

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

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Office of Research Administration
University of Oklahoma

Sponsored by
Oklahoma Department of Transportation
Research and Development Division

in cooperation with the
Federal Highway Administration

January 1990

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. FHWA/OK 89 (07)	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE Evaluation of Causes of Excessive Settlements of Pavements Behind Bridge Abutments and Their Remedies; Phase II (Executive Summary)		5. REPORT DATE January 1990	
		6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) J.G. Laguros, M.M. Zaman, and I.U. Mahmood		8. PERFORMING ORGANIZATION REPORT ORA 157-293	
		10. WORK UNIT NO.	
9. PERFORMING ORGANIZATION AND ADDRESS The University of Oklahoma Norman, OK 73019		11. CONTRACT OR GRANT NO. ODOT 86-04-2 Item 2148	
		13. TYPE OF REPORT AND PERIOD COVERED	
12. SPONSORING AGENCY NAME AND ADDRESS Oklahoma Department of Transportation Research and Development Division 200 NE 21st Street Oklahoma City, OK 73105		14. SPONSORING AGENCY CODE	
		15. SUPPLEMENTARY NOTES Done in cooperation with FHWA	
16. ABSTRACT To evaluate the causes of bridge approach settlement a survey of 758 bridge approaches in seventy-seven counties of Oklahoma was conducted. In this survey, data related to the following items were collected: (i) bridge, abutment, approach, and slope protection structure. (ii) embankment material. Information related to the construction and maintenance for these approaches was collected by interviewing ODOT personnel and searching records maintained at ODOT. The analyses of data show that the settlement problem is extensive in Oklahoma, namely, 83% of the approaches surveyed experienced settlement. It was observed that on the basis of long term performance rigid and flexible approaches are similar, but on a short term basis, rigid approaches experience lower differential settlement. Pile supported abutments as compared to stub type and high embankments with no drainage for the fills appear to be conducive to larger settlements. In general, skewed approaches have a higher settlement than nonskewed approaches. Regression techniques were used to develop an empirical relationship between the approach settlement and the causative parameters such as age of the approach, embankment height, traffic volume, and skewness of the approach. As a preliminary work for the next phase of the study, soil samples were collected from two sites. Comprehensive laboratory testing was conducted on these samples with the purpose of determining their site-specific embankment and foundation soil characteristics which may be used in a settlement prediction model.			
17. KEY WORDS Bridge approach, Settlement, Bump, Pavement, Embankment		18. DISTRIBUTION STATEMENT	
19. SECURITY CLASSIF. (OF THIS REPORT) None	20. SECURITY CLASSIF. (OF THIS PAGE) None	21. NO. OF PAGES 20	22. PRICE

EXECUTIVE SUMMARY
OF FINAL REPORT
ODOT Study No. 86-04-2
ORA 157-293

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Submitted to

Research Division
OKLAHOMA DEPARTMENT OF TRANSPORTATION

From the

OFFICE OF RESEARCH ADMINISTRATION
University of Oklahoma
Norman, Oklahoma

January 1990

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INTRODUCTION

Differential settlement between the approach pavement and the bridge deck has been a nationally recognized problem for a long time. A large number of abutments and approach embankments founded on oxbow lakes in Oklahoma have made this settlement problem particularly critical (Fig. 1). Differential settlement leads to an unsafe and uncomfortable riding surface, undesirable movement and cracking of abutment headwall (Fig. 2), extensive tilting of expansion devices (Fig. 3), and creates high impact loads on the bridge structures. The usual remedy is periodic maintenance involving patching or mudjacking the approach pavement both of which are costly and cause inconvenience. Even then, only the pavement surface is corrected. In heavy traffic areas, the maintenance operation may tend to impede the normal flow of traffic.

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

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

To accomplish its intended goals, the study was proposed to be conducted in five different phases.

WORK ACCOMPLISHED IN PHASE I

The research work for Phase I, which started in May 1985 and was complet-



Fig. 1. A rough bridge approach.



Fig. 2. An abutment headwall showing extensive cracking.



Fig. 3. An expansion device showing extensive tilting.



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

ed in February 1986, consisted of three major tasks: (1) comprehensive search of available literature, (b) survey of various state, federal and private agencies involved in construction and/or maintenance of pavements and bridges, and (c) analysis of survey response. The computer search facilities of the Highway Research Information Service (HRIS) as well as the search facilities at the University of Oklahoma were used. In addition, manual searches were conducted to locate pertinent literature.

