National Cooperative Highway Research Program

NCHRP Synthesis 234

Settlement of Bridge Approaches
(The Bump at the End of the Bridge)

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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Transportation Research Board
National Research Council

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

NATIONAL ACADEMY PRESS
Washington, D.C. 1997

Subject Area
Pavement Design, Management and Performance; Bridges, Other Structures, Hydraulics and Hydrology; Maintenance

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NCHRP SYNTHESIS 234

Project 20-5 FY 1993 (Topic 26-10)
ISSN 0547-5570
ISBN 0-309-6007-9
Library of Congress Catalog Card No. 96-061814

Price $24.00

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Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to state Departments of Transportation (DOT) geotechnical, structural, roadway design, construction, and maintenance engineers; DOT research staff; and personnel in local transportation agencies. This synthesis describes the current state of the practice for the design, construction, and maintenance of bridge approaches to reduce, eliminate, or compensate for settlement at the bridge/abutment/embankment interface or "the bump at the end bridge." It discusses the geotechnical and structural engineering design and procedural factors to reduce the bump at the end of the bridge, and includes numerous illustrations.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board presents data obtained from a review of the literature and a survey of the state DOTs. It is a supplemental update to *Synthesis of Highway Practice 159: Design and Construction of Bridge Approaches,* (1990).

The synthesis identifies and describes techniques that have been used to alleviate the problem of the bump at the end of the bridge including the location and cause of settlement and methods used to reduce settlement. In addition, the types of interaction between various divisions of the DOTs in the design, construction, and maintenance of bridge approaches are addressed.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

Jean-Louis Briaud, Ph.D., P.E., Spenser J. Buchanan Professor, Department of Civil Engineering, Texas A&M University and Research Engineer, Texas Transportation Institute; Ray W. James, Ph.D., P.E., Associate Research Engineer, Texas Transportation Institute, and Senior Lecturer, Department of Civil Engineering, Texas A&M University; and Stacey B. Hoffman, E.I.T., Research Assistant, Department of Civil Engineering, Texas A&M University, were responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Robert K. Barrett, Manager of Geoservices Research, Colorado Department of Highways; Jerry Bellin, Preliminary Designer, Oregon Department of Transportation; Vernon L. Bump, Geotechnical Engineer, South Dakota Department of Transportation; Robert A. Burnett, Associate Soils Engineer, New York State Department of Transportation; Joseph A. Caliendo, Associate Professor, Utah State University; Jerry A. DiMaggio, Senior Geotechnical Engineer, Federal Highway Administration; Alfred F. DiMillio, Acting Chief, Materials Division, Federal Highway Administration; G.P. Jayaprakash, Engineer of Soils, Geology and Foundations, Transportation Research Board; and Abid M. Qanbari, Bridge Quality Assurance Engineer, Pennsylvania Department of Transportation.

The Principal Investigators responsible for the conduct of this synthesis were Stephen F. Maher and Sally D. Liff, Senior Program Officers. This synthesis was edited by Linda S. Mason.

Crawford F. Jencks, Senior Program Officer and Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-05 staff and the Topic Panel. Michael Adams, Federal Highway Administration and John D. O'Fallon, Bridge Research Engineer, McLean, Virginia, also provided input to the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

SETTLEMENT OF BRIDGE APPROACHES
(The Bump at the End of the Bridge)

SUMMARY

A bump often develops at the end of a bridge near the interface between the abutment and the embankment. Reduction in steering response, distraction to the driver, added risk and expense to maintenance operations, and reduction in a transportation agency's public image are all undesirable effects of these uneven and irregular transitions.

This report is a synthesis of practice for the design, construction, and maintenance related to settlement of bridge approaches. The content is based on a literature review, the responses to a survey questionnaire of 72 engineers from 48 state departments of transportation (DOTs), and discussions with DOT engineers.

The bump at the end of a bridge is a complex problem involving a number of components, including the natural soil on which the embankment and the abutment are built, the approach fill material, the foundation type used for the bridge abutment, the abutment type, the structure type, the bridge/roadway joints, the approach slab, the roadway paving, and the construction methods. The problem affects 25 percent of the bridges in the United States, approximately 150,000 bridges, and the amount of money spent every year on the repair of this problem nationwide is estimated to be at least $100 million. The most commonly reported causes of the bump are (in order of importance):

- Compression of the fill material
- Settlement of the natural soil under the embankment
- Poor construction practices
- High traffic loads
- Poor drainage
- Poor fill material
- Loss of fill by erosion
- Poor joints
- Temperature cycles.

