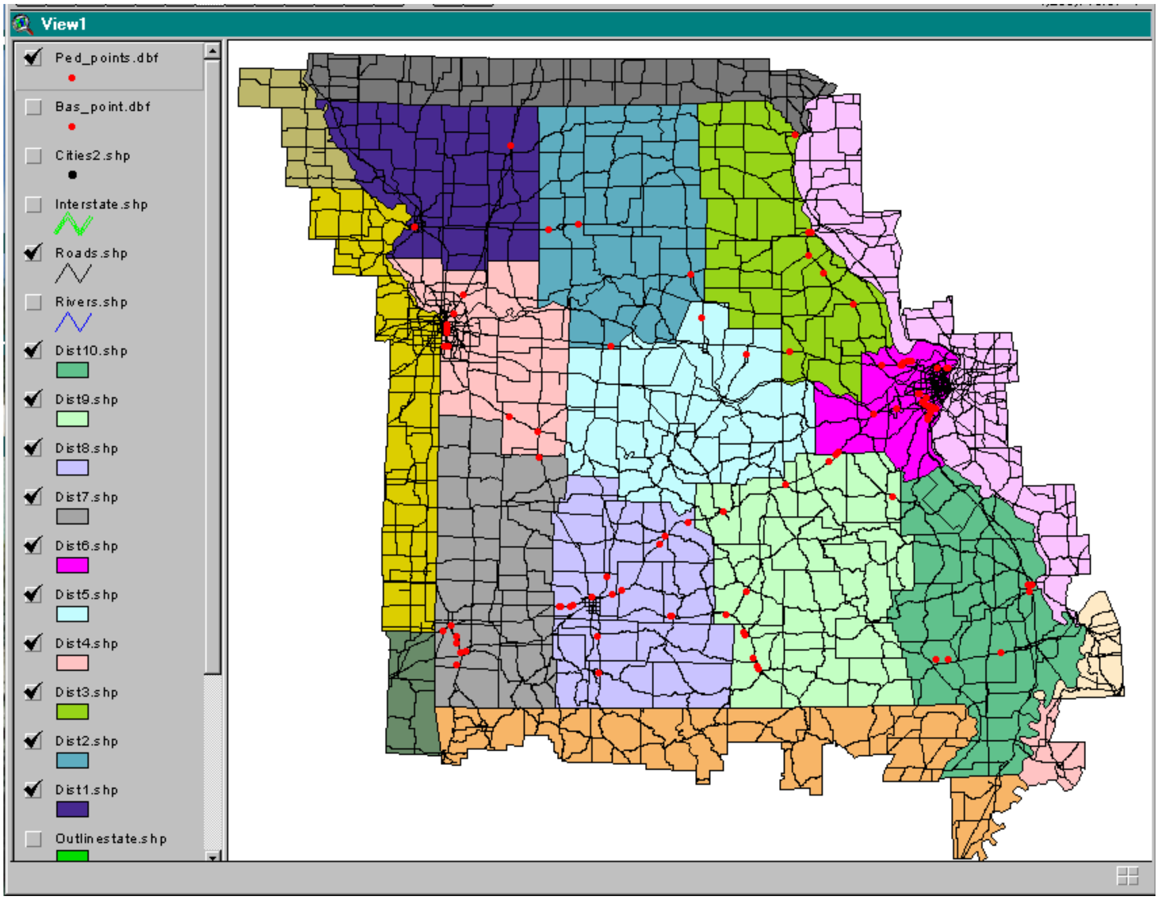



Figure 30 – Pavement edge drain sites across Missouri, based on contract data from 1993 through 2000 (dots shows the general location of PED construction).

In many cases, the outlets were found to be damaged due to either mowing activities or to erosion around the concrete apron typically placed at the opening of the outlet. These conditions can cause the PED to clog and no longer drain subsurface water from beneath the pavement. A drainage management system is warranted in order to maintain sufficient drainage of the pavement substructure throughout its life.

Others have done extensive evaluation of PED (TRR 1991, NCHRP 1997) and found several issues that keep them from performing at optimal levels. These conditions include:

- Outlet crushing/clogging,
- Drain silting up,
- Filter clogging, and
- Impermeable base.

In this survey, only the first issue (outlet crushing/clogging) was observable, and indeed the PED outlets in Missouri often suffered this fate. It is entirely possible that any of the other issues were acting to lower the performance of the drains. In the survey, PED rated low to medium (seventh to tenth) on the frequency and severity of occurrence. A literature review of PED was performed and the bibliography is provided in Appendix D.

**Bridge Approach Slabs (BAS)**

In 1993 MoDOT instituted a revised design for bridge approach slabs (BAS). The BAS is used to transition the pavement from a roadway, which may be an embankment or natural material onto a bridge deck (Figure 31). This transition is often referred to as "the bump at the end of the bridge," and has been studied, analyzed, redesigned and applied by numerous transportation agencies. A literature review of this problem was conducted and the bibliographic list is shown in Appendix C. A satisfactory solution remains to be identified. Since the revised MoDOT design has been applied for about eight years, we were tasked with trying to evaluate how well the new design was performing.

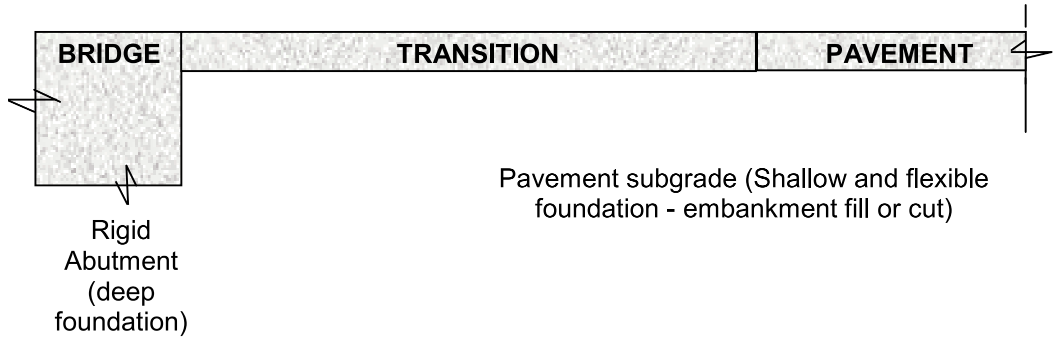
In the survey, BAS were found to be the second most common geotechnical problem, only exceeded by soil slope instability. They were third most frequent in maintenance and fifth in maintenance severity. One reason the BAS may be so high in the reporting is that poorly performing BAS are immediately evident to the user—the motoring public–due to the bump before the bridge.

BAS Causes of Problems

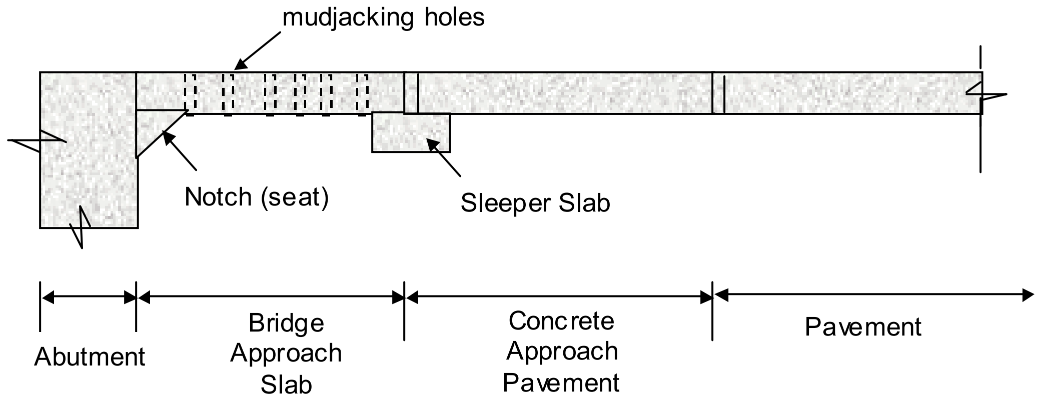
- Structural Failure
  - (a) Slab cracking and bending due to gap below
  - (b) Notch or Seat-on-abutment
- Settling of fill beneath sleeper slab
- Rotation of the sleeper slab – could be due to localized bearing capacity failure or settlement
- Drainage below and around the sleeper slab

Repair Methods:

- Mud jacking
- Asphalt or concrete wedge (leveling the differential settlement)
- Grinding the pavement to match the joints.




(a) General Concept




(b) MoDOT Design (1993)

Figure 31 – Typical Bridge Approach Slab (BAS)

The locations of various BAS are shown in Figure 32. In the site visits from Districts 1 through 5, practically all of the new BAS appeared to be functioning properly; i.e., there was no excessive 'bump' at the slab-to-bridge transition. The site visits were made at recently completed projects (last several years). These did not show many problems; however, the broader survey by the DG, RE, AE indicated a significant level of problems with the BAS. Note that all of these BAS contain mud-jacking holes and have typically been mud-jacked into place after construction. Based on discussions with MoDOT personnel, it appears that mudjacking the slabs into place has become the standard operation procedure. However, when maintenance cannot get to this operation in a timely fashion the deformation or "bump" starts becoming noticeable by the driving public and ultimately a safety hazard may develop.

Mudjacking has been performed with regular concrete pumping and in some cases a viscous foam (Urtek®) that sets with time has been used. The Urtek® product and its installation was typically performed by a subcontractor. MoDOT personnel considered this an expensive option. Districts 9 and 10 were particularly concerned about the overall problem of bridge approach slab performance due to poor performance of some recently built bridges and their ability to keep up with maintenance operations. In discussions with construction inspectors, the fast track way of building bridges has pushed for accelerated placement of fills, which may need some time to settle. Construction sequence should be considered to improve the performance of the bridge approach slabs. One option suggested was leaving the construction of the bridge approach slab and concrete pavement to the paving contractor, which happens typically one season after the bridge is built.

Another concern related to the new BAS design is the ‘sleeper slab’ and its footing and transition to the actual BAS. The footing (Figure 31b) is subject to the same settlement of the underlying fill. This, in effect, moves the ‘bump’ from the end of the bridge to some distance before the bridge. The idea is to spread the settlement over a longer length; however, some problems are evident due to excessive settlement of the sleeper slab/footing. Drainage below this sleeper slab is important, since the slab is designed to settle/then be mudjacked; this may cause water to pond below the slab, hence, worsening the problem.

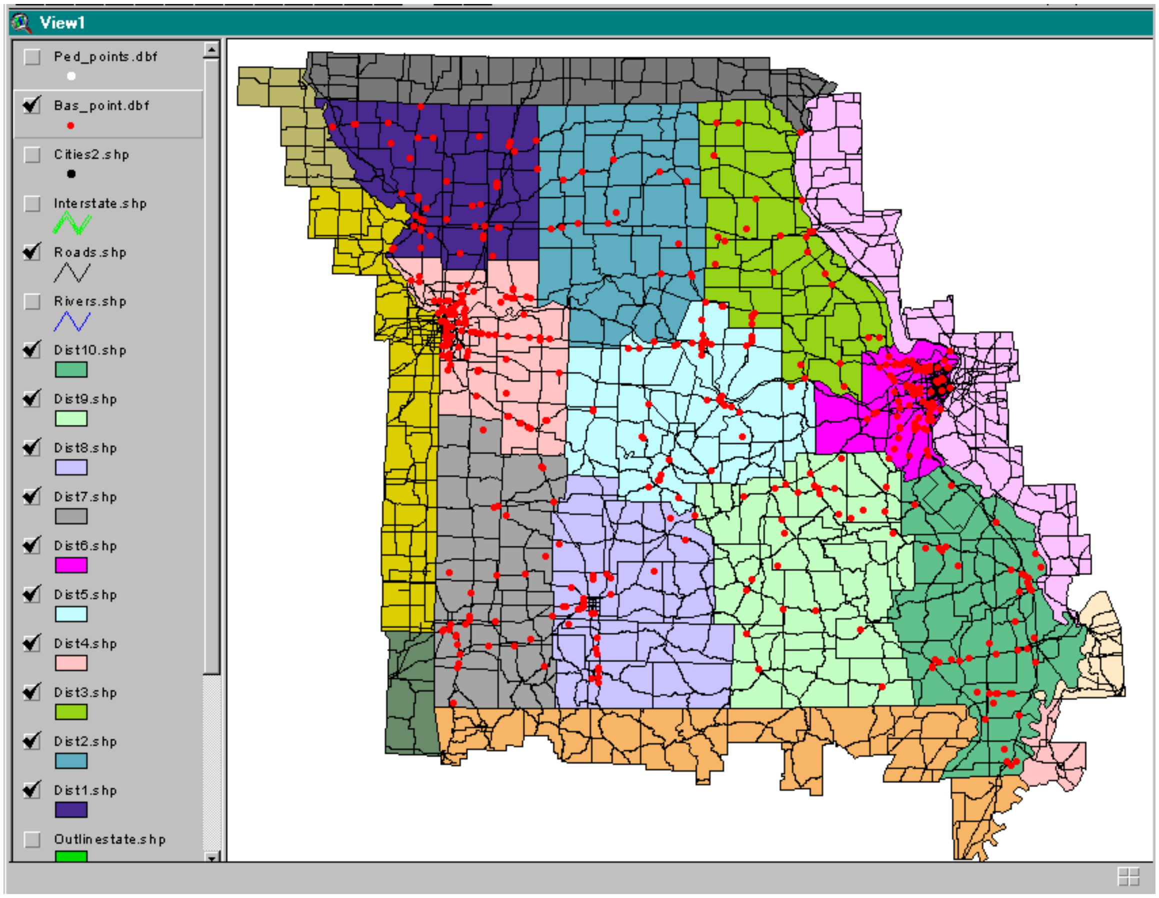



Figure 32 – Bridge Approach Slab (BAS) sites across Missouri based on contract data from 1993 through 2000 (red dots show the approximate location of BAS contracts).

## DISCUSSION

The objective of this project was to identify geotechnical-related problems, not necessarily the causes, facing MoDOT and to provide a prioritization to be considered when determining which issues should be addressed. While issues/problems vary among locales or Districts, it is quite clear from the findings that the most often cited problems are those that are impacting the pavement surface (ride quality) or pose imminent safety hazards (impending rock falls). Until a situation (slope, BAS, subsurface drainage, scour, erosion, etc.) begins to impact the pavement, there is a general feeling among MoDOT personnel that the issue has a lower priority than those that are impacting the pavement. This perspective is logical since it is generally the quality of the ride or lack there of, that the motoring public notices first. Other things being equal, if the ride is smooth, little attention (or funding) is given to solving problems that are in an early stage; e.g., poorly draining subsurface of a road or small slope failures. In certain instances, the full impact of problems such as roadway settlements, small slope instabilities and poor drainage are not realized since maintenance personnel have built-in programs to pave over or otherwise treat the symptoms on a routine basis. However, in many cases the true cause of the problem is never corrected, which leads to long-term, perpetual maintenance of items that could be corrected at the source with no further maintenance needed.

### Discussion of the Cited Problems

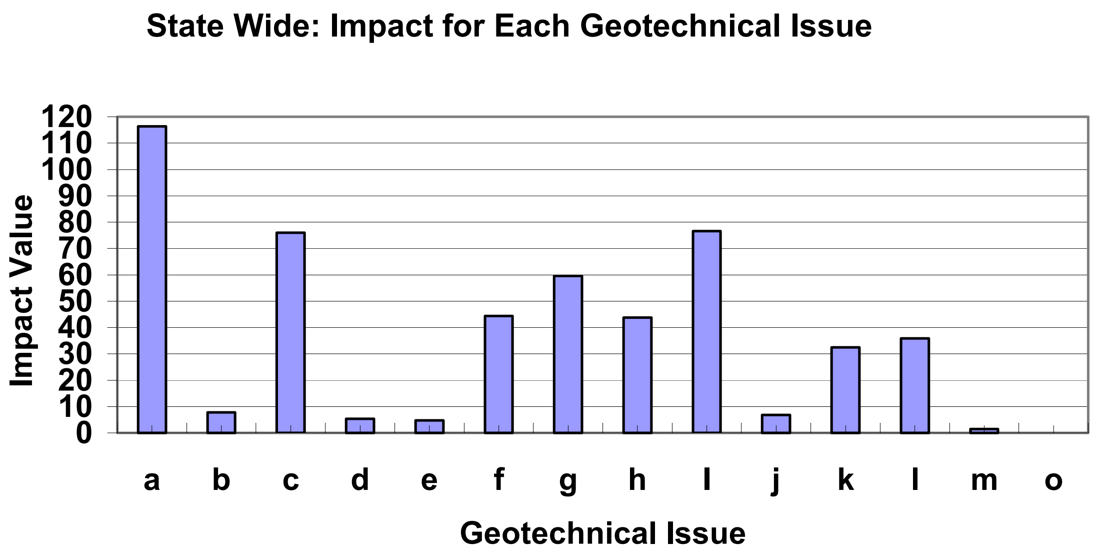
Given the above setting, the survey results show several issues that rank significantly higher than most. These issues include soil slope stability, bridge approach slabs, erosion, and pavement (collectively, unstable subgrades, subsurface drainage and settlement). All of these issues are known to occur to some extent in all ten highway Districts. For the state overall, these issues also rank high in frequency of maintenance and severity. (Frequency of maintenance indicates the number of occurrences that maintenance personnel must attend to and severity indicates the relative cost of repairing a given site.) It should be noted that the frequency and severity were rated by the various survey respondents based on their experience. Therefore, some variance between what one respondent reported as frequency and severity versus another respondent's ratings is expected.

A measure of a problem's importance was developed by combining the frequency of occurrence with the severity. The combined effect is reported as "Impact." The impacts for the geotechnical issues identified in this project are given on a state-wide basis in Table 15 and

Figure 33. Again, soil slope instability represented the issue with the highest impact. Pavements (unstable subgrades and subsurface drainage), erosion and bridge approach slabs followed closely behind and showed similar impact. Impacts on a District by District basis are given in Appendix E. All of these issues are associated with water, either present as excess or due to lack of control of water. Soil slopes tend to fail at periods of high moisture content, pavements settle when subgrades become weak or unstable when drainage systems fail to remove excess water from beneath roadways, erosion/scour occur when excessive water velocities impact soils or weak rock and BAS settle when embankment soils become saturated and soften. In addition, mud seams in rock become weak and fail more frequently under high moisture conditions. The extensive role of water in contributing to these and other geotechnical problems is given in Table 16.