To obtain the views on various aspects of approach pavement settlements and their remedies, a survey questionnaire was sent to 52 state DOTs and 36 Corps of Engineers districts. Of the 61 respondents, 42 considered the problem to be significant or very significant and 8 considered the problem insignificant in their states. Only six organizations had undertaken some research work to investigate this problem. The majority of the organizations (43) indicated the use of specially designed approach slabs but only a few claimed their effectiveness in reducing approach settlement. The survey response revealed that embankment foundation was the most significant causative factor in the settlement process followed by construction techniques and type of embankment material. Further analysis of the questionnaire indicated that the causes of approach settlement could not be generalized for all sites and/or all states in the nation. Overall, the problem seemed to be quite extensive.

WORK ACCOMPLISHED IN PHASE II

Phase II involved a level-one survey of 758 selected bridge approaches in Oklahoma to obtain first-hand information on the referenced settlement problem. This was accomplished by site visits associated with visual inspection and collection of information pertaining to design, construction and

maintenance of these 758 bridge approaches. A brief description of each task accomplished to reach the objectives of Phase II is given in the following sections.

FIELD SURVEY OF BRIDGE APPROACHES

A survey form for the level-one survey was prepared after several modifications. The form consisted of three parts and included information from (a) field visits to the approach site, (b) maintenance personnel, and (c) records maintained at the ODOT bridge division. A field survey manual was prepared and used as a guideline to complete the desired information for each bridge approach. The total approach settlement was estimated from the existing settlement, evidence of previous maintenance measures and differential settlement of the curb (Fig. 4).

A total of 758 bridge approaches were selected in a way that they covered a wide range of parameters/factors that contribute to the approach settlement problems in the state.

The survey emphasized Divisions 3, 6, and 8 where an average of approximately 14 approaches per county was surveyed. For the other divisions, an average of approximately 7 approaches per county was surveyed. Of the total 758 bridge approaches surveyed, 636 were over waterways, 122 were overpass or underpass, 320 were rigid, 438 were flexible, 58 were on interstate, 622 were on state highways and 78 were on county roads. All the bridge approaches were surveyed during the period July 1987 to July 1988.

Interview of Maintenance Personnel

The supervisors of seventy-seven ODOT maintenance districts, as well as interstate units, were interviewed to obtain information regarding maintenance

of the approach pavements surveyed. For each approach, the section pertaining to maintenance information was filled out with the assistance of the maintenance crew. Many times the maintenance supervisors visited the approach site with the research team to point out special maintenance problems. Due to limitation of time and lack of complete recordkeeping, the maintenance information for the approaches on county roads was not collected.

Information from ODOT Bridge Division

Information pertaining to approach construction, embankment of the approach and foundations soil were obtained from the records maintained at the ODOT bridge division in Oklahoma City.

Limitations of Information Collected

Information collected from the above mentioned sources (field visits, maintenance personnel and ODOT bridge division) had some limitations. Sometimes the physical evidence of any prior maintenance such as mudjacking, level patching or previous overlays would be buried under a new layer of asphalt concrete overlay. In such situations, the field estimate of settlement could be expected to be inaccurate. The embankment material type was determined by drilling boreholes to a depth of the top 1½ feet with a post auger and inspecting the soils, without any laboratory testing. This is not very reliable unless the embankment material is uniform or homogeneous. Presently, ODOT does not keep maintenance records of bridge approaches in sufficient detail. For information relating to maintenance, the recollection of the maintenance personnel was relied upon. Thus there was a possibility of omission of some maintenance work for a particular bridge approach. Also with older bridges, the maintenance personnel could not give information covering the entire

service life. In some cases, a bridge had been maintained for a few years by some other agency, such as a city administration, and then the maintenance responsibilities had been transferred to ODOT or vice versa. Information regarding these cases was also incomplete. Some information, pertaining to construction history, embankment or foundation soil characteristics, sought from the records was not available.

It should be pointed out that the results of the statistical analyses given below as well as the conclusions drawn from this study should be judged carefully in light of the above limitations.

Analysis of Information

The information obtained from three different sources generated an extremely large number of records. A commercially available software, "dBASE III PLUS", was used to develop a database for the purpose of storing, organizing, and analyzing the collected information.