A special case, integral bridge abutments, appears to create a consistent bump problem resulting from temperature cycles and the associated compression and decompression of the approach fill by the abutment wall.

The bump reportedly is minimized in the following cases (in order of importance):

- Abutment and embankment on strong natural soil
- Approach slab (long enough and strong enough)
- Well-compacted fills or stabilized fills
- Good fill material
- Good drainage
- Low embankments
- Adequate time period between fill placement and paving
- Good construction practice and inspection
- Low truck traffic.

Data collected for this synthesis indicate that a bump is most likely to appear if any of the following conditions are present:

- High embankments
- Abutment on piles
- High average daily truck traffic
- Soft clay or soft silt natural soil
- High intensity rainstorms
- Extreme temperature cycles
- Steep approach gradient.

There are several ways to significantly reduce the bump at the end of the bridge. However, the cost of a particular solution may be prohibitive or may exceed the life-cycle maintenance cost associated with a tolerable bump. The best current practices optimize the balance between proper design, proper construction, and acceptable maintenance while satisfying budget constraints and safety levels. Within this framework it must be accepted that the problem will not be solved for all bridges. The 10 considerations described below comprise the best practices around the country, which seem to minimize but not eliminate the bump at the end of the bridge.

First, within the context of best practice, the bump at the end of the bridge is acknowledged as a stand-alone design issue and its prevention could be a design goal. Failures in engineering rarely occur because the design rules are not accurate. Rather, problems develop when a factor has been completely overlooked.

Second, someone is responsible for this design issue. It appears that the geotechnical engineer has the best background in this respect. The problems of differential settlement, erosion, and compaction represent the major components of the bump problems; all are geotechnical engineering issues.

Third, teamwork and open-mindedness are very helpful. Where best practice is observed, meetings take place and information flows to all affected parties, existing approaches are challenged if they have not been successful and new approaches are considered. The bump develops at the connection between a geotechnical engineer's design—the embankment, and a structural engineer's design—the bridge. Note here that a proper foundation and embankment design should include a thorough site and soil testing investigation. Furthermore, proper construction is paramount and maintenance can be significantly impacted. The maintenance engineer, the construction engineer, the structural engineer, the pavement engineer, and the geotechnical engineer must act as a team.

Fourth, settlement calculations are carried out unless it is obvious that settlement is not a problem. The settlement versus time curve should be established for both the embankment and the bridge abutment. Each requires proper testing of the natural soil and of the embankment fill. The differential settlement versus time that will develop after the final paving is then calculated. Since the stiffness of the fill is not known at the time of design, the approach is to assume a certain stiffness and ensure that this stiffness is met or exceeded at the construction stage. This is usually done by controlling compaction.

Fifth, if the differential settlement is large enough and if it cannot be decreased by soil improvement techniques, an approach slab is considered. The decision to use an approach slab is affected by the magnitude of the differential settlement, the average daily traffic, and the cost of maintenance. The safe but expensive solution is to use approach slabs in all cases. The approach slab should be long enough to maintain a smooth transition between the embankment and the bridge. Slopes of 1/200 are considered tolerable. The approach slab is designed to handle such a free span under full traffic load; typical dimensions are lengths of 6 to 7 m (18 to 21 ft) and thicknesses of approximately 250 mm (10 in.). For large predicted settlements, a jackable or otherwise repairable slab may be specified.

Sixth, expansion/contraction between the structure and the approach roadway is accounted for. One way is to ensure that the bridge end panels are designed and constructed so that they do not move when bridge length changes during temperature cycles.

Seventh, the issue of drainage is addressed carefully. Water should be directed away from the embankment fill which should be protected against erosion. Using an erosion-resistant material near the abutment and geosynthetics to contain the fines are common erosion-prevention procedures.

Eighth, proper specifications are used in choosing material for the embankment fill, for compaction of the embankment, for drainage provisions, and for joint installations. It is particularly important to achieve required compaction against the backwall of the abutment.

Ninth, knowledgeable and thorough inspection during construction, in particular on the geotechnical aspects, helps to ensure a quality finished product.

Tenth, the final inspection prior to opening the structure to traffic includes:

- Verifying that the joints were installed correctly and have been tested for water-tightness;
- Verifying that the roadway profile meets grade specifications for the bridge deck and the approach roadway; and
- Verifying that the structure and roadway drains are adequate.