Table 15 – Impact of each geotechnical Issue on a state-wide basis. Impact combines frequency of occurrence and severity.

| **Impact** | | **Geotechnical Issue** |
|---|---|---|
| 116 | a | Soil Slope instability |
| 77 | i | Erosion on embankments, slopes and/or stream banks |
| 76 | c | Unstable pavement subgrades |
| 60 | g | Bridge approach embankments and slab problems |
| 44 | f | Scour under bridges and river banks |
| 44 | h | Pavement subsurface drainage(edge drains) problems |
| 36 | l | Sinkholes/Mines |
| 32 | k | Settlement Problems |
| 8 | b | Rock slope instability |
| 7 | j | Bridge abutments or earth retaining structure problems |
| 5 | d | Bridge foundation problems |
| 5 | e | Earthquake foundation problems |
| 2 | m | Freeze/thaw |




| Item | Geotechnical Issue |
|---|---|
| a | Soil Slope instability |
| b | Rock slope instability |
| c | Unstable pavement subgrades |
| d | Bridge foundation problems |
| e | Earthquake foundation problems |
| f | Scour under bridges and river banks |
| g | Bridge approach embankments and slab problems |
| h | Pavement subsurface drainage(edge drains) problems |
| I | Erosion on embankments, slopes and/or stream banks |
| j | Bridge abutments or earth retaining structure problems |
| k | Settlement Problems |
| l | Sinkholes/Mines |
| m | Freeze/thaw |
| o | Other |

Figure 33 – Impact for specific geotechnical issues on a state-wide basis

Ten of the 20 state-wide geotechnical concerns cited in this survey involve water as a critical variable in the process. Removing all or at least the excess water from the situation via adequate drainage or other means can reduce the magnitude or eliminate the problem entirely. Given the extensive role that water plays in these issues warrants a general focus on water and its control in geotechnical applications. The significance of the role of water on soil behavior is not a recent finding. In 1939, Karl Terzaghi wrote ". . . in engineering practice, difficulties with soils are almost exclusively due not to the soils themselves, but to the water contained in their voids. On a planet without water, there would be no need for soil mechanics."

Table 16 – Role of water on specific geotechnical issues.

| Issue | Role of Water |
|---|---|
| Soil Slope Instability | Decrease shear strength<br>Increase driving force<br>Reduce stability |
| Unstable Pavement Subgrade | Weakens soil, causes swelling in clays |
| Scour | Erodes foundation soils/rock, transports sediment |
| Pavement Subsurface Drainage (PED) | Failure of drainage allows excess water in substructure |
| Erosion | Transports sediment, provides shear force to dislodge sediment |
| Settlement | High water content increases settlement |
| Bridge Approach Slab (BAS) | Softens embankment soil, results in settlement |
| Freeze/Thaw Pavements | High groundwater enables process |
| Natural springs | Require adequate drainage |
| Mud Seams in Rock Cuts | Seams weaken when wetted (see soil slope instability) |

Several of the geotechnical problems identified can be grouped into a common theme of "Design" or "Design/Construction" (Table 17). This theme suggests the source of the problem may be in the design or construction of the cited geotechnical aspect. In most cases, since no in-depth study was conducted, the specific source or sources of the problems were not identified during this project. However, suggestions have been made to focus on the problems and to identify the key variables and sources of the problems.

The highest ranking in the "Design" or "Design/Construction" group was bridge approach slabs. In general, the BAS all contain pre-cast mudjack holes, used to level the slab (BAS) some time after construction. Recall the main concern with BAS is the end of the slab resting on the approach fill which often settles, particularly when the approach is a thick compacted soil and also when the slab is constructed immediately after the fill is placed; i.e., no time is allowed for consolidation of the embankment fill. The 1993 design enables maintenance personnel to relatively easily level the slabs after they have initially settled. Additional holes for mudjacking may be necessary in the pavement slab leading up to the BAS. While many BAS were found to be performing well, it is possible that insufficient time has elapsed since construction for problems with the new BAS to occur, if they ever are to occur. The high ranking may be survey respondents' response to having to mudjack the BAS. The cost is not trivial. There is also concern that the design including the sleeper slab and footing simply moves the settlement issue away from the bridge, but may not significantly reduce the problem of differential settlement. Precast holes may become necessary in the adjacent concrete pavement. A detailed, long-term performance evaluation of the BAS is necessary to identify key variables and problem sources.

Table 17 – Geotechnical issues related to design or design/construction processes

| **Issue** | **Comments** |
| --- | --- |
| Bridge Approach Slabs (BAS) | • Structurally usually adequate<br>• Settlement of sleeper slab concern<br>• Design of approach slabs |
| Bridge Foundations | • Isolated areas of poor foundation materials<br>• Deep foundations used<br>• Rock socket designs—concern<br>• Pinnacled or karst rock concerns |
| Earthquake Foundations | • Lack of local *in situ* dynamic information on soils, rock—design |
| Bridge Abutments and Retaining Walls | • Construction of MSE walls<br>• Small-block walls |
| Inferior Rock Grades in Pavement | • Testing and acceptance of rock<br>• Alternate specifications<br>• Inadequate design to compensate for use of marginal materials |
| Backfilling with High Plasticity Soils | • Construction, segregation and placement of material types<br>• Soil improvement techniques |
| Precast Box Culvert with High Fills | • Design analysis of stresses on culvert<br>• Field performance monitoring<br>• Fill control on high fills |

Bridge foundations and earthquake foundations are both noted as ‘design’ issues. In the former, design of rock sockets was of concern, and in the later adequate information on the response of subsurface materials to dynamic motions is required but not readily available for Missouri. Both of these areas represent needs for specific research programs.

Bridge abutments and retaining walls did not rate highly as a state-wide problem. District 4 noted problems with walls placed along the Blue River and its tributaries. These are all associated with soft, compressible foundation soils. Walls constructed under these conditions are known to undergo significant settlements and movements. Adequate subsurface investigation and soil properties, along with appropriate designs can reduce or eliminate retaining structure problems. New technologies such as mechanically stabilized earth (MSE) may also require an increased level of inspection activities until contractors become adequately skilled in their application.

Some pavements show accelerated wear or structural failure due to inferior rock used in the concrete mix. This issue was particularly noted in District 4 and is applicable to all areas of the state where the quarried rock may be lower grade than desired for concrete pavements. Enhanced testing and acceptance criteria should be applied in areas of known low-grade rock seams. In addition, mix designs or design procedures can be altered to account for lower quality materials. Some specific research may be necessary to develop mix designs incorporating poorer quality constituents but resulting in adequate level of performance.

In some locations, embankments must be constructed using marginal soils; e.g., high plasticity clays (District 2) and degraded shales (District 4). It is good practice to segregate the fill material at the borrow site and then selectively place the material in the embankment; e.g., place high plasticity material in the interior (core) of the embankment and cover it with a stronger (lower plasticity) or coarse-grained material. The downside features to this are: slides occur along the soil embankment/shale embankment interfaces and the additional time and construction quality control (CQC) necessary to ensure the proper materials are placed in the desired location. The first issue might be addressed by benching the shale/soil interface. For MoDOT, this might mean additional trained inspectors are required on these types of projects. All of this translates into higher costs and longer construction times, and as currently priced, such is often outside of the scope of most projects. The problem of poor materials still exists when all of the on-site or available materials are of poor quality.

In several locations in the state, extremely high fills (>100 feet) are being placed above culverts (typically precast concrete box culverts). The survey respondents noted some concern over the performance of the culverts. It is not clear whether the concern is based on: (1) structural failure of joint or separation of joints and piping of surrounding soil; (2) settlement and change in the profile grades of the flow line; (3) excessive structural load on top of the culvert due to the high fill; or some other issues. These fills tend to be large-rock fill, which makes density control difficult to quantify. Instrumentation and performance monitoring of several of the culverts could improve or at least confirm the design and performance assumptions.

### General Observations on the Critical Factors Affecting Performance of Geotechnical Facilities

The written survey results provided a basis for discussions which were conducted with personnel from each of the ten Districts. The following general observations regarding critical factors affecting the performance of the geotechnically-related MoDOT infrastructure were developed largely from these discussions. The critical factors are listed below. In general, the critical factors can be lumped into a single parameter—geotechnical involvement in the design, construction and maintenance operations of MoDOT.

An informal poll of the geotechnical personnel from the Districts suggests they spend about 80 percent of their effort in the design phase and 20 percent handling construction and maintenance issues in the field. The geotechnical personnel at MoDOT headquarters spend slightly more time on special issues as they are responsible for all such issues across the State. The design involvement is largely consumed by performing geotechnical site characterization for proposed rights-of-way, determining strength and deformation properties of soil and rock and providing geotechnical reports for proposed roadway alignments and bridge locations. These activities constitute the prelude to the entire design process and are essential components but should not be the end of geotechnical involvement in the design process. Unfortunately, it is sometimes the case in the current system. This leads to the unnecessary development of geotechnical problems later on throughout the design, construction and maintenance of MoDOT's transportation infrastructure. In these cases, geotechnical involvement is on a "consultant" basis, i.e., the specific group requests assistance from the State's geotechnical specialists; however, this is too often after serious problems have developed either during or post-construction. Solving problems at this point is seldom a cost-effective approach. In the following, each phase of a project is considered and the existing geotechnical role is examined to highlight the possible type/level of involvement that will help reduce or eliminate some of the geotechnical problems cited in this survey.

**Critical Factors Affecting the Performance of MoDOT's Geotechnical Related Infrastructure**

- Geotechnical Input in Design
- Geotechnical Input in Construction
- Geotechnical Input in Maintenance

**Geotechnical Involvement in Design**

Currently, MoDOT's geotechnical staff typically provides soil and/or rock properties and subsurface stratigraphy to the civil design and structures units. These units then proceed with design of foundations, retaining structures, embankments, slopes, drainage structures and pavement systems with little or no further input from the geotechnical staff. "Special Foundations Investigations" can be requeted from the 'Support Center' when deemed necessary; however, the findings of this survey have shown settlement of foundations, retaining structures, embankments and failure of slopes in embankments to be significant geotechnical issues. These are complicated problems, which can be analyzed during design and accommodated for through design and construction changes, thereby relieving post-construction problems; however, full and continuous involvement of personnel with advanced geotechnical training and knowledge throughout the design and construction process is required. Independent analyses such as settlement, or foundation design should be performed by the geotechnical staff. The geotechnical staff should be consulted with greater frequency and throughout the complete design-build process.

Several design elements which require detailed geotechnical involvement are listed below. All of these elements should be performed in close collaboration with the civil designer or the structural engineer; however, the geotechnical personnel should take the lead on these items.

**Design Elements Requiring Detailed Geotechnical Involvement**

- Foundations
- Slopes
- Embankments
- Settlement Analyses
- Retaining Structures
- Pavement Subsurface Drainage

In some projects, e.g., embankment fill on soft foundation, the preferred design approach may be the 'observational design' methodology (Peck 1969). In such cases, geotechnical staff should take the lead on the design and follow through with the construction/monitoring phase.

In recent discussions with two other state DOT's, they indicated that in their organization the geotechnical design group is either housed adjacent to the bridge and design sections or in one case several geotechnical staff are permanently assigned to those sections. In these cases, geotechnical specialists are fully involved in the design process throughout the entire project. In MoDOT's case, assignment of at least one geotechnical specialist to the bridge section would go a long way to help ensure more frequent oversight of designs involving geotechnical considerations, and thus help to reduce the number of geotechnical issues occurring during and after construction.

**Geotechnical Input in Construction**

Often in the midst of construction, the contractor unearths conditions which vary from those expected based on the original geotechnical explorations and the project plans. Field changes are made possibly without consultation of the geotechnical staff. In many instances this does not create further problems; however, when the project change is specifically related to a geotechnical aspect, it is prudent to, at the minimum, notify the geotechnical staff and, if possible, the geotechnical engineer responsible for the design. Examples of such conditions can include those listed in Table 18. Note, this table is not exhaustive. It is best to have a geotechnically-trained inspector on site for critical aspects (foundations, steep slopes, fill on soft soils, BAS, PED, etc.) (Table 19). However, carefully prepared inspection manuals, coupled with high quality training of inspectors, can facilitate the alerting of the proper staff of potential issues during construction.

Table 18 – Changed site conditions which warrant consultation with the original geotechnical engineer or geotechnical staff.

- Foundation depth higher or lower than designed
- Pinnacled rock
- Karst conditions
- Occurrence of natural springs
- Shale exposure
- Exposure of problem soils such as high plasticity clays or loess which were not anticipated
- Changes in drainage design
- Changes in slope geometry
- Load testing
- Pile driving specs

Table 19 – Construction element critical to geotechnical involvement.

- Inspection of Geotechnical Systems
- Monitoring
- Inspection Training/Manuals
- Observational Method

The essence of good geotechnical practice in construction is understanding and recognizing when conditions out of the ordinary are encountered; i.e., conditions that were not recognized at the time of design and which therefore were not properly addressed. Recognition of these 'changed conditions' and alerting a geotechnical specialist is essential to avoiding future construction and/or protracted maintenance problems.

**Geotechnical Input in Maintenance**

The maintenance program probably makes more requests for geotechnical consultation than design or construction groups outside of the preliminary design input that is standard practice for MoDOT. It is good that they consult the geotechnical experts but unfortunate that they have such need. Much of the need results from the lack of continuous geotechnical input to the prior phases of a project. Based on the survey findings, the most frequent reason for maintenance to consult their geotechnical specialists is soil slope instability. The major concern is the high frequency of repair of minor to medium size slope failures and the impact they have on the safety of the roadway.

In some cases, maintenance has built-in programs to 'treat' specific problems; e.g, roadway settlement which is 'repaired' using overlays. While these programs solve the symptoms, at least temporarily, in some cases the maintenance is ongoing and, if lifecycle costs are considered, it is found to be an uneconomical situation. In such cases, consultation by a geotechnical specialist can lead to determination of the root cause of the problem and should lead to a re-design and fix of the actual cause, thereby reducing or totally eliminating further maintenance.

A diagram of an idealized role of the MoDOT geotechnical specialists is shown in Figure 34. The objective is to minimize the frequency of occurrence and severity of the geotechnical-related problems documented in this survey. It is also expected that increased involvement of geotechnical specialists across the spectrum of MoDOT activities will lead to reduced maintenance and longer-term, higher-performance transportation infrastructure; i.e., reduced lifecycle costs.

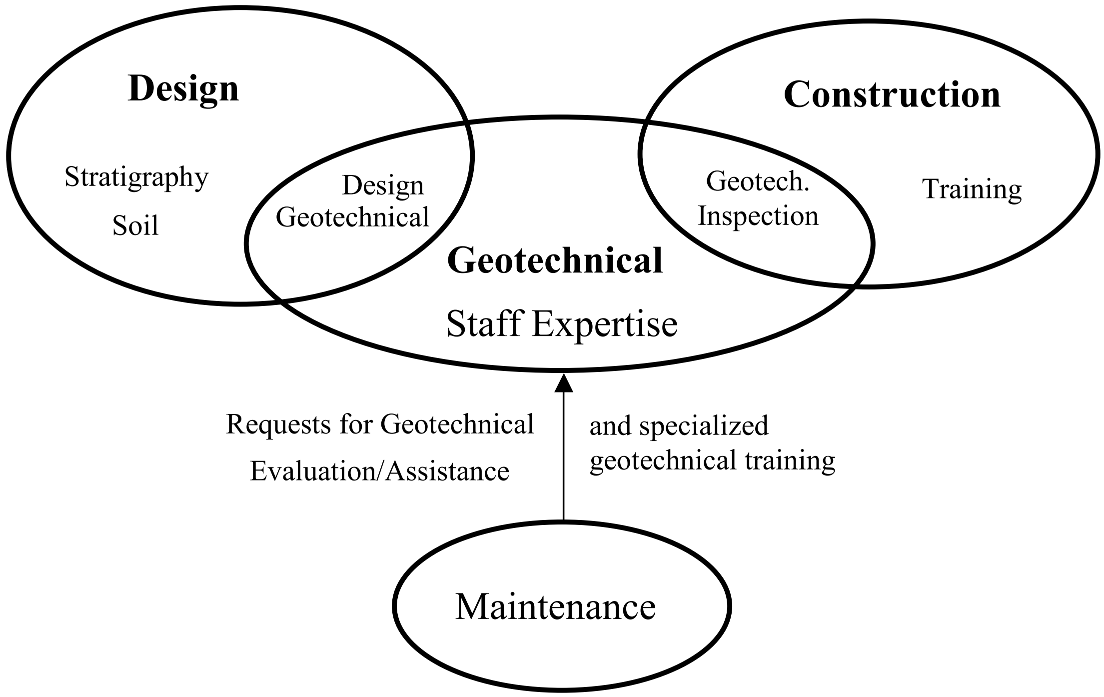



Figure 34 – Ideal Role of MoDOT Geotechnical Specialists for Minimization of Geotechnical Problems in Projects and Infrastructure.

**Summary**

There is a broad spectrum of geotechnical-related problems facing the infrastructure of MoDOT's highway system. The most frequent problems (slope failures, pavement quality, BAS, and erosion/scour) are present across the state. Less frequent problems (foundations, rock slopes, sinkholes, settlement) occur in single Districts or are regional in extent. Half of all the problems, including all of the most frequent ones, involve excess or uncontrolled water. *Some of the problems identified result directly or indirectly from a succinct discontinuity in the role of geotechnical specialists throughout the design, construction and, to some extent, the maintenance operations of MoDOT.*

## CONCLUSIONS

The principal objective of this project was to identify geotechnical-related problems facing MoDOT. It was also desired to 'rank' the problems to the extent possible. We used a paper survey, personal interviews and site visits to collect information regarding the types, frequency and severity of various geotechnical-related problems in the state.

In general, the most critical or severe problems are those that are impacting the pavement surface (ride quality). Until a situation (slope, BAS, subsurface drainage, scour, erosion, etc.) begins to impact the pavement, there is a general feeling that the issue has a lower priority than those that are impacting the pavement. This perspective is understandable since it is generally the quality of the ride that the motoring public notices first. Other things being equal, if the ride is smooth, little attention (or funding) is given to solving problems that are in an early stage; e.g., poorly draining roadway or small slope failures.