Two types of analyses were pursued: (a) exploratory analysis to evaluate the relationship of the settlement of bridge approaches with the various approach characteristics such as embankment height, age, type of approach, foundation soil type, traffic, etc., and (b) statistical evaluation of the information for establishing an empirical relationship between the settlement and the various causative parameters.

Fig. 5 shows the statistics of different approach classifications in each division. The three types of classification shown in the figure are:

SN: Approach settled but no maintenance performed

SM: Approach settled and maintenance performed

OS: No significant settlement evident.

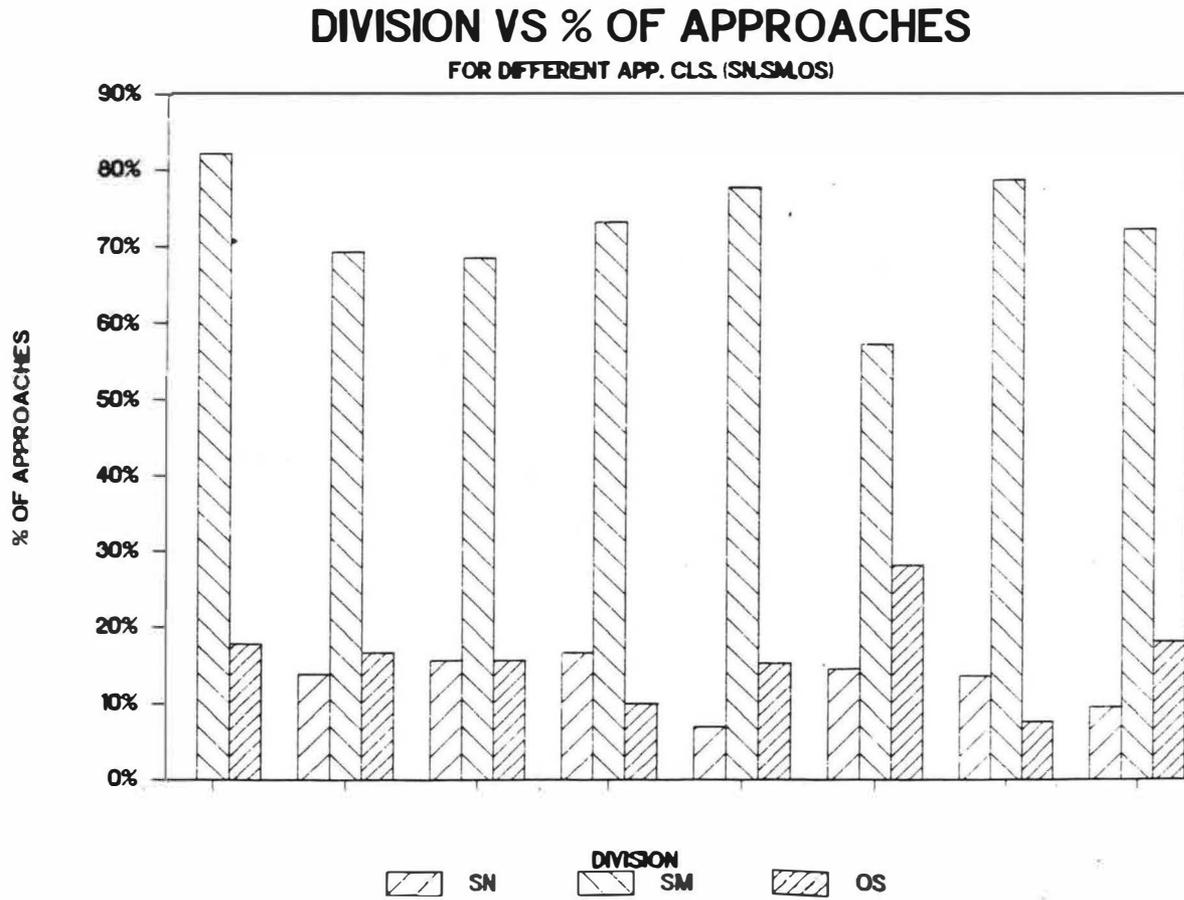


Fig. 5. Percentage of approaches under SM, SN, and OS classification for each division.

It is observed in Fig. 5 that the highest percentage of approaches under the SM classification was in Division 1 (82%). The maximum number of approaches under SN and OS classifications were found to be in Division 4 (17%) and Division 6 (28%), respectively. Furthermore, Fig. 5 indicates that the approaches in Division 6 experienced less settlement than in other divisions. Overall 83% of all the bridge approaches surveyed have experienced settlement.