As mentioned earlier, these steps do not lead to the absence of a bump but rather to minimizing this problem. While all efforts should be made to solve the problem at the design stage, it will always be wise to provide for an easy future maintenance.

CHAPTER ONE

INTRODUCTION

There are approximately 600,000 bridges in the United States. Thirty-five percent of those bridges are deficient and the cost of repair is estimated at $78 billion (*1*). A part of this infrastructure degradation is a problem known as the bump at the end of the bridge (2). This problem has been studied by a number of state departments of transportation and researchers and has been the subject of two previous National Cooperative Highway Research Program (NCHRP) studies: *Synthesis of Highway Practice 2: Bridge Approach Design and Construction Practices* (*3*) and *Synthesis of Highway Practice 159: Design and Construction of Bridge Approaches* (*4*). Synthesis 159 discusses in detail various technologies associated with minimizing settlement, such as ground improvement techniques, which are not the focus of the current synthesis.

The bump develops when there is differential settlement or movement between the bridge abutment and the pavement of the approach embankment. Figure 1 illustrates a typical bridge approach system and the components involved. The bump may cause riding discomfort and is a potential safety hazard to motorists. Hazard and inconvenience are compounded when a lane is closed to traffic to make repairs. When the differential movement occurs, a discontinuity may also develop in the alignment of guard rails. A bump that is allowed to persist increases the chance of damage to the bridge deck from the dynamic impact of vehicles. Hu et al. (*5*) calculated that these impact loads may be four to five times larger than the static loads. Damage to the bridge deck can also be caused by snow plows in the winter (*6*). In addition, the bump can cause damage to vehicles.

For these reasons, all state DOTs remedy the problem in some way. A survey of the state DOTs indicates that the cost of repairing the bump is significant, though only a small fraction of most DOT operations budgets are allocated to this concern. With 150,000 bridges in the nation affected by this problem, the total estimated cost is at least $100 million dollars per year; this aspect is discussed in chapter 4.

Identifying the cause of the problem can be very complex. Both causes and solutions are site-dependent and can also be design-dependent. To understand why the bump occurs, one must have a knowledge of the components involved. These are described in chapter 2. The current practice and the techniques for mitigating the problem of the bump at the end of the bridge are the focus of this synthesis. Chapter 3 examines the previous works on these topics, while chapter 4 explains the current practice of detection, design, construction, and maintenance based on the survey responses from departments of transportation (Appendixes A and B). Conclusions and recommendations for future work are found in chapter 5.