In certain instances, the full impact of problems such as roadway differential movements, small slope instabilities, and poor drainage are not realized since maintenance personnel have built-in programs to pave over or otherwise treat the 'symptoms' on a routine basis. However, the root cause of the problem is never treated in many cases, which leads to long-term maintenance of items that could be corrected at the source with no further maintenance required.

Four issues rose to the top of the list of geotechnical-related challenges facing the Districts. The issues are slope stability (soil), pavement (in terms of stability, subbase support, and drainage), bridge approach slabs, and erosion control (both on new construction and long-term facilities). There are different factors driving these issues to the top of the list of geotechnical-related problems facing the Districts.

Slope stability is at the top of the list because of the danger represented by an earth structure failure and consequent safety issues, as well as the aesthetics of roadways that are noticed by the traveling public. Many of these slope failures are minor in nature, but their high frequency of occurrence represents continually recurring maintenance problems and excessive costs. Soil slope instability ranked the highest impact (frequency and severity) for the state-wide survey.

The pavement drainage and subbase support problems are driven by the fact that the first thing noticed by the public is the ride quality of the roadways. Poor drainage and subbase support as well as shrink-swell of highly plastic clays have resulted in numerous and frequently recurring pavement problems. There appears to be a weak geographic clustering of the most severe pavement problems associated with both traffic volume and geologic conditions.

The erosion control issue is largely driven by the US Environmental Protection Agency's recent regulations limiting the level of suspended solids in water courses. The increased regulations and enforcement have forced MoDOT and construction contractors to increase efforts to control erosion from construction sites. In addition, erosion of existing MoDOT facilities continues to result in significant damage to structures and acceleration of slope instabilities.

Special attention was placed on bridge approach slabs (BAS) and the evaluation of the new (1993) design. It is evident that the design is not the only factor affecting performance. The construction techniques, timing and sequence are major factors in the performance of an embankment and slab immediately adjacent to the bridge. Visits were made to BAS sites of every District. Good and bad cases have been observed and the speculated reasons for performance vary. In general, the BAS typically must be mudjacked into place after construction, and then subsequently they settle or the adjacent pavement settles, resulting in an unsatisfactory performance.

Pavement edge drains (PED) were also a specific focus of this project; however, they are difficult to locate in the field since they are buried beneath the pavement. In some cases, contractors substituted two-foot thick rock fills in place of PED, although post-construction information did not readily identify this substitution. When PED were located, the spacing of the drain outlets varied at the different stretches of alignment. The PED seem to be working satisfactorily when the pavement has enough structural thickness. However, when the installation of the PED was not associated with other pavement improvements, the performance did not improve. Partial obstruction of the outlets results in poor drainage, but does not necessarily correlate with poor pavement performance.

A major contributing factor to the cause of many of the recurring problems is the disconnect between the geotechnical specialists of MoDOT and the specific units of Design, Construction and Maintenance. *Significant reduction in the frequency of geotechnical-related problems is likely in the event that the geotechnical unit is included in team-fashion in all MoDOT's roles (design, construction and maintenance).*

## RECOMMENDATIONS

We offer three main recommendations that, if enacted, will lead to a substantial reduction in geotechnical-related problems, reduced lifecycle costs, and improved performance of MoDOT infrastructure. The three main areas are:

1. Organization
2. Philosophy, and
3. Specific Research Needs

The first two areas involve a long-term outlook and promise to return the most benefit if enacted. The third area is a set of short-term actions that have benefits, but they are limited in extent, scope and magnitude.

*A. Organization*

MoDOT's Geotechnical unit consists of the headquarters staff (within the Materials unit) and the District Geologists and their staffs housed around the State. Seventy to eighty percent of effort by these geotechnical specialists can be considered proactive. This portion of their efforts is primarily focused on the design phase; however, some of their efforts are involved in the construction and maintenance phases of MODOT's highway system. The geotechnical personnel provide high quality site characterization information for design of new roadways and re-alignments and changes to existing infrastructure. This information is essential for design of cost-effective transportation facilities. Their involvement and level of effort in the design phase must remain high.

The geotechnical involvement in the construction and maintenance phases accounts for approximately twenty percent of their effort. Their involvement is by definition, in general, on a reactive basis, i.e., responding to unanticipated situations that develop during construction or observed during maintenance activities. The proactive involvement of MoDOT's geotechnical specialists have led to changes in design standards, such as the recommended steepness of soil slopes, which is reducing the number of construction and maintenance issues. Increasing the involvement of MoDOT's geotechnical specialists during design and especially construction. Can further reduce some of the issues cited in this survey. Provision of fulltime geotechnical specialists in the design and construction phases of the geotechnical–related aspects of a project; e.g.; foundations, retaining structures, embankments, pavement drainage systems, etc.

is essential to reduce maintenance and increase the effective performance life of MoDOT's transportation infrastructure. Geotechnical expertise must be involved in the maintenance aspect of MoDOT infrastructure, possibly through training courses for maintenance personnel to better recognize when geotechnical specialist should be consulted. If MoDOT's geotechnical specialists are made aware of the recurring maintenance issues, permanent repair can be evaluated and design changes considered. Increased participation of MoDOT's geotechnical specialists across the spectrum of the department's design, construction and maintenance activities will continue to decrease lifecycle costs and improve the performance level of MODOT infrastructure.

*B. Philosophy*

The second area that represents a long-term effort is a revision to the research philosophy of the Department. Presently, research is sometimes focused on 'apparent' problems. Little 'evidence-based' need is available for decision-making and prioritization of research agendas. What is missing are data bases including moderate- to long-term studies on the performance of MoDOT infrastructure. Currently, design changes are sometimes implemented before the true performance or the causes of poor performance have been documented and quantified. In such cases, the implemented changes may not offer any improvement above the design being replaced.

It is critical to institute long-term performance monitoring programs and to establish a baseline of the existing systems, their faults and causes, prior to developing and constructing new designs which have a high likelihood of suffering the same problems as the previous design (Walter 1986). An example is the case of the change in the design of the BAS. It is not readily evident that the performance is any better than that of the previous design. Changes which increase the effective performance and reduce lifecycle costs must be based on sound performance data.

This recommendation applies to the Research division more so than to the Geotechnical or other units. Setting up long-term monitoring programs to collect high quality performance data is a necessary research function in order to prioritize research programs and to modify existing designs appropriately. In addition, it is equally important to reduce, analyze and disseminate the performance data to design, construction and maintenance units within MoDOT and to potential researchers. The latter group is especially well-suited to performance monitoring and analysis of data and requires the performance data in order to develop projects leading to effective solutions and overall improvements.

*C. Specific Research Needs*

This project represents the initial attempt at establishing a baseline on the field performance of geotechnical aspects of MoDOT infrastructure. The scope of observed geotechnical design features was too vast to allow detailed study of any single feature, although pavement edge drains and bridge approach slabs were singled out for greater depth of study. Details of key variables (root causes) leading to poor or good performance were not determined; i.e., no infrastructure features were instrumented. All details in this project were observational in nature.

Based on the results of the survey, several issues can be given higher priority for research based on their occurrence frequency and severity as noted by the survey participants. These items include:

- Soil slope instability,
- Pavements,
- Erosion/scour, and
- Bridge approach slabs.

The pavements category is stated in general since several confounding factors are involved and are difficult to de-couple based solely on the results of this survey. The factors include: unstable subgrades, settlement problems and subsurface drainage performance.

The items above are suggested as higher or highest priority research topics. An outline suggesting the principal research tasks for each of the above issues is given below.

Soil Slope Instability:

1. Develop a detailed database on the costs of both initial construction and maintenance of slopes.
2. Document the moisture conditions throughout the life of embankments, cuts, fills, stream banks and soft foundations.
3. Determine the key variables: soil type, geology, climate, construction process, and their impact or significance.

4. Systematically evaluate specific slope repair methods: rock fill, tiebacks, drilled shafts, micropiles, pins, drainage, physiochemical stabilization, and geosynthetics.
5. Evaluate effects of construction specifications and quality control quality assurance, on the short- and long-term performance of the slope.
6. Evaluate the performance of zoned-fills.

Pavements:

1. Develop a spatial comparison of pavement ratings and maintenance/repair intervals. Correlate with pavement types, drainage systems, subgrade types.
2. Establish a network of test sections and performance monitoring of pavement sections including the subbase, base and drainage systems.
3. Evaluate and incorporate updated pavement designs, adapted to Missouri conditions.
4. Determine and document the benefits of more rigorous pavement designs.
5. Incorporate mechanistic design of pavements into Missouri DOT system.
6. Evaluate effects of subgrade stabilization and its incorporation into pavement design.

Erosion:

1. Goals have been established and include: Environmental compliance (keeping soil out of waterways) and Maintain facilities (keeping soil 'in place'). Now field performance evaluations of current practices to document how they are meeting (or not) the stated goals is warranted.
2. Perform large-scale laboratory evaluations to isolate key variables: climate, soil types, soil stabilization type and timing. The lab studies provide better control, a wide variety of test variables and are less costly than field studies.
3. Perform field performance demonstrations to finalize evaluation of best lab-determined methods for erosion control.
4. Define what erosion control solutions work in Missouri and under what conditions.

Bridge Approach Slabs:

1. Monitor the construction process.
2. Monitor settlement/heave of BAS.
    a) Surface
    b) Within the fill
    c) At the foundation level

3. Perform a finite element analysis of the deformations.
4. Locate the sources of the problems: foundation, fill, structural components, and construction methods and control.
5. Redesign: could include lightweight fill, flowable fill, structure, construction process.
6. Construct and monitor the performance (long-term).

In general, research should involve a significant component of long-term performance monitoring and analysis since scant baseline data is available for these or any topics identified in this survey. Research projects that involve instrumentation and performance data gathering on these aspects of geotechnical infrastructure are needed to provide a fundamentally sound, defensible basis for a research and design program on any of these topics.

**IMPLEMENTATION PLAN**

The results and recommendations of this project should be implemented into the MoDOT organization through four specific actions:

1. Project Final Presentation
2. Organizational/Philosophy Meetings
3. Technical Advisory Group—adoption of long-term performance monitoring projects
4. Technical Advisory Group—adoption of short-term research for highest priority issues.

The project final presentation will provide an overview of the project findings and an introduction to the recommendations. The organizational/philosophy meetings are the crucial element to actually making long-term, substantial impacts, including enhanced performance and reduced life cycle costs for MoDOT's geotechnical-related infrastructure. These meetings must involve the decision makers for the Design, Materials, Construction, Maintenance and Research units of MoDOT. They must agree on initiating baselining programs for performance monitoring and effectively integrating the role of the geotechnical engineering unit in all aspects of the design, construction and maintenance units.

Two items involve the technical activities group (TAG). The first is the adoption of the noted short-term research needs (slopes, pavement, BAS, erosion). These should involve the geotechnical and pavements TAGs, along with the structures TAG. The second item is the consideration of adoption of a philosophy of long-term performance monitoring projects by the TAGs. The TAGs will need to consider how to develop such projects.

## PRINCIPAL INVESTIGATOR AND PROJECT MEMBERS

| | |
|---|---|
| Principal Investigator: | Dr. Thomas M. Petry, University of Missouri–Rolla |
| Co-PI's: | Dr. John Bowders, University of Missouri-Columbia<br>Dr. J. Erik Loehr, University of Missouri-Columbia<br>Dr. Ronaldo Luna, University of Missouri-Rolla |

## IMPLEMENTATION OBJECTIVE

Implementation of the recommendations from this project will result in the following outcomes:

1. Improved prioritization of research efforts using 'evidence-based' prioritization.
2. Increased likelihood of success and expanded impact of future research projects.
3. Reduced frequency and severity of geotechnical-related problems.
4. Reduced life-cycle costs for geotechnical-related infrastructure.
5. Improved customer (state resident) satisfaction through increased effective performance life of geotechnical-related infrastructure.

## AFFECTED BUSINESS UNITS AND PRINCIPAL CONTACTS

The following units will be impacted by the successful implementation of the findings of this project:

| Unit | Contact |
|---|---|
| Project Operations | Connie Baldwin |
| Geotechnical | Mike Fritz |
| Pavements | Lance Taylor, Pat McDaniel |
| Design | Dianne Heckemeyer |
| Bridge | Shyam Gupta |
| Maintenance | Jim Carney |
| Research | Ray Purvis |

**IMPLEMENTATION PERIOD**

Implementation of the findings from this project should begin immediately. The initial efforts will be made at three levels within MoDOT. Management can begin a series of work sessions to develop an organizational procedure for effectively incorporating geotechnical expertise into all elements of MoDOT efforts – design, construction and maintenance. The Research division should bring in continuous quality improvement expertise to help design a research program that emphasizes long term performance monitoring and performance baseline development. Research should also consider shorter term projects for the specific topics cited through the findings of this project as high priority - Soil slope instability, Pavements, Bridge approach slabs, and Erosion/scour.

| | 2003 | | | | 2004 | | | | 2005 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Organizational/Philosophy Development meetings** | | | | | | | | | | | |
| | | | | | | | | | | | |
| **TAG Short-Term Research Projects** | | | | | | | | | | | |
| | | | | | | | | | | | |
| **TAG Long-Term Performnace Monitoring** | | | | | | | | | | | |

**FUNDING**

Organizational Meetings – from MoDOT HQ

Short term research - RDT

Long term research - RDT

**TECHNOLOGY TRANSFER**

This report should be distributed to the Chief Engineer, all District Geologists, District Engineers and Area Engineers. It should also be distributed to the Geotechnical, Structures and Pavement TAGS. As long-term databases are established, the information will need to be disseminated through MoDOT's Research unit. Information will need to be disseminated both internally and to those who may work, with MoDOT; e.g., university researchers, contractors, other state DOT's.

**PROCEDURE**

Procedures for implementing the findings and recommendations from this project will largely be developed by MoDOT personnel. It is recommended that MoDOT include outside entities such as a continuous quality improvement consultant and facilitator to assist in philosophy and organizational development activities. Personnel from these organizations bring expertise and unbiased viewpoints that can greatly aid in the development of effective strategies be they for incorporating geotechnical expertise across the MoDOT system or developing a long-term performance monitoring research program.

**BUDGET**

There is no budget estimate for the implementation of the findings of this project. Much of the effort will be internal to MoDOT and will be performed by on-board employees within their current setting. A budget will be necessary for the quality consultants and facilitators; however, theses services are temporary. A budget for short-term focused research projects and long-term performance monitoring and data analysis research will need to be developed. Funding for the research activities should be contained within the existing framework of the research unit. It is important to consider the estimated cost savings included in both reduced life cycle costs and for reduced occurrences of geotechnical problems as the recommendations from this project are put into action.

## CITED REFERENCES


Abramson, L., Lee, T., Sharma, S. and Boyce, G.., (2002), *Slope Stability and Stabilization Methods*, 2nd Ed.,New York, John Wiley.

Annandale G.W. (2000) "Prediction of Scour at Bridge Pier Foundations Founded on Rock and Other Earth Materials," *Transportation Research Record* 1696, pp 67-70.

Arnold J.B., Wall G., Moore N., Baldwin C.S., Shelton I.J. (1987) "*Soil Erosion - Causes and Effects*" Ridgetown College of Agricultural Technology, I.J. Shelton, Ontario Institute of Pedology, Guelph, Ontario, Canada.

Bowders JJ, Loehr JE and Owen JW (2000) "Shear Behavior of Compacted Loess," Geotechnical Special Publication No. 99, *Proceedings* of the ASCE/GeoInstitute conference, Advances is Unsaturated Geotechnics, Denver, CO, pp.235-246.

Briaud, J.L., Chen, H.C., Kwak, K.W., Han, S.W., and Ting. F.C.K., (2001) "Multiflod and Multilayer Method for Scour Rate Prediction at Bridge Piers," J. of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 2, pp. 114-125.

Briaud, J.L., Tink, F.C.K., Chen, H.C., Cao, Y., Han, S.W., and Swak, K.W. (1001) "Erosion Function Apparatus for Scour Rate Predictions," J. of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 2, pp 105-113.

Cedergren, H. R., (1989), *Seepage, Drainage, and Flow Nets*, third Edition, John Wiley and Sons, New York, pp 465.

Cedergren, H. R., (1994), "America's Pavements: World's Longest Bathtubs", *Civil Engineering*, pp 56-58.

Cedergren, H. R., (1996), "Geotechnical Engineering Principles Sorely Needed in Pavement Design", *Geotechnical News*, pp 50-53.

Dubbe, D.D., Usmen, M.A. and Moulton, L.K. (1984) "Expansive Pyritic Shales," *Transportation Research Record* 993, Transportation Research Board, Washington, DC, pp 19-27.

Fleming RW and Varnes DJ (1991) "Slope Movements, Chp 9 in The Heritage of Engineering Geology; The First Hundred Years," Centennial Special Volume 3, GA Kiersch, Ed., Geological Society of America.

Knobbe, S., (1998), "Slide Investigation Job No. J6I0651B Route I-270, St. Louis County". Interoffice Correspondence Memorandum, dated August 31, 1998, Missouri Department of Transportation, 7pp.

Koerner, R.M. (1984) *Construction and Geotechnical Methods in Foundation Engineering*, McGraw-Hill, New York, pp 496.

Landers, M.N., and Mueller, D.S., (1995) "Distribution of Channel Scour at Bridges in the US," FHWA RD 95, 184.

Loehr, J.E., Bowders, J.J., and Salim, H., (2000) "Slope Stabilization Using Recycled Plastic Pins – Constructability," *Final Report*, RDT-00-007, RI 98-007, Missouri Dept of Transportation, Research Development and Technology, pp. 74.

Missouri State Highway Commission (1962), Geology and Soils Manual, Division of Materials, Geology and Soils Section, W.C. Davis Editor, 436 pp.

Moulton L.K. (1986) *Tolerable Movement Criteria for Highway Bridges*, FHWA Report No. FHWA-TS-85-228, 86pp.

National Cooperative Highway Research Program, (1997) *NCHRP Synthesis* 239, "Pavement Subsurface Drainage Systems, A Synthesis of Highway Practice, Transportation Research Board, National research Council, Washington DC, 44 pgs.

National Cooperative Highway Research Program, (2002) *NCHRP Report* 472, "Comprehensive Specification for Seismic Design of Bridges," Transportation Research Board, National Research Council, Washington DC, 47 pgs.