Fig. 6 indicates that the average settlement of approach pavements, which ranges from 1.0 to 3.1 inches, increases with increase in the range of age group. The 31-40 age group is an exception. The reason for this exception is suspected to be inaccurate information relating to older bridges. Also it is observed in Fig. 6 that major portion of the settlement occurs within the first 20 years.

Fig. 7 shows that the average settlement (ranging from 2 to 5 inches) increases with increasing embankment height. The exception is observed for approaches with embankment height higher than 60 feet. The possible reason is that the small number (19) of approaches for this group led to an inaccurate estimate of the average settlement.

Fig. 8 indicates that higher approach settlement is associated with approaches built on foundations of silts and clays with a liquid limit of 50% or less, (Group 2 in the figure). Other types of foundation soil are (Group 1) coarse grained soils (more than 50% retained on #200 sieve) and (Group 3) silts and clays (liquid limit greater than 50%). The exclusion of total compressibility of foundation soil in the analyses may be the reason for Group 2 soil being associated with higher approach settlement compared to the more plastic Group 3 soil. Similar figures relating approach settlement with other causative factors were generated and they are presented in the final report.

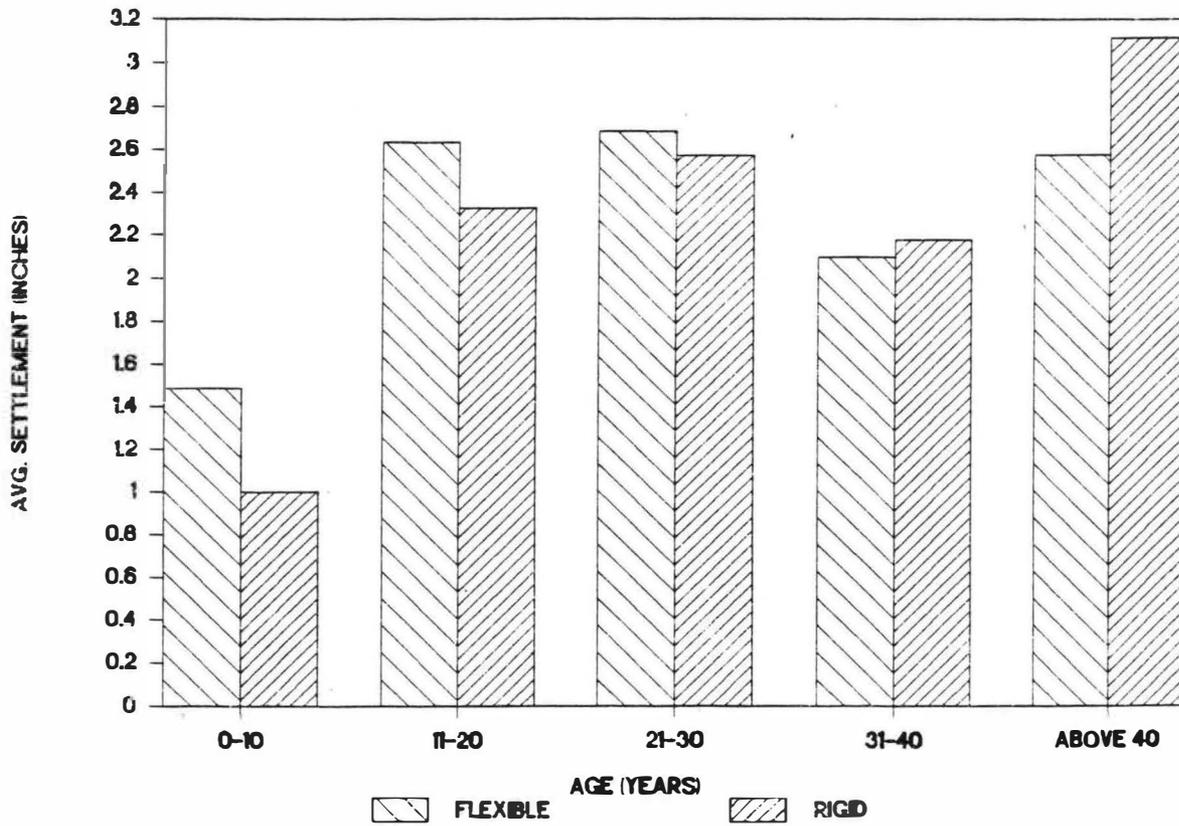
AGE OF THE BRDG. VS AVG. SETTLEMENT

Fig. 6. Settlement vs. approach age relationship for flexible and rigid approaches.