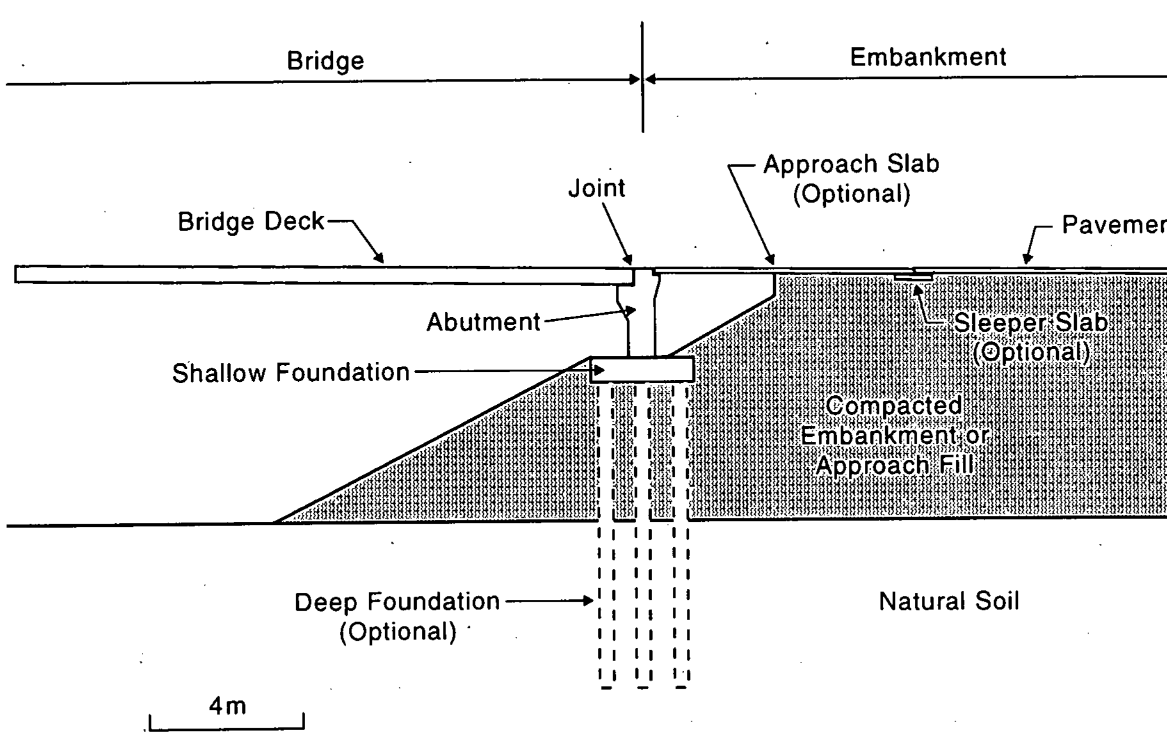


FIGURE 1 Elements of a bridge approach system.

CHAPTER TWO

COMPONENTS INVOLVED

Many components are involved in the development of the bump at the end of a bridge (Table 1) and many factors contribute to its existence (Figure 2), which make identifying the cause and a feasible solution very complex. This chapter discusses the various components and their relation to the bump at the end of the bridge.

TABLE 1

ITEMS THAT AFFECT BRIDGE APPROACH PERFORMANCE (after *7*)

Soil types	Rock Granular Compressible soil Expansive soil
Foundation types	Pile supported Spread footing, shallow Spread footing, deep Spread footing on MSE wall
Structure types	C.I.P. concrete Precast, prestressed concrete Post tensioned concrete Steel
Abutment types	Spill through Pile supported Column and spread footing supported Vertical wall Integral with superstructure
Bridge-end condition	Fixed Expansion
Construction methods	Build structure first Build end fills, then bridge end bents Construct wingwalls on falsework Construct wingwalls on fills
Roadway paving	AC paving PC paving Terminal anchor for CRCP paving
Bridge/roadway joint	Expansion joint No expansion joint

NATURAL SOIL

Compression of the natural soil is a problem common to most bridge projects. Knowing the type of natural soil on which the bridge and the approach embankment are to be built gives an indication of future performance. Rock, gravel, and sand deposits are not likely to result in long-term settlement problems. Compression of these cohesionless soils usually occurs as soon as the load is applied with small long-term settlements. However, clays and silts are much more likely to exhibit time-dependent settlement and lateral deformations. Penetration tests can give an idea about the softness of a clay or a silt, but the strength and compressibility of the soil must also be measured properly.

It is very important to accurately calculate both short-term and long-term settlement for the bridge and for the approach embankment. At the design stage, knowing that settlement of the approach embankment is expected can guide design and construction decisions to prevent or minimize the formation of the bump. Briaud and Tucker (*8*) and Briaud and Gibbens (*9*) give an overview of settlement calculations for embankments on natural soil and spread footings on sand. Other problems to be kept in mind and addressed in the design process are the short- and long-term stability, and creep related lateral deformations.

APPROACH FILL

There are many types of approach fill materials that can be used. Fill material that is readily available may be more economical but may not perform as well as a select fill material, which typically is a granular, cohesionless soil with some fines that will compact easily and will result in little or no post-construction settlement if properly compacted. The compaction process is of paramount importance to reduce the bump problem. Even with proper compaction, fills with significant clay content may exhibit time-dependent movements, including heave or settlement.

Lightweight fills may be useful. They lessen the load of the embankment on the natural soil, thus reducing the amount of settlement that occurs in the natural soil. Wahls (*4*) and Elias and Christopher (*10*) list lightweight fills that have been used. They include tree bark, sawdust, peat, fuel ash, slag, cinders, scrap cellular concrete, low-density cellular concrete, expanded clay or shale (lightweight aggregate), and expanded polystyrene. However, some of these materials may introduce other problems, such as consolidation of bark, sawdust, peat, and deleterious effects on other elements (cinders around steel). It is essential to select these materials with great care (*10*).