Owen JW and Bowders JJ (2002) "Drained Strength of Compacted Silty Loess," *Journal of Geotechnical and Geoenvironmental Engineering*, in review, Jan. 2002.

Owen, J.W., (2001) "Shear Strength of Compacted Loess, *MS Thesis*, Civil and Environmental Engineering, University of Missouri, Columbia, MO, pp.108.

Peck R.B. (1969) Ninth Rankine Lecture, "Advantages and Limitations of the Observational Method in Applied Soil Mechanics," *Geotechnique*, 19(2):171-187.

Petry, T.M. (2001) "Investigation of Agents of Practical Use to Stabilize Slopes and Erosion Along the I-55 Corridor, South of Sikeston, Missouri", Missouri Department of Transportation, RDT 01-006, May 2001, 66pp.

Shoemaker, M.L., Anderson, N.L., Shaw, A.E., Baker, J.A., Hatheway A.W., Newton, T.E. and Conley, J. (1998) "Reflection seismic study of previously mined (lead/zinc) ground, Joplin, Missouri," *in* Anderson, N.L., Cardimona, S., and Newton, T., Editors, Highway Applications of Engineering Geophysics with an Emphasis on Previously Mined Ground: Missouri Department of Transportation Special Publication, 124-135.

Sowers, G.F., (1996), *Building on Sinkholes: Design and Construction of Foundations in Karst Terrain*, American Society of Civil Engineers, 202 pp.

Terzaghi, K., (1939) "Soil Mechanics – A New Chapter in Engineering Science," *Journal of the Institution of Civil Engineers*, Vol. 12, pp. 106-141.

Transportation Research Record No. 1329, (1991) "Geocomposite Pavement Drain Systems," Transportation Research Board, National Research Council, Washington, DC, 61 pp.

Unklesbay A.G. and Vineyard J.D. (1992) *Missouri Geology, Three Billion Years of Volcanoes, Seas, Sediments and Erosion*, Univ of Missouri Press, Columbia, Missouri, 189pp.

Walton, M. (1986) *The Deming Management Method*, Dodd Mead, 262 pp.

## Appendix A: Written Survey Instrument

For Office Use Only

| ________District Geologist _______ Area Engineer ______________Other (Specify) |
|---|

**MoDOT Geotechnical Issues Questionnaire – 2000**

Purpose: **Civil Engineering faculty from the University of Missouri-Rolla and University of Missouri-Columbia are involved in a project to identify, and prioritize significant problems having to do with earth materials in Missouri transportation facilities. There will be particular emphasis on evaluating the effectiveness of recently implemented designs for bridge approach slabs and pavement edge drains. The success of this project depends heavily on acquiring information from MoDOT District level personnel who have dealt with problems involving earth materials during design, construction and maintenance. This survey will serve as the initial means for gather such data. Following the survey, we will be contacting personnel from each District for further discussions on the specific findings of this survey. We thank you in advance for your response to this survey and look forward to interacting with you over the next two years.**

**MO DOT District:** ______________________________________________

**Name:** ________________________________________________________

**Title:** _________________________________________________________

**Address:** ______________________________________________________

**Phone:** _______________________________________________________

**e-mail:** _______________________________________________________

1. Given the following examples of geotechnical problems, which ones do you believe apply to your District? (circle all that apply)

   a) soil slope instability
   b) rock slope instability
   c) unstable pavement subgrades
   d) bridge foundation problems
   e) earthquake evaluation
   f) scour under bridges and river banks
   g) bridge approach embankments and slabs problems
   h) pavement subsurface drainage (edge drains) problems
   i) erosion of soils on embankments, slopes and/or stream banks
   j) problems with bridge abutments and/or earth retaining structures
   k) settlement problems
   l) sinkholes / mines

   m) other: ____________________________________________________

   ____________________________________________________

   ____________________________________________________

2. Which geographic area(s) or roadway stretch(es) in your District do you believe is (are) more prone to geotechnical problems? Please indicate the order of their severity with 1 being most severe and the largest number being least severe.

3. Geotechnical (earth materials) problems have occurred in my District during construction of:

| Highway | General Location | Nature of Problem(s) |
| --- | --- | --- |

4. Geotechnical problems which have happened during construction have been addressed by:

| **Highway** | **General Location** | **Solution Applied** |
| --- | --- | --- |

5. Geotechnical Problems which first happened during construction and which are reoccurring and represent a maintenance problem:

| Highway | General Location | Nature of Problem(s) |
| --- | --- | --- |

**6.** From the list provided below, rank the following maintenance problems in a scale of 1 to 5 by <u>frequency</u> of event, 1 being the most common and leave blank if not a problem:

| | | **Frequency** |
|---|---|---|
| a) | Soil slope instability | 1 2 3 4 5 |
| b) | Rock slope instability | 1 2 3 4 5 |
| c) | Unstable pavement subgrades | 1 2 3 4 5 |
| d) | Bridge foundation problems | 1 2 3 4 5 |
| e) | Earthquake evaluation | 1 2 3 4 5 |
| f) | Scour under bridges and river banks | 1 2 3 4 5 |
| g) | Bridge approach embankments and slabs problems | 1 2 3 4 5 |
| h) | Pavement subsurface drainage (edge drains) problems | 1 2 3 4 5 |
| i) | Erosion on embankments, slopes and/or stream banks | 1 2 3 4 5 |
| j) | Bridge abutments or earth retaining structures problems | 1 2 3 4 5 |
| k) | Settlement Problems | 1 2 3 4 5 |
| l) | Sinkholes / Mines | 1 2 3 4 5 |
| m) | other: ________________________________ | 1 2 3 4 5 |
| | ____________________________________ | 1 2 3 4 5 |
| | ____________________________________ | 1 2 3 4 5 |

**7.** From the list provided below, rank the following maintenance problems in a scale of 1 to 5 by <u>severity</u> of event, 1 being the most severe and leave blank if not a problem:

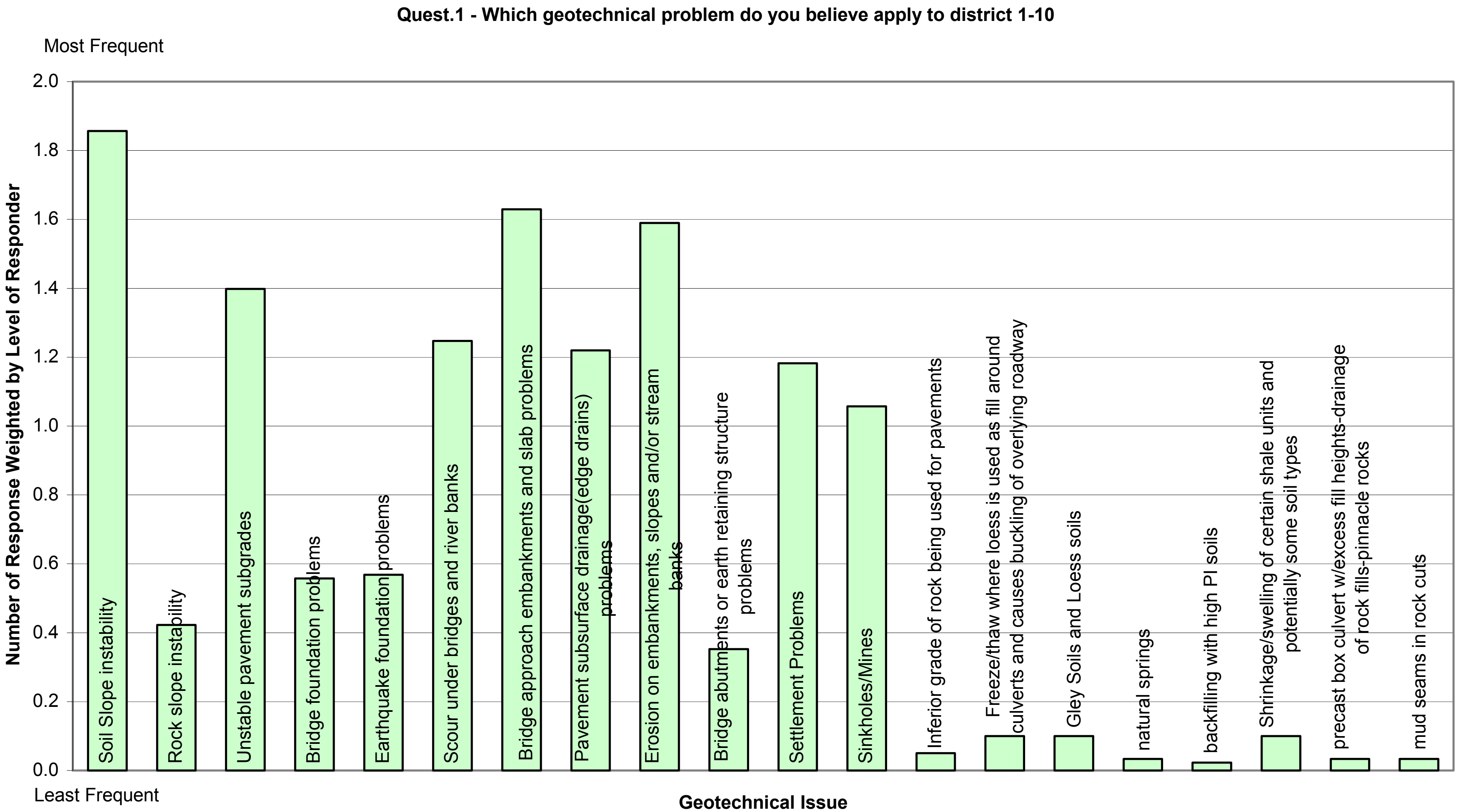
**Severity**

| | | |
|---|---|---|
| a) | Soil slope instability | 1 2 3 4 5 |
| b) | Rock slope instability | 1 2 3 4 5 |
| c) | Unstable pavement subgrades | 1 2 3 4 5 |
| d) | Bridge foundation problems | 1 2 3 4 5 |
| e) | Earthquake evaluation | 1 2 3 4 5 |
| f) | Scour under bridges and river banks | 1 2 3 4 5 |
| g) | Bridge approach embankments and slabs problems | 1 2 3 4 5 |
| h) | Pavement subsurface drainage (edge drains) problems | 1 2 3 4 5 |
| i) | Erosion on embankments, slopes and/or stream banks | 1 2 3 4 5 |
| j) | Bridge abutments or earth retaining structures problems | 1 2 3 4 5 |
| k) | Settlement Problems | 1 2 3 4 5 |
| l) | Sinkholes / Mines | 1 2 3 4 5 |
| m) | other: ________________________________ | 1 2 3 4 5 |
| | ____________________________________ | 1 2 3 4 5 |
| | ____________________________________ | 1 2 3 4 5 |

8. Are there other issues you would like to include concerning problems with earth materials, pavement edge drains or bridge approach slabs in your District?

We want to thank you very much for the time and insights offered for this project.

## Appendix B: Survey Responses to Questions 1, 6 and 7



**Frequency of Responses to Question 1**
Date Completed:
The values are NOT normalized for number of reponders.

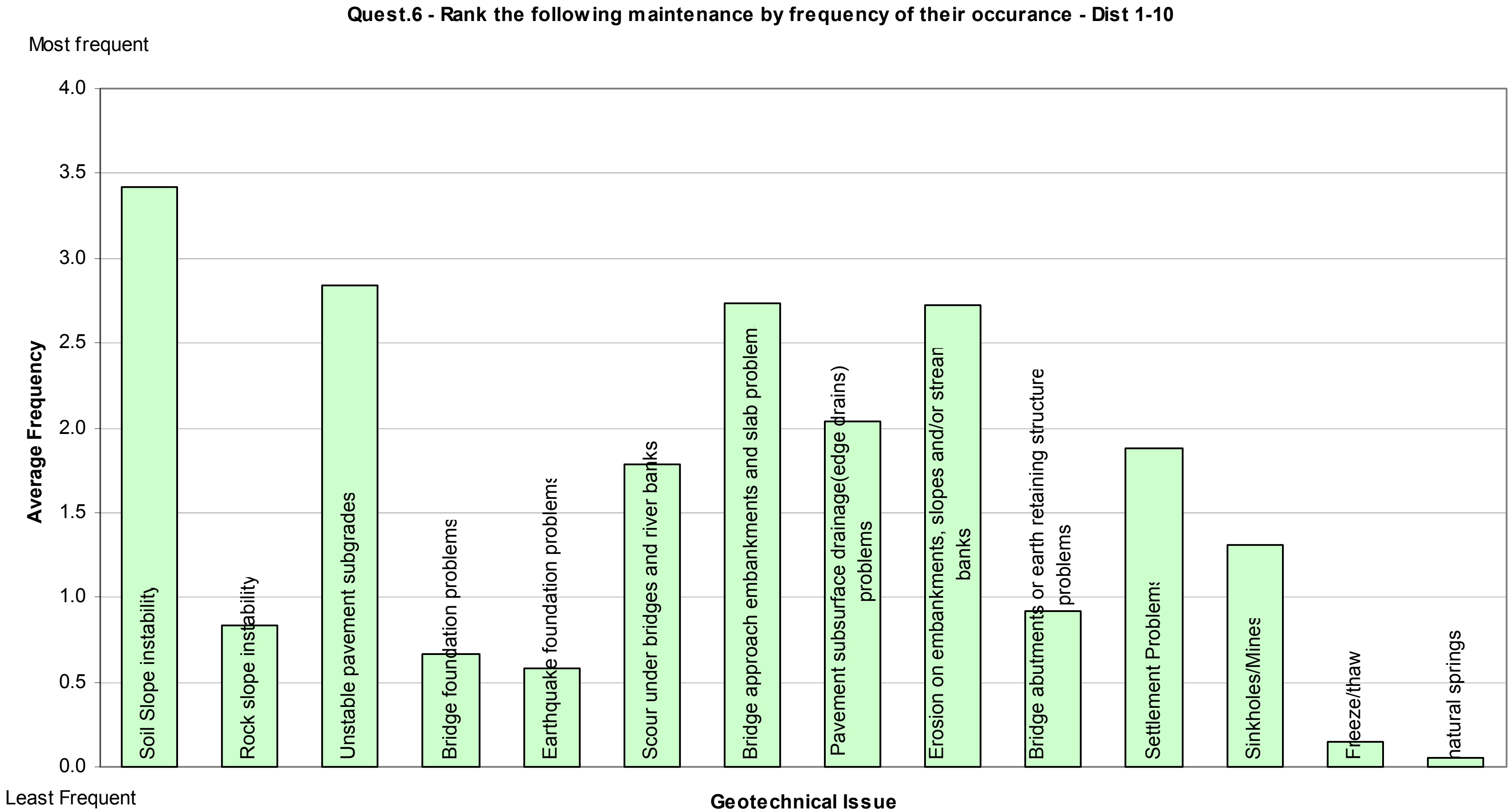
**MoDOT Surveys**
Not Complete

| | |
|---|---|
| Number of District Geologist (DG) | 10 |
| Number of (SCI) | 50 |
| Number of (CI) | 50 |
| Number of Operation Engineer (OE) | 20 |
| Number of Resident Engineer (RE) | 44 |
| Number of Area Engineer (AE) | 30 |
| Value for each response of District Geologist (DG) | 0.10 |
| Value for each response of (SCI) | 0.02 |
| Value for each response of (CI) | 0.02 |
| Value for each response of Operation Engineer (OE) | 0.05 |
| Value for each response of Resident Engineer (RE) | 0.02 |
| Value for each response of Area Engineer (AE) | 0.03 |

a= Soil Slope instability
b= Rock slope instability
c= Unstable pavement subgrades
d= Bridge foundation problems
e= Earthquake foundation problems
f= Scour under bridges and river banks
g= Bridge approach embankments and slab problems
h= Pavement subsurface drainage(edge drains) problems
I= Erosion on embankments, slopes and/or stream banks
j= Bridge abutments or earth retaining structure problems
k= Settlement Problems
l= Sinkholes/Mines
other m= have an inferior grade of rock being used for pavements
o= Freeze/thaw where loess is used as fill around culverts and causes buckling of overlying roadway
p= Gley Soils and Loess soils
q= natural springs
r= backfilling with high PI soils
s= Shrinkage/swelling of certain shale units and potentially some soil types
t= precast box culvert w/excess fill heights-drainage of rock fills-pinnacle rocks
u= mud seams in rock cuts

| Dist | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 6 | 6 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Title** | OE | OE | RE | RE | DG | AE | AE | AE | AE | DG | AE | DG | AE | AE | RE | DG | AE | AE | RE | DG | AE | RE | CI |
| **a** | 0.05 | 0.05 | 0.02 | 0.02 | 0.10 | 0.03 | 0.03 | 0.03 | 0.03 | 0.10 | 0.03 | 0.10 | 0.03 | 0.03 | 0.02 | 0.10 | 0.03 | 0.03 | 0.02 | 0.10 | 0.03 | 0.02 | 0.02 |
| **b** | | | | | | | | | | | 0.03 | | | | | | | | | 0.10 | 0.03 | | |
| **c** | 0.05 | | | 0.02 | 0.10 | 0.03 | 0.03 | 0.03 | | | 0.03 | 0.10 | 0.03 | 0.03 | 0.02 | 0.10 | | 0.03 | 0.02 | 0.10 | 0.03 | | |
| **d** | | | | | 0.10 | 0.03 | 0.03 | | | | | | | | 0.02 | 0.10 | 0.03 | | | 0.10 | | | |
| **e** | | | | | | | | | | | | | | | | | | | | 0.10 | 0.03 | | |
| **f** | 0.05 | 0.05 | 0.02 | 0.02 | 0.10 | | 0.03 | 0.03 | | 0.10 | 0.03 | | 0.03 | 0.03 | | 0.10 | 0.03 | | 0.02 | 0.10 | 0.03 | | |
| **g** | | 0.05 | 0.02 | 0.02 | | 0.03 | 0.03 | 0.03 | | 0.10 | 0.03 | 0.10 | 0.03 | 0.03 | 0.02 | 0.10 | 0.03 | | 0.02 | 0.10 | 0.03 | 0.02 | 0.02 |
| **h** | | 0.05 | 0.02 | | | 0.03 | 0.03 | 0.03 | 0.03 | 0.10 | 0.03 | 0.10 | 0.03 | 0.03 | 0.02 | 0.10 | 0.03 | 0.03 | 0.02 | 0.10 | 0.03 | | |
| **I** | 0.05 | 0.05 | 0.02 | 0.02 | 0.10 | 0.03 | 0.03 | 0.03 | 0.03 | 0.10 | 0.03 | | 0.03 | 0.03 | 0.02 | 0.10 | 0.03 | | | 0.10 | 0.03 | 0.02 | 0.02 |
| **j** | | | | | | | 0.03 | 0.03 | | | 0.03 | | | | 0.02 | | 0.03 | | | 0.10 | 0.03 | | 0.02 |
| **k** | 0.05 | | | | 0.10 | 0.03 | 0.03 | 0.03 | 0.03 | | 0.03 | | 0.03 | 0.03 | 0.02 | 0.10 | 0.03 | 0.03 | 0.02 | 0.10 | 0.03 | 0.02 | 0.02 |
| **l** | | | | | | | | | | | 0.03 | 0.10 | 0.03 | | | 0.10 | | | | 0.10 | 0.03 | | |
| **m** | 0.05 | | | | | | | | | | | | | | | | | | | | | | |
| **o** | | | | | 0.10 | | | | | | | | | | | | | | | | | | |
| **p** | | | | | | | | | | 0.10 | | | | | | | | | | | | | |
| **q** | | | | | | | | | | | | | | 0.03 | | | | | | | | | |
| **r** | | | | | | | | | | | | | | | 0.02 | | | | | | | | |
| **s** | | | | | | | | | | | | | | | | 0.10 | | | | | | | |
| **t** | | | | | | | | | | | | | | | | | | | | | | | |
| **u** | | | | | | | | | | | | | | | | | | | | | | | |