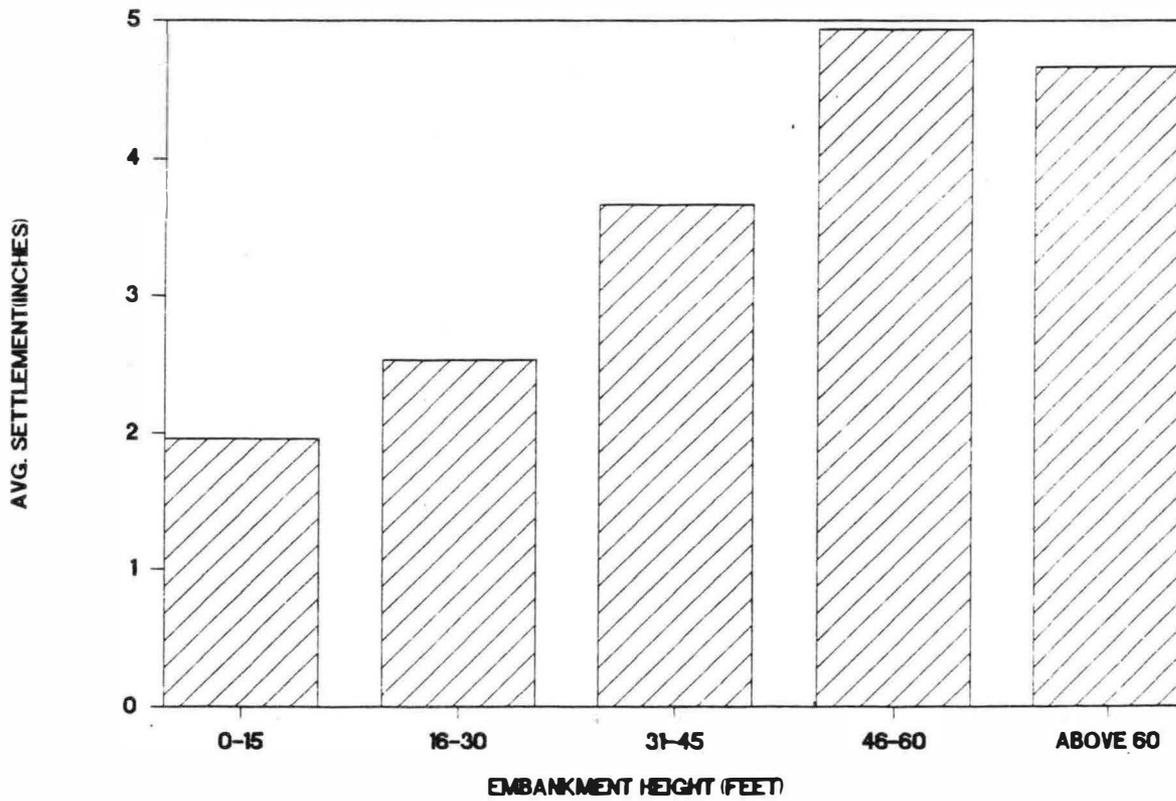
EMBK. HT VS AVG SETTLEMENT

Fig. 7 Settlement vs. approach embankment height relationship.

AVG. SETTLEMENT VS FDN. SOIL CLS.