FOUNDATION

The bridge abutment requires a foundation. This foundation can be bored piles, driven piles, or spread footings (Figure 3). The foundation type depends on the foundation soil, the type

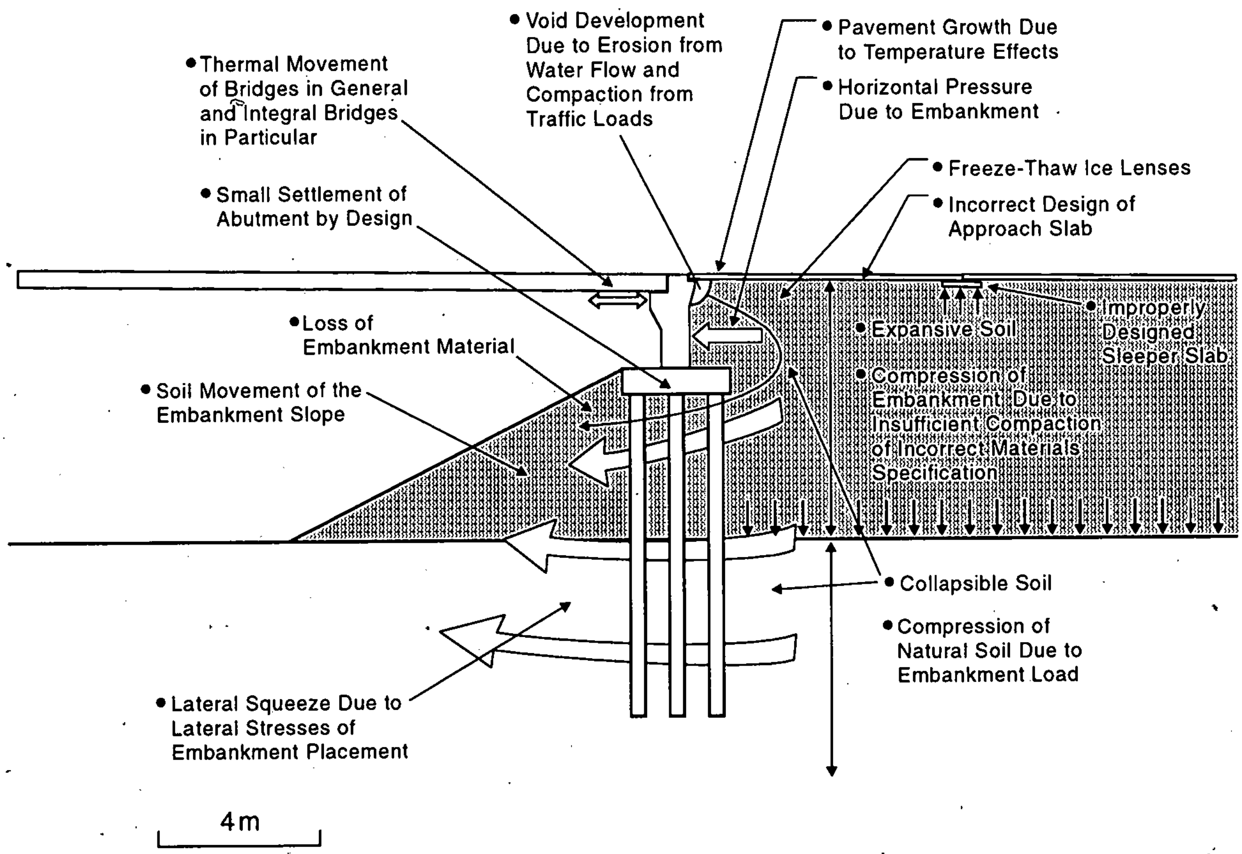


FIGURE 2 Problems leading to the existence of a bump.

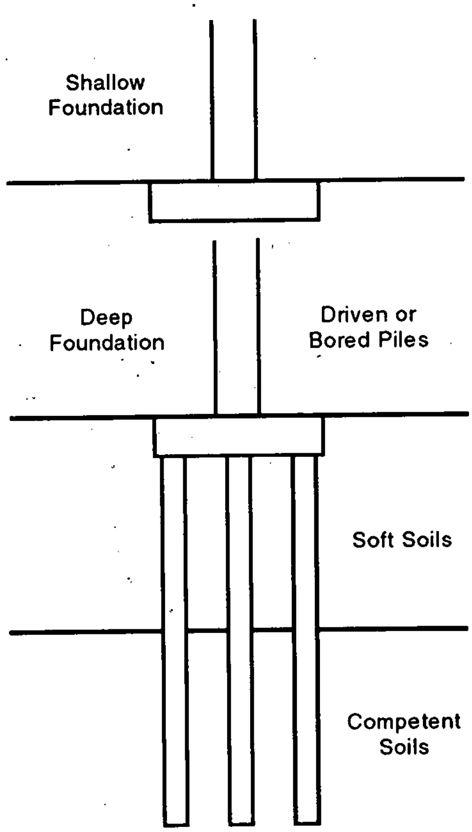


FIGURE 3 Types of foundations.