| Dist | 6 | 6 | 6 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Title** | RE | SCI | DG | AE | AE | DG | AE | RE | DG | AE | RE | RE | DG | AE | AE | AE | AE | RE | RE | RE | RE | DG | Total |
| **a** | 0.02 | 0.02 | 0.10 | 0.03 | 0.03 | 0.10 | 0.03 | 0.02 | | 0.03 | 0.02 | 0.02 | 0.10 | 0.03 | 0.03 | | 0.03 | 0.02 | 0.02 | | | 0.10 | 1.86 |
| **b** | | | 0.10 | | 0.03 | | | 0.02 | | | | | 0.10 | | | | | | | | | | 0.42 |
| **c** | 0.02 | | 0.10 | 0.03 | 0.03 | | | 0.02 | 0.10 | 0.03 | 0.02 | 0.02 | | 0.03 | 0.03 | 0.03 | | | 0.02 | | | 0.10 | 1.40 |
| **d** | | | | | | | | | | 0.03 | 0.02 | 0.02 | | | | 0.03 | | | | 0.02 | | | 0.56 |
| **e** | | | 0.10 | | | | | | | | 0.02 | 0.02 | 0.10 | | 0.03 | 0.03 | | 0.02 | | | | 0.10 | 0.57 |
| **f** | | | 0.10 | 0.03 | 0.03 | | 0.03 | | | 0.03 | 0.02 | | | 0.03 | 0.03 | | | | 0.02 | | | 0.10 | 1.25 |
| **g** | | 0.02 | 0.10 | | 0.03 | 0.10 | 0.03 | 0.02 | | 0.03 | 0.02 | 0.02 | 0.10 | | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.10 | 1.63 |
| **h** | | | 0.10 | 0.03 | 0.03 | | | | | 0.03 | 0.02 | 0.02 | | | | | | 0.02 | | | | 0.10 | 1.22 |
| **I** | 0.02 | 0.02 | 0.10 | | 0.03 | | 0.03 | 0.02 | | 0.03 | 0.02 | 0.02 | 0.10 | 0.03 | 0.03 | 0.03 | | | 0.02 | 0.02 | 0.02 | 0.10 | 1.59 |
| **j** | | 0.02 | | | | | | | | | | | | | | | | 0.02 | | | | | 0.35 |
| **k** | | 0.02 | 0.10 | | | | | 0.02 | | 0.03 | 0.02 | | | 0.03 | | 0.03 | | 0.02 | 0.02 | | | 0.10 | 1.18 |
| **l** | 0.02 | | 0.10 | | | 0.10 | 0.03 | | 0.10 | 0.03 | 0.02 | 0.02 | 0.10 | | | | | | | | 0.02 | 0.10 | 1.06 |
| **m** | | | | | | | | | | | | | | | | | | | | | | | 0.05 |
| **o** | | | | | | | | | | | | | | | | | | | | | | | 0.10 |
| **p** | | | | | | | | | | | | | | | | | | | | | | | 0.10 |
| **q** | | | | | | | | | | | | | | | | | | | | | | | 0.03 |
| **r** | | | | | | | | | | | | | | | | | | | | | | | 0.02 |
| **s** | | | | | | | | | | | | | | | | | | | | | | | 0.10 |
| **t** | | | | | 0.03 | | | | | | | | | | | | | | | | | | 0.03 |
| **u** | | | | | | | 0.03 | | | | | | | | | | | | | | | | 0.03 |


Quest.6 - Rank the following maintenance by frequency of their occurance - Dist 1-10
Most frequent
Least Frequent
Average Frequency
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Soil Slope instability
Rock slope instability
Unstable pavement subgrades
Bridge foundation problems
Earthquake foundation problems
Scour under bridges and river banks
Bridge approach embankments and slab problem
Pavement subsurface drainage(edge drains) problems
Erosion on embankments, slopes and/or stream banks
Bridge abutments or earth retaining structure problems
Settlement Problems
Sinkholes/Mines
Freeze/thaw
natural springs
Geotechnical Issue

**Frequency of Responses to Question 6**
Date Completed:

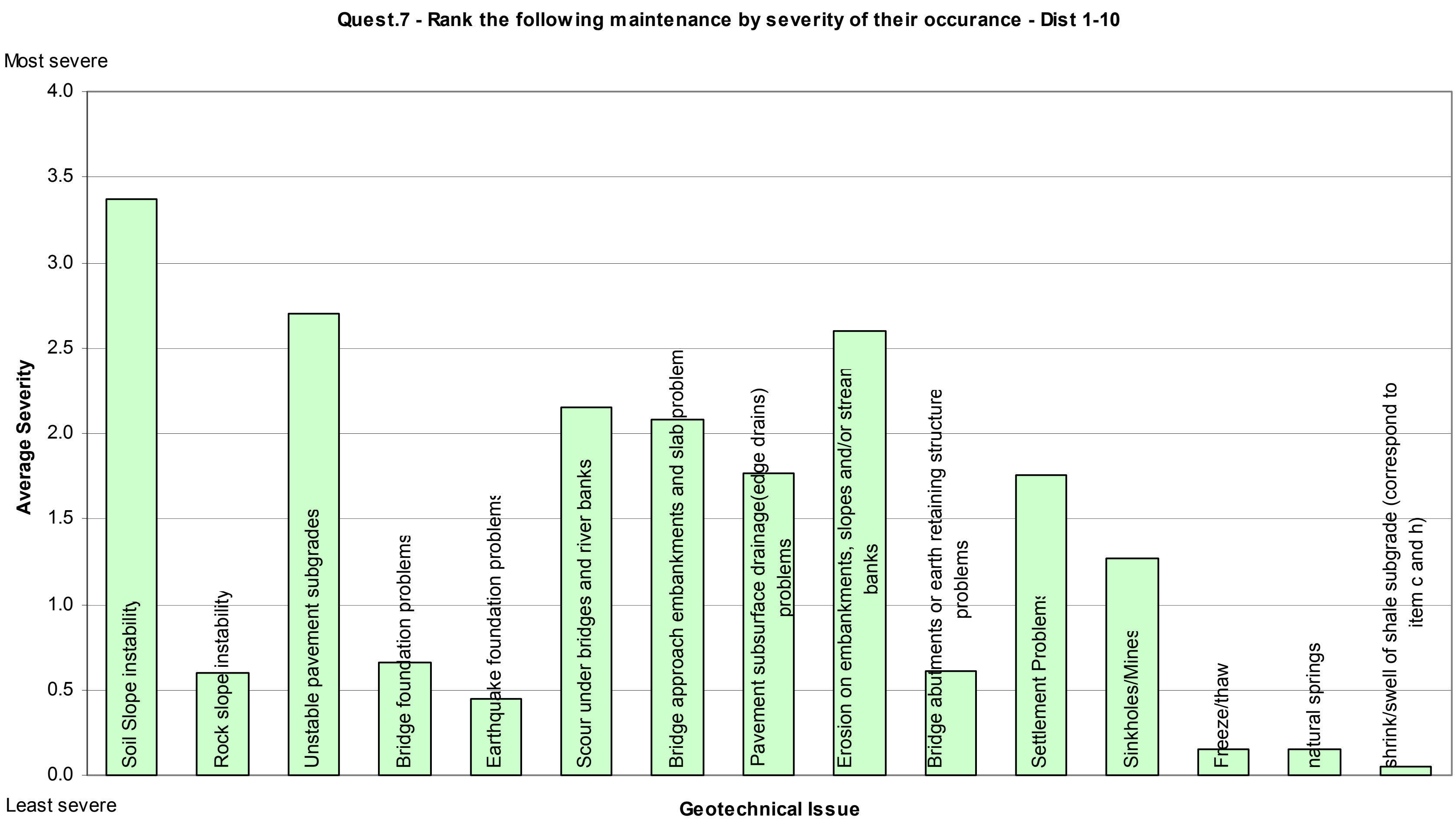
**MoDOT Surveys**
Not Complete

| | |
|---|---|
| Number of District Geologist (DG) | 10 |
| Number of (SCI) | 50 |
| Number of (CI) | 50 |
| Number of Operation Engineer (OE) | 20 |
| Number of Resident Engineer (RE) | 44 |
| Number of Area Engineer (AE) | 30 |
| Value for each response of District Geologist (DG) | 0.10 |
| Value for each response of (SCI) | 0.02 |
| Value for each response of (CI) | 0.02 |
| Value for each response of Operation Engineer (OE) | 0.05 |
| Value for each response of Resident Engineer (RE) | 0.02 |
| Value for each response of Area Engineer (AE) | 0.03 |

a= Soil Slope instability
b= Rock slope instability
c= Unstable pavement subgrades
d= Bridge foundation problems
e= Earthquake foundation problems
f= Scour under bridges and river banks
g= Bridge approach embankments and slab problems
h= Pavement subsurface drainage(edge drains) problems
I= Erosion on embankments, slopes and/or stream banks
j= Bridge abutments or earth retaining structure problems
k= Settlement Problems
l= Sinkholes/Mines
other m= Freeze/thaw
o= natural springs

| Dist | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Title | OE | OE | RE | RE | DG | AE | AE | AE | AE | DG | AE | DG | AE | AE | RE | DG | AE | AE | RE | DG | AE | RE | CI | SCI | OE | DG | AE | AE | DG | AE | RE | DG | AE | RE | RE | DG | AE | AE | AE | AE | RE | RE | RE | DG |
| a | 4 | 4 | 4 | 3 | 5 | 3 | 5 | 4 | 2 | 5 | 5 | 3 | 4 | 5 | 1 | 5 | 3 | 2 | 4 | 2 | 0 | 5 | 5 | 5 | 3 | 5 | 2 | 5 | 3 | 3 | 4 | 0 | 3 | 5 | 2 | 3 | 2 | 1 | 4 | 2 | 3 | 5 | 2 | 3 |
| b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 1 | 1 | 1 | 3 | 1 | 0 | 4 | 1 | 1 | 4 | 0 | 0 | 2 | 1 | 3 | 0 | 0 | 4 | 0 | 0 | 0 | 1 | 0 |
| c | 4 | 3 | 0 | 1 | 2 | 4 | 3 | 3 | 3 | 3 | 4 | 2 | 4 | 3 | 2 | 3 | 4 | 4 | 4 | 4 | 5 | 3 | 2 | 2 | 4 | 3 | 2 | 3 | 3 | 1 | 2 | 3 | 4 | 3 | 2 | 0 | 5 | 0 | 4 | 3 | 4 | 4 | 1 | 2 |
| d | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 |
| e | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 3 | 2 | 0 | 0 | 0 | 5 | 4 | 0 | 1 | 0 |
| f | 5 | 4 | 5 | 4 | 5 | 0 | 4 | 4 | 3 | 1 | 2 | 1 | 1 | 3 | 0 | 0 | 0 | 3 | 3 | 2 | 1 | 2 | 0 | 0 | 2 | 0 | 1 | 2 | 1 | 3 | 0 | 0 | 5 | 3 | 1 | 0 | 3 | 0 | 3 | 2 | 0 | 1 | 2 | 2 |
| g | 0 | 5 | 3 | 5 | 0 | 5 | 3 | 3 | 4 | 1 | 4 | 3 | 2 | 5 | 4 | 0 | 1 | 3 | 4 | 3 | 2 | 4 | 5 | 4 | 2 | 4 | 0 | 5 | 2 | 3 | 4 | 2 | 5 | 4 | 3 | 3 | 0 | 1 | 4 | 4 | 3 | 2 | 1 | 5 |
| h | 0 | 3 | 3 | 1 | 0 | 3 | 4 | 1 | 2 | 2 | 4 | 0 | 3 | 5 | 0 | 4 | 1 | 4 | 3 | 4 | 3 | 3 | 0 | 0 | 3 | 3 | 1 | 5 | 2 | 1 | 0 | 3 | 4 | 3 | 4 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 1 |
| I | 5 | 0 | 0 | 3 | 4 | 5 | 4 | 4 | 3 | 5 | 4 | 1 | 4 | 4 | 3 | 0 | 0 | 3 | 2 | 3 | 2 | 5 | 5 | 4 | 3 | 5 | 0 | 4 | 1 | 3 | 3 | 0 | 5 | 4 | 5 | 4 | 0 | 0 | 0 | 2 | 0 | 3 | 3 | 3 |
| j | 2 | 0 | 2 | 0 | 0 | 2 | 2 | 3 | 2 | 2 | 3 | 0 | 0 | 2 | 3 | 0 | 3 | 3 | 0 | 1 | 2 | 3 | 3 | 2 | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 |
| k | 0 | 3 | 1 | 0 | 2 | 2 | 2 | 3 | 2 | 3 | 3 | 1 | 1 | 5 | 3 | 2 | 3 | 3 | 3 | 1 | 2 | 4 | 5 | 4 | 3 | 1 | 0 | 0 | 2 | 1 | 1 | 2 | 4 | 3 | 1 | 0 | 4 | 0 | 0 | 3 | 1 | 0 | 1 | 2 |
| l | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 4 | 3 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 3 | 0 | 5 | 2 | 1 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| m | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Dist | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | Total Resp | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Title | OE | OE | RE | RE | DG | AE | AE | AE | AE | DG | AE | DG | AE | AE | RE | DG | AE | AE | RE | DG | AE | RE | CI | SCI | OE | DG | AE | AE | DG | AE | RE | DG | AE | RE | RE | DG | AE | AE | AE | AE | RE | RE | RE | DG | Total | Multiplier | Avg |
| a | 0.20 | 0.20 | 0.09 | 0.07 | 0.50 | 0.10 | 0.17 | 0.13 | 0.07 | 0.50 | 0.17 | 0.30 | 0.13 | 0.17 | 0.02 | 0.50 | 0.10 | 0.07 | 0.09 | 0.20 | 0.00 | 0.11 | 0.10 | 0.10 | 0.15 | 0.50 | 0.07 | 0.17 | 0.30 | 0.10 | 0.09 | 0.00 | 0.10 | 0.11 | 0.05 | 0.30 | 0.07 | 0.03 | 0.13 | 0.07 | 0.07 | 0.11 | 0.05 | 0.30 | 6.85 | 2.04 | 3.36 |
| b | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.10 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.13 | 0.02 | 0.02 | 0.02 | 0.15 | 0.10 | 0.00 | 0.13 | 0.10 | 0.03 | 0.09 | 0.00 | 0.00 | 0.05 | 0.02 | 0.30 | 0.00 | 0.00 | 0.13 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 1.66 | 2.04 | 0.81 |
| c | 0.20 | 0.15 | 0.00 | 0.02 | 0.20 | 0.13 | 0.10 | 0.10 | 0.10 | 0.30 | 0.13 | 0.20 | 0.13 | 0.10 | 0.05 | 0.30 | 0.13 | 0.13 | 0.09 | 0.40 | 0.17 | 0.07 | 0.04 | 0.04 | 0.20 | 0.30 | 0.07 | 0.10 | 0.30 | 0.03 | 0.05 | 0.30 | 0.13 | 0.07 | 0.05 | 0.00 | 0.17 | 0.00 | 0.13 | 0.10 | 0.09 | 0.09 | 0.02 | 0.20 | 5.69 | 2.04 | 2.79 |
| d | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.07 | 0.03 | 0.07 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.20 | 0.10 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.03 | 0.00 | 0.00 | 0.10 | 0.05 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.02 | 0.00 | 1.34 | 2.04 | 0.66 |
| e | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.07 | 0.02 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.07 | 0.20 | 0.00 | 0.00 | 0.00 | 0.17 | 0.09 | 0.00 | 0.02 | 0.00 | 1.16 | 2.04 | 0.57 |
| f | 0.25 | 0.20 | 0.11 | 0.09 | 0.50 | 0.00 | 0.13 | 0.13 | 0.10 | 0.10 | 0.07 | 0.10 | 0.03 | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 | 0.07 | 0.20 | 0.03 | 0.05 | 0.00 | 0.00 | 0.10 | 0.00 | 0.03 | 0.07 | 0.10 | 0.10 | 0.00 | 0.00 | 0.17 | 0.07 | 0.02 | 0.00 | 0.10 | 0.00 | 0.10 | 0.07 | 0.00 | 0.02 | 0.05 | 0.20 | 3.56 | 2.04 | 1.75 |
| g | 0.00 | 0.25 | 0.07 | 0.11 | 0.00 | 0.17 | 0.10 | 0.10 | 0.13 | 0.10 | 0.13 | 0.30 | 0.07 | 0.17 | 0.09 | 0.00 | 0.03 | 0.10 | 0.09 | 0.30 | 0.07 | 0.09 | 0.10 | 0.08 | 0.10 | 0.40 | 0.00 | 0.17 | 0.20 | 0.10 | 0.09 | 0.20 | 0.17 | 0.09 | 0.07 | 0.30 | 0.00 | 0.03 | 0.13 | 0.13 | 0.07 | 0.05 | 0.02 | 0.50 | 5.47 | 2.04 | 2.68 |
| h | 0.00 | 0.15 | 0.07 | 0.02 | 0.00 | 0.10 | 0.13 | 0.03 | 0.07 | 0.20 | 0.13 | 0.00 | 0.10 | 0.17 | 0.00 | 0.40 | 0.03 | 0.13 | 0.07 | 0.40 | 0.10 | 0.07 | 0.00 | 0.00 | 0.15 | 0.30 | 0.03 | 0.17 | 0.20 | 0.03 | 0.00 | 0.30 | 0.13 | 0.07 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.07 | 0.00 | 0.02 | 0.10 | 4.08 | 2.04 | 2.00 |
| I | 0.25 | 0.00 | 0.00 | 0.07 | 0.40 | 0.17 | 0.13 | 0.13 | 0.10 | 0.50 | 0.13 | 0.10 | 0.13 | 0.13 | 0.07 | 0.00 | 0.00 | 0.10 | 0.05 | 0.30 | 0.07 | 0.11 | 0.10 | 0.08 | 0.15 | 0.50 | 0.00 | 0.13 | 0.10 | 0.10 | 0.07 | 0.00 | 0.17 | 0.09 | 0.11 | 0.40 | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.07 | 0.07 | 0.30 | 5.45 | 2.04 | 2.67 |
| j | 0.10 | 0.00 | 0.05 | 0.00 | 0.00 | 0.07 | 0.07 | 0.10 | 0.07 | 0.20 | 0.10 | 0.00 | 0.00 | 0.07 | 0.07 | 0.00 | 0.10 | 0.10 | 0.00 | 0.10 | 0.07 | 0.07 | 0.06 | 0.04 | 0.05 | 0.00 | 0.00 | 0.00 | 0.20 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.02 | 0.00 | 1.84 | 2.04 | 0.90 |
| k | 0.00 | 0.15 | 0.02 | 0.00 | 0.20 | 0.07 | 0.07 | 0.10 | 0.07 | 0.30 | 0.10 | 0.10 | 0.03 | 0.17 | 0.07 | 0.20 | 0.10 | 0.10 | 0.07 | 0.10 | 0.07 | 0.09 | 0.10 | 0.08 | 0.15 | 0.10 | 0.00 | 0.00 | 0.20 | 0.03 | 0.02 | 0.20 | 0.13 | 0.07 | 0.02 | 0.00 | 0.13 | 0.00 | 0.00 | 0.10 | 0.02 | 0.00 | 0.02 | 0.20 | 3.76 | 2.04 | 1.84 |
| l | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.10 | 0.13 | 0.30 | 0.03 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.20 | 0.07 | 0.05 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.20 | 0.10 | 0.00 | 0.50 | 0.07 | 0.02 | 0.02 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.20 | 2.63 | 2.04 | 1.29 |
| m | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 2.04 | 0.15 |
| o | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 2.04 | 0.05 |