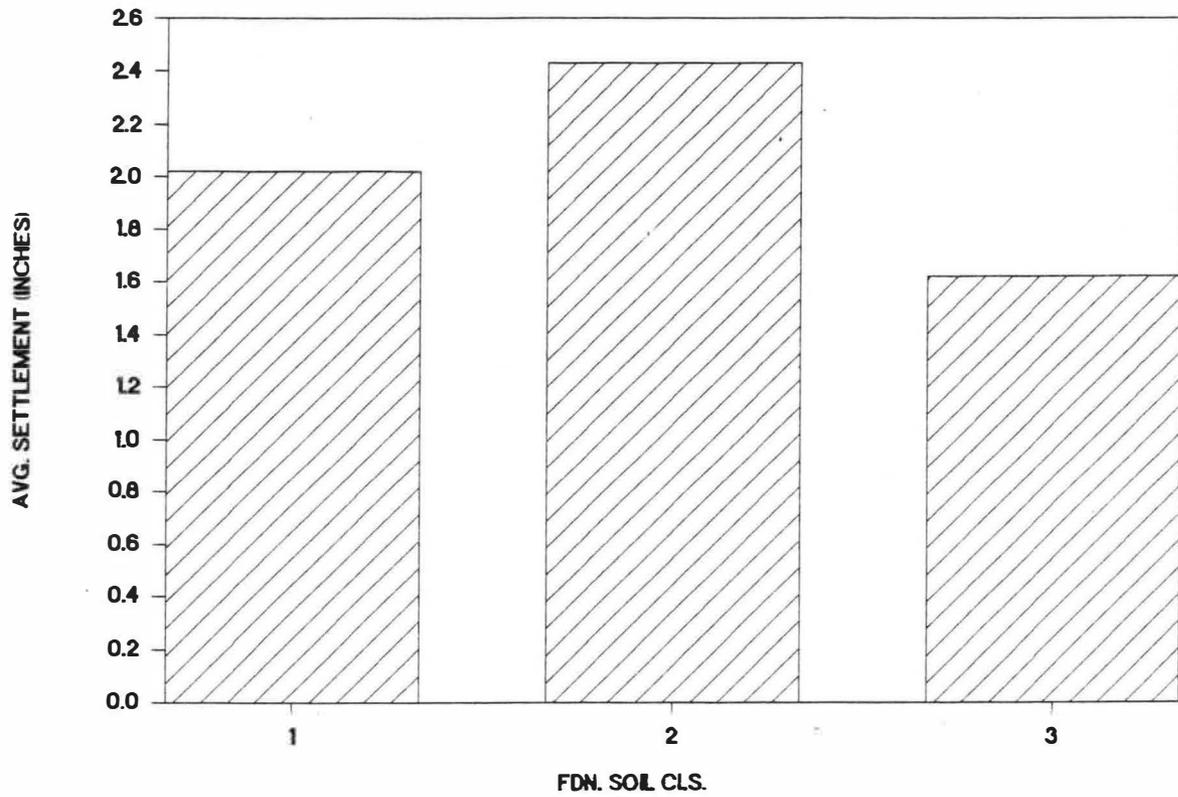


Fig. 8 Settlement vs. foundation soil type relationship.

A regression analysis package, SAS with provision for linear and nonlinear regression analyses, was used to develop relationships between settlement and other data. For example, the following relationships were obtained for the flexible and rigid approaches:

Flexible approaches:

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

Rigid approaches:

$$\begin{aligned} \text{TSET} = & .000032 (\text{AGE})^3 - .000003 (\text{EHGT})^3 - .079417 \text{ Log } (\text{EHGT}) \\ & + .010869 (\text{SKEW}) + .069695 \text{ Log } (\text{TRAFFIC}) \\ & + .003868 (\text{AGE} \times \text{EHGT}) - .022576 \text{ Log } ((\text{AGE} \times \text{TRAFFIC})) \end{aligned}$$

In the above equations

TSET = total settlement of the approach, inches

AGE = age of the approach, years

EHGT = embankment height, feet

SKEW = skewness of the approach, degrees

TRAFFIC = average daily traffic.

In this phase, the effect of some significant parameters such as compaction of embankment material, creep of embankment, drainage behind the abutment, etc., could not be assessed because of the unavailability of information. Also, the statistical analyses are currently being refined to obtain more realistic relations between the approach settlement and the causative factors.

COMPREHENSIVE STUDY OF TWO SELECTED SITES

In Phase III, site specific embankment and foundation soil properties

will be evaluated for some 20-30 sites across the state as a part of the "Level-Two" survey. To prepare the desired background for Phase III and, with ODOT's approval, the original (Phase II) proposal was modified to include comprehensive laboratory testing of soil sampled from two selected sites. The purpose was to determine their site-specific embankment and foundation soil characteristics. Of the seven sites considered, the two sites selected were:

1. Bridge 63-23 WX0465 on US 270 in Pottawatomie County (Shawnee site)
2. Bridge 67-02 X0894 on US 270 in Seminole County (Wewoka Creek site)

Both bridges are over 25 years old and have experienced settlements ranging from 6 to 10 inches. They have been mudjacked, level patched and overlaid a few times. Other considerations in their selection were the considerable embankment height (25-30 feet) and foundation soil thickness (over 40 feet), since they are considered conducive to settlement.