of bridge (which will determine the load carried by the abutment), and whether the structure bridges over water or not. Different soil types have different engineering properties. Depending on the bearing capacity and deformation properties of the soil, some foundation types may be more suitable than others. For example, if the natural soil is made of soft clay or silt, a pile foundation is typically used to transfer the load to a more suitable soil type. Sometimes, battered piles are used because of their ability to resist lateral forces from the embankment fill (Figure 4); however, seismic forces can "punch" these piles through the deck. Bored piles are constructed of concrete and reinforcing steel. Driven piles are typically prestressed concrete piles or steel piles, though sometimes timber piles are used.

Shallow foundations, or spread footings, that rest in the embankment fill have also been successfully constructed on many soil types. Laguros et al. (*11*) indicate that the bump problem and differential settlement occurred less frequently when a shallow foundation was used in this manner. The reason is that the abutment settles with the embankment and the part of the bump due to the differential settlement between the embankment and the abutment is not there. In a way, the spread footing plays the role of the sleeper slab and the first span plays the role of the approach slab.

It is a little-known fact that deep foundations settle about the same amount on the average as shallow foundations. This was demonstrated in two independent studies performed by Moulton (*12*) and Hearne (*13*). Deep foundations do settle, yet

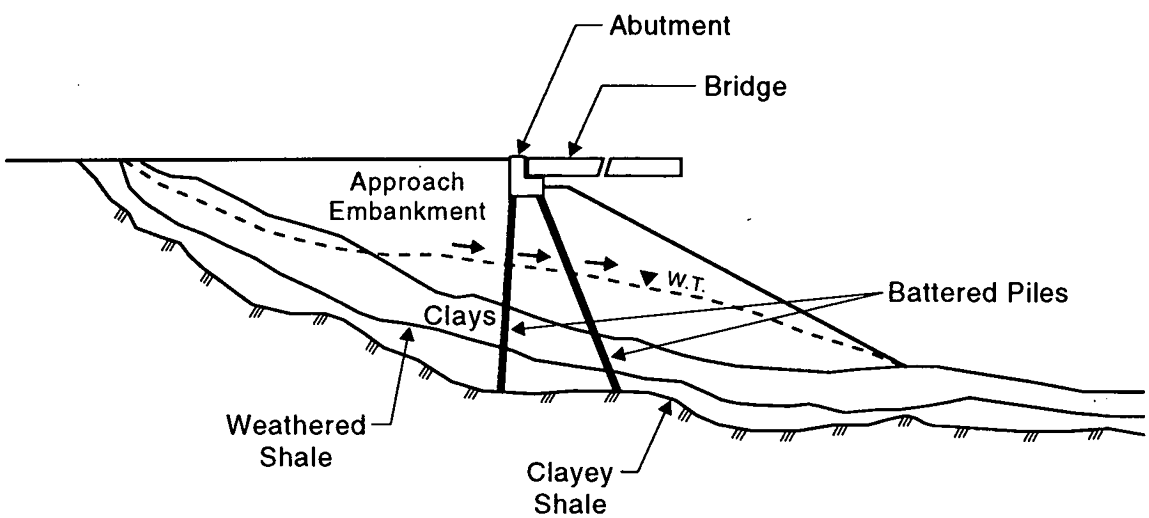


FIGURE 4 Example of battered piles (after *4*).

settlement calculations for deep foundations are very rarely performed, perhaps due to the myth that they do not settle. On the other hand, shallow foundations can be designed to meet a design settlement. Shallow foundations are rarely used for river crossings because of scour problems; they are also rarely used directly on very compressible soils.

ABUTMENT TYPE

The purpose of the abutment is two fold: the abutment supports the structural loads, and the abutment wall, together with the wingwalls, retains the approach embankment.

There are three major and at least two minor types of abutments. The major types are closed or high abutment, stub or perched abutment, and pedestal or spill-through abutment (Figure 5). A closed abutment has a wall that extends the entire height of the embankment and must be constructed before the embankment. In this case, it is difficult to compact the embankment fill near the abutment due to the confined space. Closed abutments are also subjected to higher lateral earth pressures than other abutment types.