Quest.7 - Rank the following maintenance by severity of their occurance - Dist 1-10
Most severe
Least severe
Average Severity
Geotechnical Issue
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Soil Slope instability
Rock slope instability
Unstable pavement subgrades
Bridge foundation problems
Earthquake foundation problems
Scour under bridges and river banks
Bridge approach embankments and slab problem
Pavement subsurface drainage(edge drains) problems
Erosion on embankments, slopes and/or stream banks
Bridge abutments or earth retaining structure problems
Settlement Problems
Sinkholes/Mines
Freeze/thaw
natural springs
shrink/swell of shale subgrade (correspond to item c and h)

**Frequency of Responses to Question 7**

Date Completed:

**MoDOT Surveys**

Not Complete

| | |
|---|---|
| Number of District Geologist (DG) | 10 |
| Number of (SCI) | 50 |
| Number of (CI) | 50 |
| Number of Operation Engineer (OE) | 20 |
| Number of Resident Engineer (RE) | 44 |
| Number of Area Engineer (AE) | 30 |
| Value for each response of District Geologist (DG) | 0.10 |
| Value for each response of (SCI) | 0.02 |
| Value for each response of (CI) | 0.02 |
| Value for each response of Operation Engineer (OE) | 0.05 |
| Value for each response of Resident Engineer (RE) | 0.02 |
| Value for each response of Area Engineer (AE) | 0.03 |

a= Soil Slope instability
b= Rock slope instability
c= Unstable pavement subgrades
d= Bridge foundation problems
e= Earthquake foundation problems
f= Scour under bridges and river banks
g= Bridge approach embankments and slab problems
h= Pavement subsurface drainage(edge drains) problems
I= Erosion on embankments, slopes and/or stream banks
j= Bridge abutments or earth retaining structure problems
k= Settlement Problems
l= Sinkholes/Mines
other m= Freeze/thaw
o= natural springs
p= shrink/swell of shale subgrade (correspond to item c and h)

| Dist | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Title | OE | OE | RE | RE | DG | OE | RE | OE | RE | DG | AE | DG | AE | AE | RE | DG | AE | AE | RE | DG | AE | RE | CI | SCI | RE | DG | AE | AE | DG | AE | RE | DG | AE | RE | RE | DG | AE | AE | AE | AE | RE | RE | RE | DG |
| a | 2 | 4 | 5 | 5 | 5 | 2 | 4 | 5 | 5 | 5 | 5 | 3 | 4 | 5 | 1 | 5 | 3 | 2 | 4 | 2 | 5 | 5 | 5 | 5 | 2 | 3 | 3 | 5 | 3 | 2 | 3 | 0 | 4 | 4 | 3 | 0 | 4 | 1 | 4 | 4 | 5 | 4 | 1 | 3 |
| b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 1 | 1 | 1 | 4 | 1 | 0 | 5 | 1 | 1 | 3 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 1 | 0 |
| c | 4 | 5 | 2 | 1 | 2 | 4 | 5 | 2 | 1 | 2 | 4 | 2 | 4 | 3 | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 2 | 4 | 3 | 3 | 3 | 3 | 1 | 0 | 0 | 4 | 3 | 2 | 0 | 5 | 0 | 5 | 3 | 4 | 4 | 1 | 2 |
| d | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 2 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 1 | 0 |
| e | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 5 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 5 | 1 | 0 |
| f | 5 | 2 | 4 | 3 | 5 | 5 | 2 | 4 | 3 | 5 | 2 | 1 | 1 | 3 | 0 | 0 | 0 | 3 | 3 | 2 | 3 | 3 | 0 | 0 | 1 | 0 | 1 | 4 | 2 | 3 | 0 | 0 | 5 | 3 | 2 | 0 | 2 | 0 | 3 | 3 | 2 | 0 | 1 | 2 |
| g | 0 | 3 | 0 | 4 | 0 | 0 | 3 | 0 | 4 | 0 | 4 | 3 | 2 | 5 | 4 | 0 | 1 | 3 | 4 | 3 | 4 | 3 | 5 | 4 | 3 | 0 | 0 | 3 | 2 | 3 | 3 | 0 | 5 | 4 | 3 | 3 | 0 | 1 | 4 | 3 | 1 | 2 | 1 | 5 |
| h | 0 | 3 | 1 | 5 | 0 | 0 | 3 | 1 | 5 | 0 | 4 | 0 | 3 | 5 | 0 | 4 | 1 | 4 | 3 | 4 | 3 | 3 | 0 | 0 | 4 | 3 | 3 | 3 | 2 | 1 | 0 | 0 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 2 | 0 | 4 | 1 | 1 |
| I | 5 | 0 | 3 | 5 | 4 | 5 | 0 | 3 | 5 | 4 | 4 | 1 | 4 | 4 | 3 | 0 | 0 | 3 | 2 | 3 | 4 | 4 | 5 | 4 | 0 | 4 | 0 | 5 | 2 | 2 | 0 | 0 | 4 | 3 | 4 | 3 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 3 |
| j | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 2 | 3 | 0 | 3 | 3 | 0 | 1 | 3 | 3 | 3 | 2 | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 |
| k | 3 | 4 | 1 | 0 | 2 | 3 | 4 | 1 | 0 | 2 | 3 | 1 | 1 | 5 | 3 | 2 | 3 | 3 | 3 | 1 | 4 | 4 | 5 | 4 | 4 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 3 | 4 | 1 | 0 | 3 | 0 | 0 | 4 | 0 | 1 | 1 | 2 |
| l | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 3 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 3 | 0 | 5 | 2 | 1 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| m | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| p | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Dist | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | Total Resp | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Title | OE | OE | RE | RE | DG | OE | RE | OE | RE | DG | AE | DG | AE | AE | RE | DG | AE | AE | RE | DG | AE | RE | CI | SCI | RE | DG | AE | AE | DG | AE | RE | DG | AE | RE | RE | DG | AE | AE | AE | AE | RE | RE | RE | DG | Total | Multiplier | Avg |
| a | 0.10 | 0.20 | 0.11 | 0.11 | 0.50 | 0.10 | 0.09 | 0.25 | 0.11 | 0.50 | 0.17 | 0.30 | 0.13 | 0.17 | 0.02 | 0.50 | 0.10 | 0.07 | 0.09 | 0.20 | 0.17 | 0.11 | 0.10 | 0.10 | 0.05 | 0.30 | 0.10 | 0.17 | 0.30 | 0.07 | 0.07 | 0.00 | 0.13 | 0.09 | 0.07 | 0.00 | 0.13 | 0.03 | 0.13 | 0.13 | 0.11 | 0.09 | 0.02 | 0.30 | 6.61 | 2.0 | 3.37 |
| b | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.17 | 0.02 | 0.02 | 0.02 | 0.09 | 0.10 | 0.00 | 0.17 | 0.10 | 0.03 | 0.07 | 0.00 | 0.00 | 0.05 | 0.02 | 0.00 | 0.00 | 0.00 | 0.13 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 1.18 | 2.0 | 0.60 |
| c | 0.20 | 0.25 | 0.05 | 0.02 | 0.20 | 0.20 | 0.11 | 0.10 | 0.02 | 0.20 | 0.13 | 0.20 | 0.13 | 0.10 | 0.05 | 0.30 | 0.13 | 0.13 | 0.09 | 0.40 | 0.13 | 0.05 | 0.04 | 0.04 | 0.09 | 0.30 | 0.10 | 0.10 | 0.30 | 0.03 | 0.00 | 0.00 | 0.13 | 0.07 | 0.05 | 0.00 | 0.17 | 0.00 | 0.17 | 0.10 | 0.09 | 0.09 | 0.02 | 0.20 | 5.29 | 2.0 | 2.70 |
| d | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.20 | 0.07 | 0.07 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.20 | 0.03 | 0.00 | 0.00 | 0.00 | 0.02 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.00 | 0.02 | 0.00 | 1.30 | 2.0 | 0.66 |
| e | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.07 | 0.07 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.11 | 0.02 | 0.00 | 0.88 | 2.0 | 0.45 |
| f | 0.25 | 0.10 | 0.09 | 0.07 | 0.50 | 0.25 | 0.05 | 0.20 | 0.07 | 0.50 | 0.07 | 0.10 | 0.03 | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 | 0.07 | 0.20 | 0.10 | 0.07 | 0.00 | 0.00 | 0.02 | 0.00 | 0.03 | 0.13 | 0.20 | 0.10 | 0.00 | 0.00 | 0.17 | 0.07 | 0.05 | 0.00 | 0.07 | 0.00 | 0.10 | 0.10 | 0.05 | 0.00 | 0.02 | 0.20 | 4.21 | 2.0 | 2.15 |
| g | 0.00 | 0.15 | 0.00 | 0.09 | 0.00 | 0.00 | 0.07 | 0.00 | 0.09 | 0.00 | 0.13 | 0.30 | 0.07 | 0.17 | 0.09 | 0.00 | 0.03 | 0.10 | 0.09 | 0.30 | 0.13 | 0.07 | 0.10 | 0.08 | 0.07 | 0.00 | 0.00 | 0.10 | 0.20 | 0.10 | 0.07 | 0.00 | 0.17 | 0.09 | 0.07 | 0.30 | 0.00 | 0.03 | 0.13 | 0.10 | 0.02 | 0.05 | 0.02 | 0.50 | 4.08 | 2.0 | 2.08 |
| h | 0.00 | 0.15 | 0.02 | 0.11 | 0.00 | 0.00 | 0.07 | 0.05 | 0.11 | 0.00 | 0.13 | 0.00 | 0.10 | 0.17 | 0.00 | 0.40 | 0.03 | 0.13 | 0.07 | 0.40 | 0.10 | 0.07 | 0.00 | 0.00 | 0.09 | 0.30 | 0.10 | 0.10 | 0.20 | 0.03 | 0.00 | 0.00 | 0.10 | 0.07 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.09 | 0.02 | 0.10 | 3.46 | 2.0 | 1.76 |
| I | 0.25 | 0.00 | 0.07 | 0.11 | 0.40 | 0.25 | 0.00 | 0.15 | 0.11 | 0.40 | 0.13 | 0.10 | 0.13 | 0.13 | 0.07 | 0.00 | 0.00 | 0.10 | 0.05 | 0.30 | 0.13 | 0.09 | 0.10 | 0.08 | 0.00 | 0.40 | 0.00 | 0.17 | 0.20 | 0.07 | 0.00 | 0.00 | 0.13 | 0.07 | 0.09 | 0.30 | 0.00 | 0.00 | 0.00 | 0.10 | 0.07 | 0.00 | 0.05 | 0.30 | 5.10 | 2.0 | 2.60 |
| j | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.07 | 0.07 | 0.00 | 0.10 | 0.10 | 0.00 | 0.10 | 0.10 | 0.07 | 0.06 | 0.04 | 0.02 | 0.00 | 0.00 | 0.00 | 0.20 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.02 | 0.00 | 1.20 | 2.0 | 0.61 |
| k | 0.15 | 0.20 | 0.02 | 0.00 | 0.20 | 0.15 | 0.09 | 0.05 | 0.00 | 0.20 | 0.10 | 0.10 | 0.03 | 0.17 | 0.07 | 0.20 | 0.10 | 0.10 | 0.07 | 0.10 | 0.13 | 0.09 | 0.10 | 0.08 | 0.09 | 0.00 | 0.00 | 0.00 | 0.10 | 0.03 | 0.02 | 0.00 | 0.10 | 0.09 | 0.02 | 0.00 | 0.10 | 0.00 | 0.00 | 0.13 | 0.00 | 0.02 | 0.02 | 0.20 | 3.44 | 2.0 | 1.76 |
| l | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.13 | 0.30 | 0.03 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.20 | 0.10 | 0.05 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.30 | 0.10 | 0.00 | 0.50 | 0.07 | 0.02 | 0.02 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.20 | 2.49 | 2.0 | 1.27 |
| m | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 2.0 | 0.15 |
| o | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 2.0 | 0.15 |
| p | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 2.0 | 0.05 |

## Appendix C – REFERENCES - BRIDGE APPROACH SLABS (BAS)


Aggour, M.S., Wolde-Tinsae, A.M., (1990). "Structural and Soil Provisions for Approaches to Bridges. Final Report. Executive Summary." Federal Highway Administration, Maryland Department of Transportation State Highway Administration, Washington D.C., June, 16.

Allen, D.L., Hopkins, T.C., Meade, B.W., (1985). "Analysis of Movements and Forces on Bridge Approaches: A Case Study (Bridge Over Chesapeake Ave. on Interstate 471 in Campbell County, Kentucky)." Federal Highway Administration, Kentucky Transportation Cabinet, Washington D.C., April, 85.

"An Evaluation of Bridge Approach Design and Construction Techniques." (1976). Federal Highway Administration National Technical Information Service, Dec., 58.

Armbruster, J.,Garcia, M.H.,Troy, C.D.,Yen, B.C., (1998). "Stream Channel Migration Effects on Bridge Approaches and Conveyance." Illinois Transportation Research Center, IL., Dept. of Civil Engineering, Illinois University, Urbana-Champaign, IL., Aug., 161.

Benak, J.V., Tadros, M.K., (1989). "Bridge Abutment and Approach Slab Settlement. Phase 1. Final Report." Nebraska Department of Roads, Lincoln, Nebraska, Lincoln College of Engineering and Technology, Nebraska University, Lincoln, Nebraska, December.

Briaud, J-L., Hoffman, S.B., James, R.W., (1997). "Settlement of Bridge Approaches ( The Bump at the End of the Bridge)." *NCHRP Synthesis of Highway Practice*. (No. 234), 81.

"Bridge Approach Design and Construction Practices." (00/00/0000). *Hrb Nchrp Synthesis of Hwy Practice*.

"Bridge Approach Pavements, Integral Bridges, and Cycle-Control Joints." (1987). *Transportation Research Record*. (No. 1113), 54-65.

"Bridge engineering handbook / edited by Wai-Fah Chen and Lian Duan." (2000). CRC Press, Boca Raton, Fla.

Bruner, R.F., James, R.W., Thompson, L.J., Xin, D., Zhang, H., Zollinger, D.G., (1991). "A Study of Bridge Approach Roughness. Final Report." Federal Highway Administration, Texas Department of Transportation, Washington D.C., Texas Transportation Institute, TX., 120.

Dadik, M., Sundaram, S., (1997). "Bridge Approach/Anchor Slab Joint Evaluation." Arizona Department of Transportation, Washington D.C., Federal Highway Administration, Sundaram Engineering, Incorporated, AZ., July, 57.

Deen, R.C., Hopkins, T.C., (1970). "The Bump At the End of the Bridge." *Highway Research Record, Hwy Res Board*.

"Design and Construction of Bridge Approaches." (1990). *NCHRP Synthesis of Highway*

*Practice*. (No. 159; July), 51.

"Drainage and Backfill Provisions for Approaches to Bridges." (1993). *Transportation Research Record*. (No. 1425), 45-53.


"An Evaluation of Bridge Approach Design and Construction Techniques." (1976). Federal Highway Administration National Technical Information Service, Dec., 58.


"Evaluation of Design Changes and Experimental PCC Construction Features. Final Report." (1987). July, 112.

"Geotextiles Eliminate Approach Slab Settlement." (1986). *Public Works*. 117(No. 1; January), 58-59.

Gopalasingam, A., Laguros, J.G., Zaman, M., (1991). "Consolidation Settlement of Bridge Approach Foundation." *Journal of Geotechnical Engineering*. 117(No. 2; Feb.), American Society of Civil Engineers, NY., 219-240.