A total of seven borings were drilled at the two study sites, five on the approach pavement and two under the bridge. For each site, continuous sampling was done in at least one hole to obtain information about the soil profile and then an offset hole was drilled to obtain undisturbed samples at desired depths. Standard penetration tests (SPT) were conducted at two boreholes, one at each site, to correlate the soil properties with the SPT values. Laboratory testing included field moisture content, field density, Atterberg limits, grain size distribution, maximum dry density and consolidation. Detail data and results are presented in the Phase II final report. The findings may be summarized as follows:

1. Sampling and comprehensive laboratory and field testing of soil can provide the desired flow, strength and settlement-related properties of embankment and foundation soil. These properties can be used to characterize the approach settlement process and to predict the settlement-time

history in a meaningful manner, which would be difficult otherwise. For the two sites studied here, as well as the additional sites to be studied in Phase III, the prediction of settlement history will be pursued in Phase IV of the project.

2. Drilling of the approach pavement provides an assessment of the previous maintenance measures at a site by visual observation of the pavement core which could not be obtained otherwise due to the existing inadequate recordkeeping procedure.
3. For the Shawnee site, the liquid limit (LL) and the plasticity index (PI) values were substantially higher than the Wewoka site, indicating larger clay/silt content in the embankment soil. The poor quality embankment soil has likely contributed to excessive approach settlement at this site.
4. Excess field moisture content is indicative of inadequate drainage conditions at both sites. This must have been a contributing factor also.
5. High embankment appears to have aggravated the approach settlement problems at both sites.
6. Although the contributions of embankment height and soil type are similar for both sites, the foundation soil at the Shawnee site appears to be less susceptible to settlement than that at the Wewoka Creek site. Therefore, of the two sites, the Wewoka Creek site appears to be more problematic.

CONCLUSIONS

This report has summarized the findings of Phase II of the research project entitled "Evaluation of Causes of Excessive Settlements of Pavements Behind Bridge Abutments and Their Remedies". In this phase a level-one survey

of 758 selected bridge approaches was undertaken to obtain first-hand information on the extent of approach pavement settlement problems in Oklahoma. Some conclusions drawn from this survey are:

1. It is evident that the approach pavement settlement problem is very extensive in Oklahoma. About 83% of the approaches surveyed have experienced settlement.
2. The settlement problem is less frequent in northwestern region of Oklahoma.
3. The settlement problem is aggravated by the absence of any drainage in the fill behind the abutment.
4. The long term performance of rigid and flexible approaches are similar. However, in the short term, rigid approaches undergo lower differential settlement.
5. A major portion of the settlement of the approaches occurs within the first twenty years of the service life of the bridge approach. This was observed from the exploratory data analyses.
6. Pile supported abutments are associated with more approach settlement than the stub type.
7. Higher embankment heights might be partly responsible for larger approach settlements.
8. In general, skewed approaches have a higher approach settlement than non-skewed approaches.
9. The ranking of the quantitative causative parameters according to significance are: (i) age of the approach, (ii) height of embankment, (iii) average daily traffic, and (iv) skewness of the approach. The contribution of traffic volume to the settlement of the approach is not very significant even though it is ranked third.

10. Effect of some of the very important parameters such as drainage, creep of embankment, compaction of fill material, etc., could not be assessed from the level-one survey data.

RECOMMENDATIONS

1. It is recommended that the approach pavement be designated as a separate subsection as done with the bridges. For rigid approaches the subsection will have a length equal to that of the approach pavement. For flexible approaches an appropriate length (e.g., 50 feet) may be specified which will be designated as the approach.
2. A database should be created to store all information regarding the approach pavement, approach foundation and construction and maintenance of the approach pavement. Phase III of this project is expected to provide some guidelines regarding the type of database that would be required.
3. Drainage of the fill should be installed in some new sites and its effect be investigated. Performance of select fill (abutment) materials and compaction should also be studied.
4. Creep of embankment soil is suspected to be an important causative factor for approach settlement. It is recommended that the significance of this factor be studied by field instrumentation and monitoring of selected sites.
5. The cost of maintenance of rigid and flexible approach pavements should be recorded to evaluate the frequency of maintenance and total costs needed for correcting approach settlement problems in the state.