Stub or perched abutments (Figure 5) are generally constructed after the embankment is constructed up to the height that corresponds to the bottom of the abutment. This simplifies the fill compaction process, except for the compaction of a small amount of backfill behind the abutment. Such abutments may rest on a shallow foundation in the embankment or on piles. Because the stub or perched abutments do not extend the entire height of the embankment, they experience the lowest lateral earth pressures of the three types.

Pedestal or spill-through abutments are stub abutments supported on columns, as seen in Figure 5. This type of abutment must be constructed before the embankment. The embankment fill will be built up on both sides of the supporting columns. It is difficult to compact the fill in the area near the abutment, especially between the columns. However, spill-through abutments also experience lower lateral earth pressures than closed abutments because there is no solid structure preventing the lateral movement of the soil (*4*). For the same reason, this lateral movement continues after construction is complete.

There are at least two other types of abutments in use. They are integral abutments and mechanically stabilized abutments. Integral abutments (Figure 5), while still not common, offer several advantages and may become more popular. In this situation, the bridge and the abutments are connected as a single structure with no expansion joint between them. Burke (*14*) shows that many DOTs have retrofit nonintegral abutments to integral or semi-integral abutments. A joint is still needed, however, between the bridge and the approach roadway for temperature compensation. While integral abutments add structural advantages, they also introduce thermal movements into the approach system. Such thermal movements add to the approach bump problem. Integral abutments also require special attention to the lateral load imposed on the foundation piles by the horizontal movement of the abutment induced by temperature cycles. Greimann et al. (*15*) describe a pile design example for integral abutments.

Mechanically stabilized abutments are stub or perched abutments founded on a spread footing resting on the reinforced embankment fill (Figure 5). The embankment fill is reinforced with geosynthetics or metallic reinforcement. This reinforcement essentially absorbs the lateral pressures caused by the embankment fill. Mechanical stabilization also allows a vertical slope at the edge of the abutment; this leads to shorter bridges with the same available opening underneath for traffic or for the stream channel. The construction of mechanically stabilized backfill (MSB) is simple and time-efficient. It is being used in a wide variety of projects including landslide repair, retaining walls, and highway embankment construction (*16*).

Wingwalls are a component of the abutment (Figure 6). They extend outwardly from the abutment, away from the bridge. The purpose of wingwalls is to contain the approach fill material near the abutment. Wingwalls can be perpendicular to the abutment or extend out at an angle. Typically, the