Hopkins, T.C., (1973). "Settlement of Highway Bridge Approaches and Embankment Foundations, Bluegrass Parkway Bridges Over Chaplin River." Kentucky Department Highways, Feb., 39.

Kemahli, A.S., (1971). "A Different Approach to Bridge Approach Slabs." *Highway Focus*. 3(No. 3; Aug.), 23-8.

Koch, J.C., Schaefer, V.R., (1992). "Void Development Under Bridge Approaches. Final Report." Federal Highway Administration, South Dakota Department of Transportation, Washington D.C., Nov., 257.

Kramer, S.L., Sajer, P., (1991). "Bridge Approach Slab Effectiveness. Final Report." Federal Highway Administration, Washington State Department of Transportation, D.C., Washington University, Seattle, WA., 235

"Long – Term Movements of Highway Bridge Approach Embankments and Pavements. Final Report." (1985). Federal Highway Administration, April, 149.

National Research Council (U.S.). Highway Research Board., (1969). "Bridge approach design and construction practices." Washington.

McNulty, E.G., (1979). "Corrective Measures for Unstable Bridge-Approach Embankment US 68, Licking River, Blue Licks." Federal Highway Administration, Washington, D.C., Kentucky Department of Transportation, KY., Nov., 63.

Monley, G.J.,Wu, J.T.H., (1993). "Tensile Reinforcement Effects on Bridge-Approach Settlement." *Journal of Geotechnical Engineering*. 119(No. 4; April), American Society of Civil Engineers, NY., 749-762.

Ojha, Surendra K., (1994). "Techniques to Identify Repairs for Bridge Approaches." *Publuc Works*. 125(No. 2; Feb.), 42-43.

"A Survey of the States on Problems Related to Bridge Approaches. Interim Report." (1985). Federal Highway Administration, Oct., 188.

Troitsky, M.S., (1994). "Planning and Design of Bridges." Wiley (John) and Sons, Incorporated, New York, NY., 318.

Wahls, Harvey E., (1990). "Design and construction of bridge approaches." Transportation Research Board, National Research Council, 1990, Washington, D.C., July.

Watkins, J.E.,Webster, S.L., (1977). "Investigation of Construction Techniques for Tactical Bridge Approach Roads Across Soft Ground." U.S. Waterways Experiment Station, Vicksburg, MI., Feb., 75.

Yee, W.S., (1974). "Long Term Settlement Study at Bridge Approaches (North Maxwell)." California Department of Transportation, CA., Dec., 21.

## Appendix D - REFERENCES – PAVEMENT EDGE DRAINS (PED)


Allen, D. L., and J. Fleckenstein (1996) "Evaluation and Performance of Geocomposite Edge Drains in Kentucky", Transportation Research Record 1329, National Academy Press, Washington, D.C.

Baldwin, J. S. (1991, January 13-17) "Evaluation of Interstate 77 Pumping Pavement", Transportation Research Board 70th Annual Meeting, Washington, D.C.

Baldwin, J. S. (1996) "Evaluation of Pumping Pavement on Interstate 77", Transportation Research Record 1329, National Academy Press, Washington, D.C.

Bhatia S. K., and L. D. Suits (Eds) (1995, June) "Recent Developments in Geotextile Filters and Prefabribated Drainage Geocomposites", ASTM

Christopher, B. R., and V. C. McGuffey (1997) "Pavement Subsurface Drainage Systems", Synthesis of Highway Practice 239, National Academy Press, Washington, D.C., pp. 1-44

Daleiden, J. F., and L. L. Peirce (1997) "Subsurface Drainage Systems in Roadway Construction", Transportation Research Record 1596, National Research Council, Washington, D.C., pp. 58-61

DeBerardino, S. J. (1995, April) "Highway edge-drain system proves effective", Geotechnical Fabrics Report, pp. 18-19

Dempsey, B. J. (1988) "Core Flow-Capacity Requirements of Geocomposite Fin-Drain Materials Used in Pavement Subdrainage", Transportation Research Record 1159, National Research Council, Washington, D.C., pp. 21-29

Dolph, D., and L. K. Heinig (1991, January) "A Summary of the Development of Open Graded Drainage Course and Fin Drains in Michigan"

Dolph, D., and L. K. Heinig (1991, January) "Michigan's Use of Fin Drains in its PCC Pavement and Recycling Programs for Presentation at TRB Committee A2K06"

Fleckenstein, L. J., and D. L. Allen (1996) "Evaluation of Pavement Edge Drains and Their Effect on Pavement Performance", Transportation Research Record 1519, National Academy Press, Washington, D.C., pp. 28-35

Frobel, R. K. (1996) "Eccentric (Angled) Loading of Prefabricated Highway Edge Drains", Transportation Research Record 1329, National Academy Press, Washington, D.C.

Goddard, J. B. (1996) "Geocomposite Edge Drain System Design", Transportation Research Record 1329, National Academy Press, Washington, D.C.

Highlands, K. L., R. Turgeon, and G. L. Hoffman (1996) "Prefabricated Pavement Base Drain", Transportation Research Record 1329, National Academy Press, Washington, D.C.

Hinshaw, K. T. (1988) "Hydraway Edgedrain Experience in Ohio", Transportation Research Record 1159, National Academy Press, Washington, D.C., pp. 30-35

Hurd, J. O., and H. Bunchack (1996) "Transverse Pipe Underdrains for Highway Groundwater Control", Transportation Research Record 1329, National Academy Press, Washington, D.C.

Hurd, J. O., and H. Dunchack (1990, April) "Transverse Pipe Underdrains for Highway Ground Water Control: A Case History"

Koerner, R. M., and B-L Hwu (1991) "Prefabricated Highway Edge Drains", Transportation Research Record 1329, National Research Council, Washington, D.C., pp. 14-20

Koerner, R. M., and B-L Hwu (1991, January 13-17) "Design and Testing of Prefabricated Highway Edge Drains", Transportation Research Board 70th Annual Meeting, Washington, D.C.

Koerner, R. M., and B-L Hwu (1996) "Prefabricated Highway Edge Drains", Transportation Research Record 1329, National Academy Press, Washington, D.C.

Koerner, R. M., G. R. Koerner, A. K. Fahim, and R. F. Wilson-Fahmy (1994) "Long-Term Performance of Geosynthetics in Drainage Applications", Report 367, National Academy Press, Washington, D.C., pp. 1-4

Smutzer, R., T. L. Rozsits, and T. R. Baas (1996, March) "The Evolution of a generic edge-drain specification", Geotechnical Fabrics Report, pp. 43-45

Steffes, R. F., V. J. Marks, and K. L. Dirks (1996) "Video Evaluation of Highway Drainage Systems", Transportation Research Record 1329, National Academy Press, Washington, D.C.

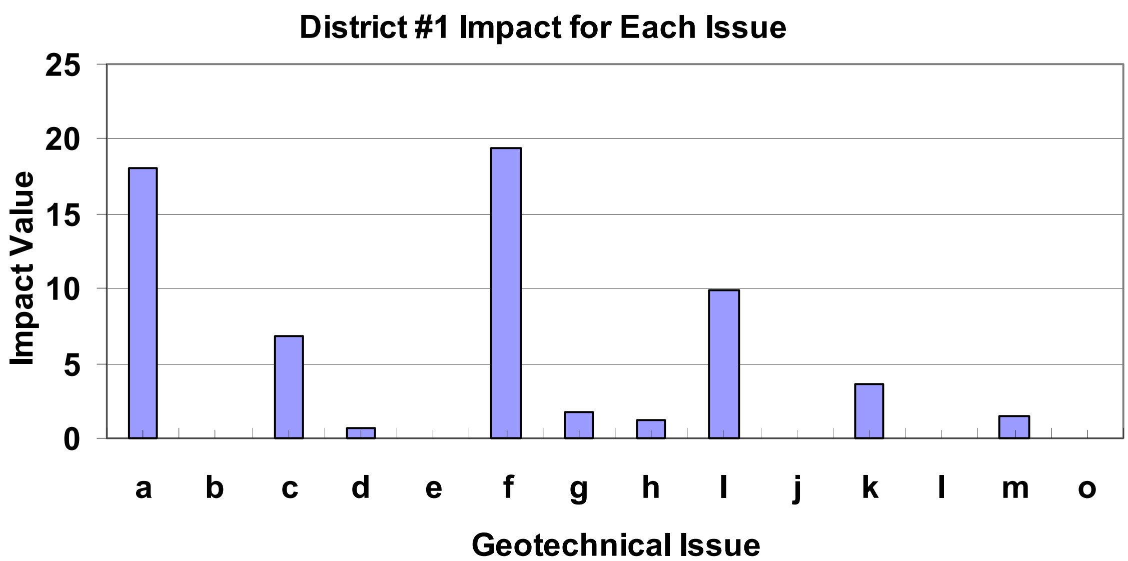
Stuart III, E., K. S. Inouye, and J. A. McKean (1996) "Laboratory Procedure for Predicting Geocomposite Drain System Performance in the Field", Transportation Research Record 1329, National Academy Press, Washington, D.C.

Stuart III, E., K. S. Inouye, and J. A. McKean "Field and Laboratory Evaluation of Geocomposite Drain Systems for Use on Low-Volume Roads", Transportation Research Record 1291, USDA Forest Service, pp. 159-165

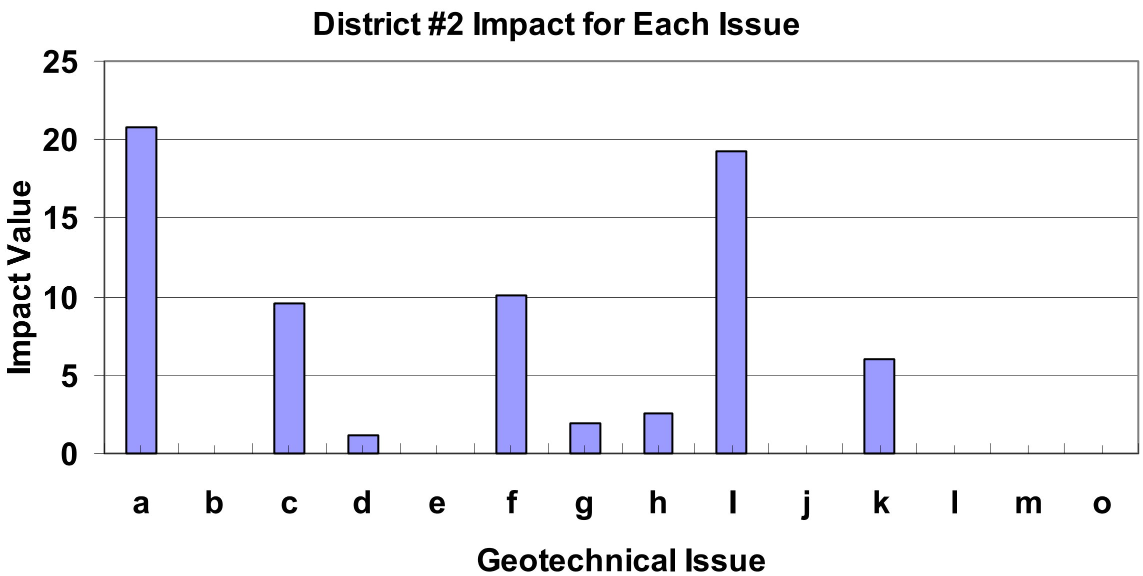
Suits, L. D., J. B. Goddard, and J. S. Baldwin (1999, June) "Testing and Performance of Geosynthetics in Subsurface Drainage", ASTM

Wallace, H. (1990, October) "Highway Subsurface Drainage Increasing", Land and Water, p. 28

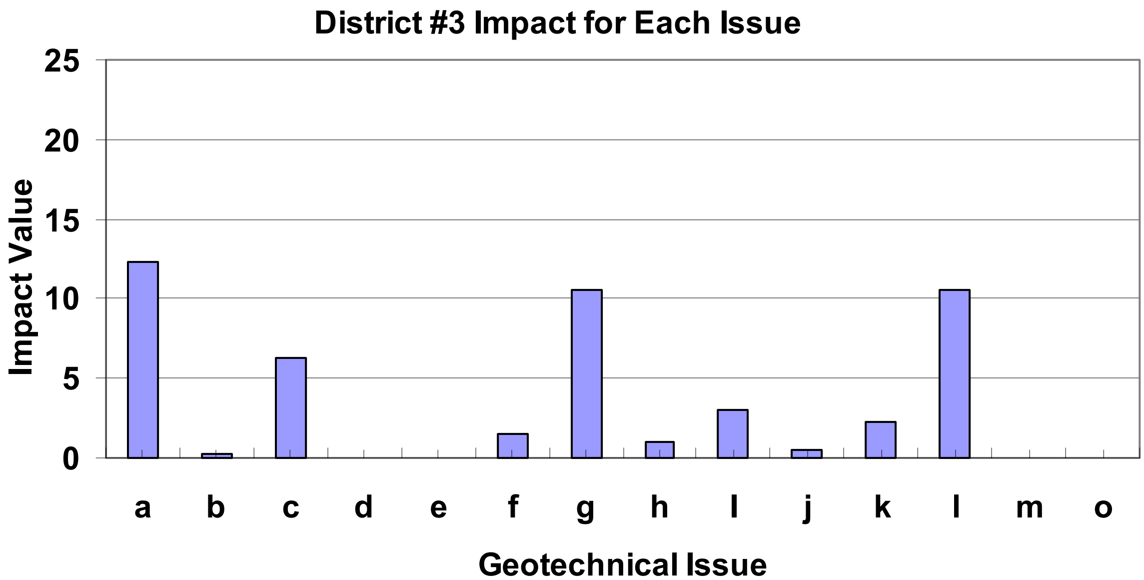
## Appendix E – Impact of Geotechnical-Related Issues for Each District



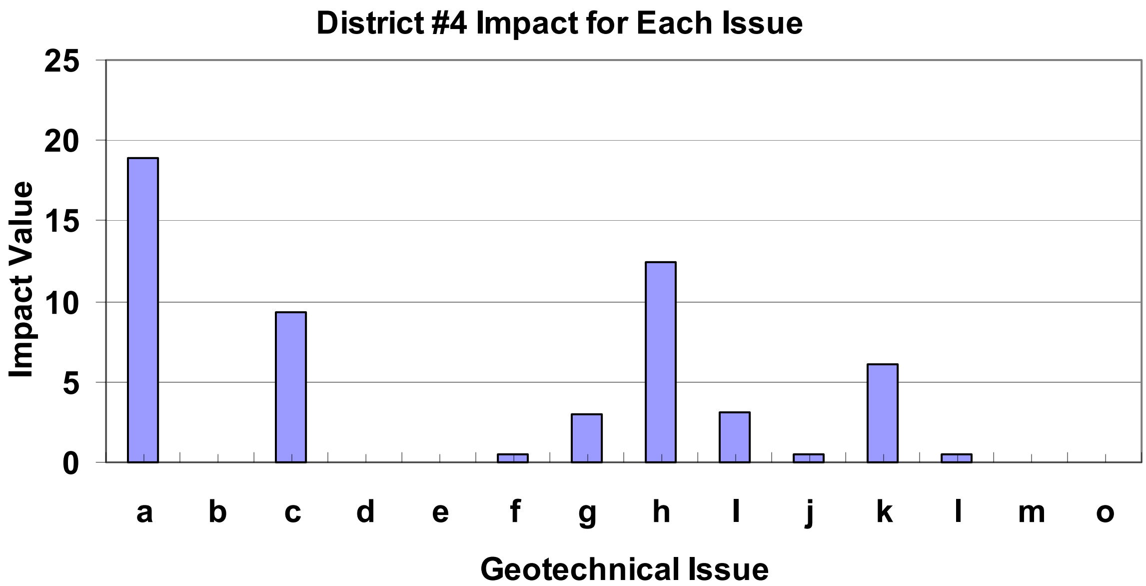

| Issue | District 1 Impact | Issue |
|---|---|---|
| a | 18.06 | Soil Slope instability |
| b | 0.00 | Rock slope instability |
| c | 6.83 | Unstable pavement subgrades |
| d | 0.66 | Bridge foundation problems |
| e | 0.00 | Earthquake foundation problems |
| f | 19.34 | Scour under bridges and river banks |
| g | 1.73 | Bridge approach embankments and slab problems |
| h | 1.15 | Pavement subsurface drainage(edge drains) problems |
| I | 9.92 | Erosion on embankments, slopes and/or stream banks |
| j | 0.00 | Bridge abutments or earth retaining structure problems |
| k | 3.54 | Settlement Problems |
| l | 0.00 | Sinkholes/Mines |
| m | 1.49 | Freeze/thaw |
| o | 0.00 | Other |



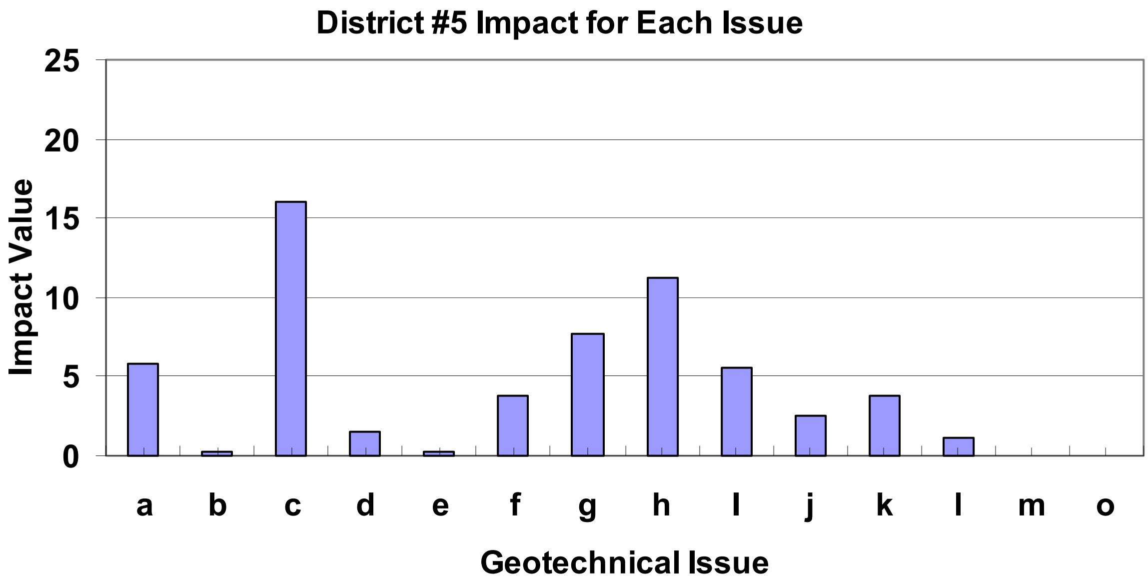

| Issue | District 2 Impact | Issue |
|---|---|---|
| a | 20.77 | Soil Slope instability |
| b | 0.00 | Rock slope instability |
| c | 9.51 | Unstable pavement subgrades |
| d | 1.09 | Bridge foundation problems |
| e | 0.00 | Earthquake foundation problems |
| f | 10.11 | Scour under bridges and river banks |
| g | 1.94 | Bridge approach embankments and slab problems |
| h | 2.52 | Pavement subsurface drainage(edge drains) problems |
| I | 19.23 | Erosion on embankments, slopes and/or stream banks |
| j | 0.00 | Bridge abutments or earth retaining structure problems |
| k | 6.00 | Settlement Problems |
| l | 0.00 | Sinkholes/Mines |
| m | 0.00 | Freeze/thaw |
| o | 0.00 | Other |



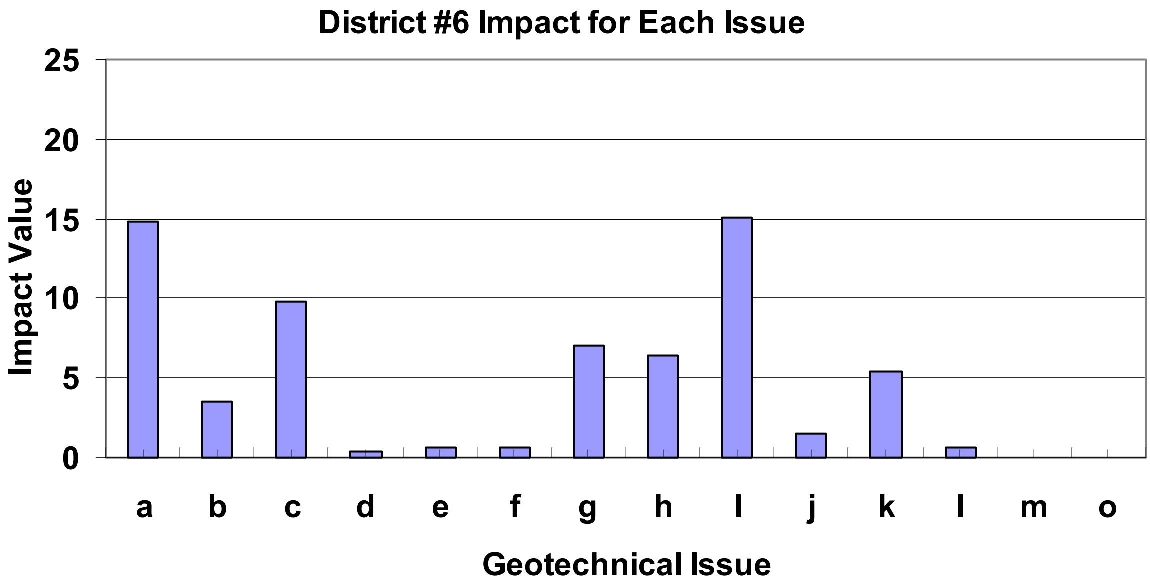

| Issue | District 3 Impact | Issue |
|---|---|---|
| a | 12.25 | Soil Slope instability |
| b | 0.25 | Rock slope instability |
| c | 6.25 | Unstable pavement subgrades |
| d | 0.00 | Bridge foundation problems |
| e | 0.00 | Earthquake foundation problems |
| f | 1.56 | Scour under bridges and river banks |
| g | 10.56 | Bridge approach embankments and slab problems |
| h | 1.00 | Pavement subsurface drainage(edge drains) problems |
| I | 3.06 | Erosion on embankments, slopes and/or stream banks |
| j | 0.56 | Bridge abutments or earth retaining structure problems |
| k | 2.25 | Settlement Problems |
| l | 10.56 | Sinkholes/Mines |
| m | 0.00 | Freeze/thaw |
| o | 0.00 | Other |



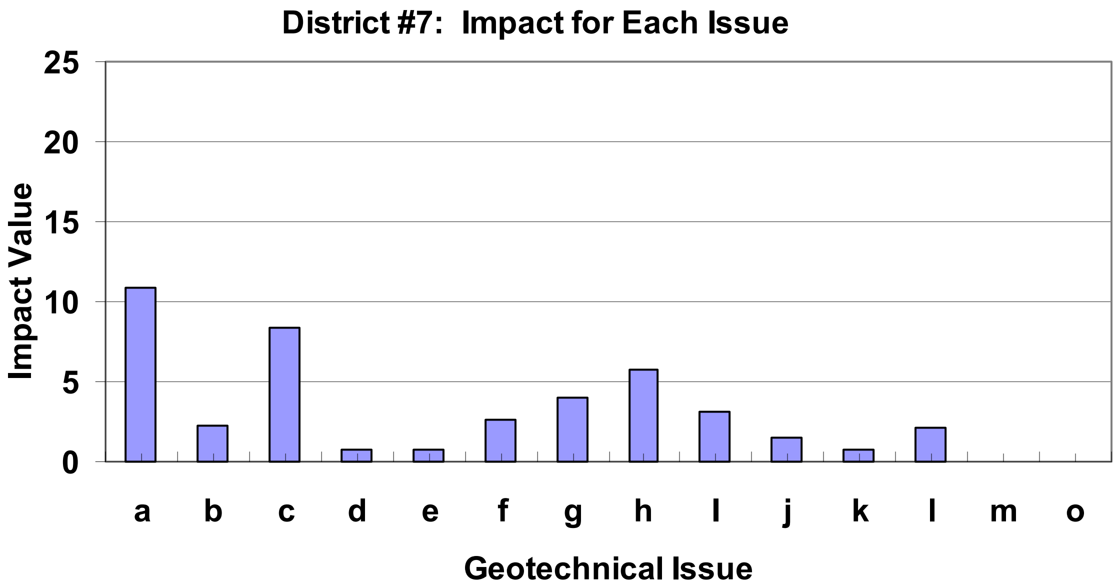

| Issue | District 4 Impact | Issue |
|---|---|---|
| a | 18.87 | Soil Slope instability |
| b | 0.00 | Rock slope instability |
| c | 9.34 | Unstable pavement subgrades |
| d | 0.00 | Bridge foundation problems |
| e | 0.00 | Earthquake foundation problems |
| f | 0.50 | Scour under bridges and river banks |
| g | 2.93 | Bridge approach embankments and slab problems |
| h | 12.39 | Pavement subsurface drainage(edge drains) problems |
| I | 3.13 | Erosion on embankments, slopes and/or stream banks |
| j | 0.51 | Bridge abutments or earth retaining structure problems |
| k | 6.11 | Settlement Problems |
| l | 0.50 | Sinkholes/Mines |
| m | 0.00 | Freeze/thaw |
| o | 0.00 | Other |



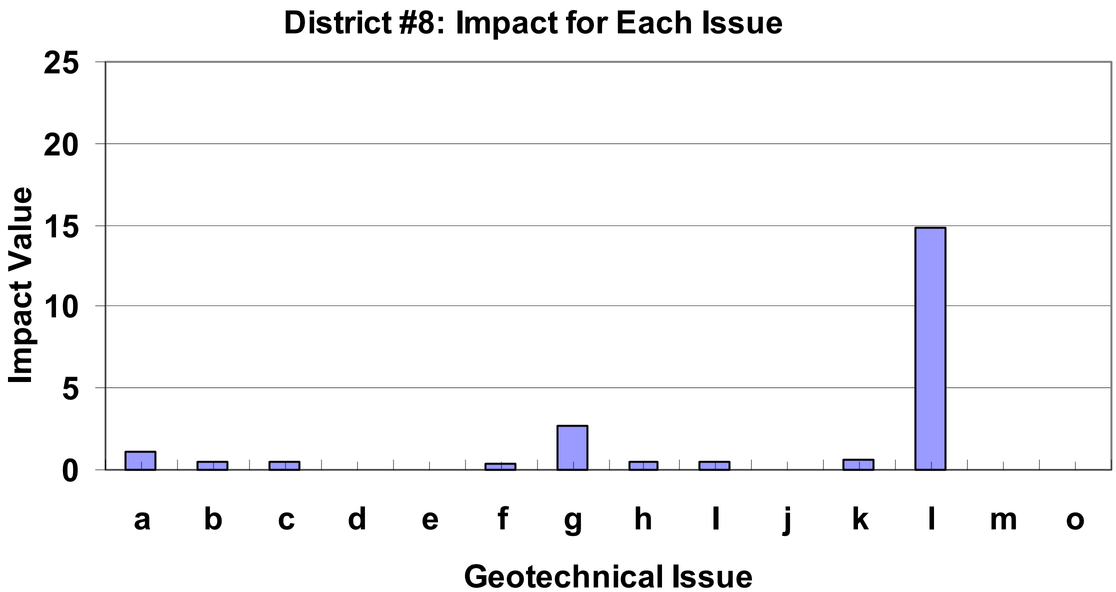

| Issue | District 5 Impact | Issue |
|---|---|---|
| a | 5.84 | Soil Slope instability |
| b | 0.28 | Rock slope instability |
| c | 16.00 | Unstable pavement subgrades |
| d | 1.52 | Bridge foundation problems |
| e | 0.28 | Earthquake foundation problems |
| f | 3.78 | Scour under bridges and river banks |
| g | 7.66 | Bridge approach embankments and slab problems |
| h | 11.24 | Pavement subsurface drainage(edge drains) problems |
| I | 5.53 | Erosion on embankments, slopes and/or stream banks |
| j | 2.51 | Bridge abutments or earth retaining structure problems |
| k | 3.78 | Settlement Problems |
| l | 1.12 | Sinkholes/Mines |
| m | 0.00 | Freeze/thaw |
| o | 0.00 | Other |




| Issue | District 6 Impact | Issue |
|---|---|---|
| a | 14.78 | Soil Slope instability |
| b | 3.48 | Rock slope instability |
| c | 9.83 | Unstable pavement subgrades |
| d | 0.43 | Bridge foundation problems |
| e | 0.63 | Earthquake foundation problems |
| f | 0.63 | Scour under bridges and river banks |
| g | 7.00 | Bridge approach embankments and slab problems |
| h | 6.42 | Pavement subsurface drainage(edge drains) problems |
| I | 15.09 | Erosion on embankments, slopes and/or stream banks |
| j | 1.54 | Bridge abutments or earth retaining structure problems |
| k | 5.40 | Settlement Problems |
| l | 0.66 | Sinkholes/Mines |
| m | 0.00 | Freeze/thaw |
| o | 0.00 | Other |

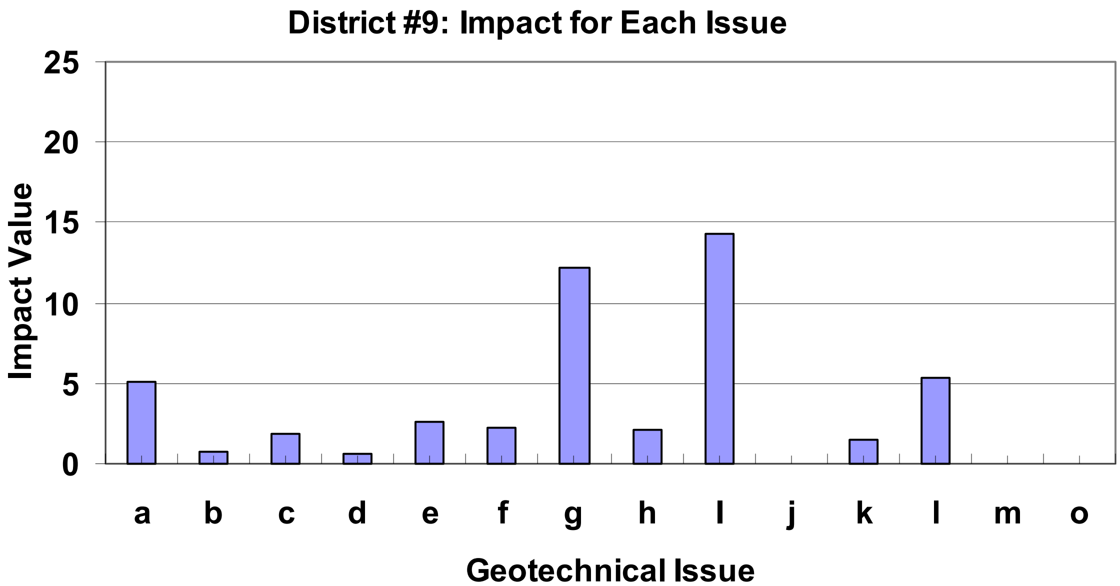



| Issue | District 7 Impact | Issue |
|---|---|---|
| a | 10.88 | Soil Slope instability |
| b | 2.24 | Rock slope instability |
| c | 8.40 | Unstable pavement subgrades |
| d | 0.72 | Bridge foundation problems |
| e | 0.72 | Earthquake foundation problems |
| f | 2.64 | Scour under bridges and river banks |
| g | 3.96 | Bridge approach embankments and slab problems |
| h | 5.76 | Pavement subsurface drainage(edge drains) problems |
| I | 3.08 | Erosion on embankments, slopes and/or stream banks |
| j | 1.44 | Bridge abutments or earth retaining structure problems |
| k | 0.72 | Settlement Problems |
| l | 2.16 | Sinkholes/Mines |
| m | 0.00 | Freeze/thaw |
| o | 0.00 | Other |

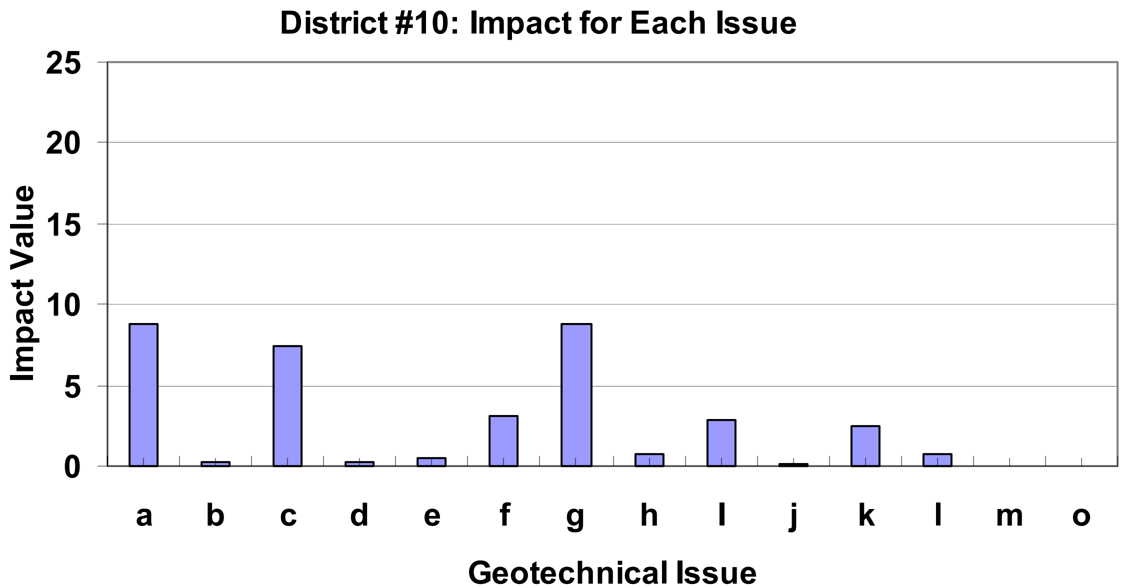



**District 8**

| Issue | Impact | Issue |
|---|---|---|
| a | 1.06 | Soil Slope instability |
| b | 0.52 | Rock slope instability |
| c | 0.52 | Unstable pavement subgrades |
| d | 0.05 | Bridge foundation problems |
| e | 0.00 | Earthquake foundation problems |
| f | 0.41 | Scour under bridges and river banks |
| g | 2.70 | Bridge approach embankments and slab problems |
| h | 0.46 | Pavement subsurface drainage(edge drains) problems |
| I | 0.46 | Erosion on embankments, slopes and/or stream banks |
| j | 0.05 | Bridge abutments or earth retaining structure problems |
| k | 0.59 | Settlement Problems |
| l | 14.78 | Sinkholes/Mines |
| m | 0.00 | Freeze/thaw |
| o | 0.00 | Other |




| Issue | District 9 Impact | Issue |
|---|---|---|
| a | 5.11 | Soil Slope instability |
| b | 0.79 | Rock slope instability |
| c | 1.91 | Unstable pavement subgrades |
| d | 0.67 | Bridge foundation problems |
| e | 2.64 | Earthquake foundation problems |
| f | 2.26 | Scour under bridges and river banks |
| g | 12.25 | Bridge approach embankments and slab problems |
| h | 2.16 | Pavement subsurface drainage(edge drains) problems |
| I | 14.29 | Erosion on embankments, slopes and/or stream banks |
| j | 0.02 | Bridge abutments or earth retaining structure problems |
| k | 1.50 | Settlement Problems |
| l | 5.31 | Sinkholes/Mines |
| m | 0.00 | Freeze/thaw |
| o | 0.00 | Other |




| Issue | District 10 Impact | Issue |
|---|---|---|
| a | 8.74 | Soil Slope instability |
| b | 0.27 | Rock slope instability |
| c | 7.42 | Unstable pavement subgrades |
| d | 0.26 | Bridge foundation problems |
| e | 0.52 | Earthquake foundation problems |
| f | 3.15 | Scour under bridges and river banks |
| g | 8.83 | Bridge approach embankments and slab problems |
| h | 0.69 | Pavement subsurface drainage(edge drains) problems |
| I | 2.84 | Erosion on embankments, slopes and/or stream banks |
| j | 0.17 | Bridge abutments or earth retaining structure problems |
| k | 2.52 | Settlement Problems |
| l | 0.72 | Sinkholes/Mines |
| m | 0.00 | Freeze/thaw |
| o | 0.00 | Other |