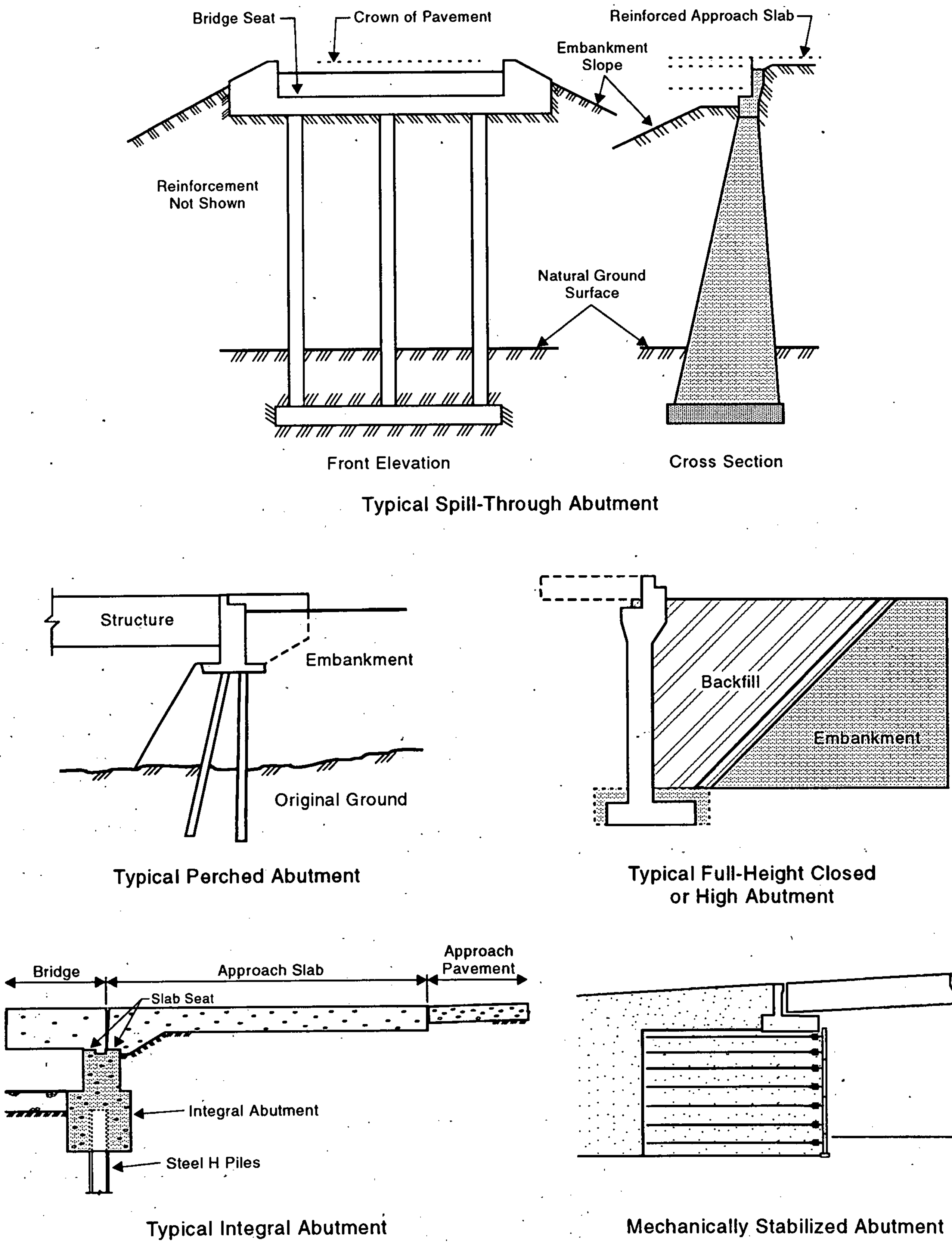


FIGURE 5 Types of abutments (after *4*).

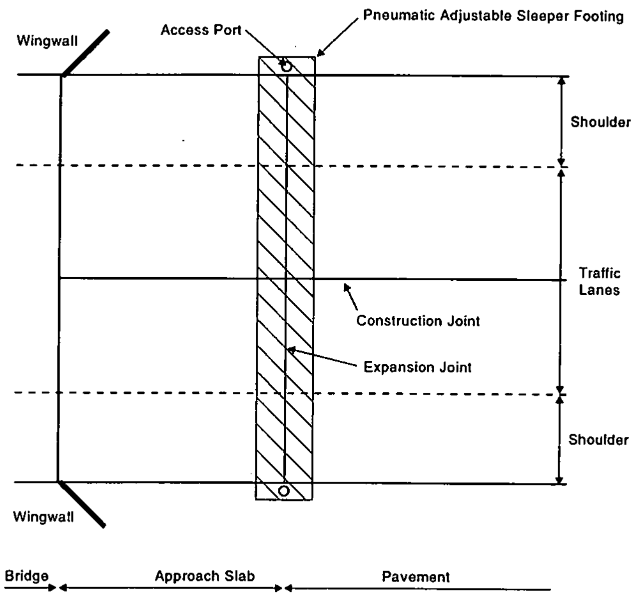


FIGURE 6 Plan view of an approach system (after *17*).

height of the wingwalls decreases as the distance from the bridge increases.

STRUCTURE TYPE

The type of structure can have an effect on the magnitude of the bump at the bridge approach. Conversely, distress at the bridge approach may have an effect on the bridge, depending on the bridge type.

Aside from the depth of foundation, the type of abutment, and the approach slab, the most significant aspect of bridge type in relation to the bump is the type of support for the end span. Simply supported end spans predominate in the United States and are more tolerant of abutment movement than spans that are continuous over the first interior bent. When the bump at the approach is due to movement of the abutment relative to the interior supports, the effect on the negative bending moment of continuous end spans can be significant.

Earlier studies usually do not report a significant correlation between the bridge or abutment type and the presence of a bump. An exception is the bump associated with the thermal expansion of integral abutment bridges; these bridges represent a small fraction of the nation's bridge population but are more prominent in some states (*18*). For such bridges, the abutment is rigidly connected to the bridge deck and the thermal expansion of the bridge deck compacts the backfill behind the abutment. When the bridge deck cools off and shortens, a gap opens behind the abutment where the fill can fall. This leads to a loss of ground behind the abutment and to a bump. As a result, integral bridges should be constructed with full-width approach slabs (*19*). Wolde-Tinsae et al. (*20*) also report that aspects of poor structural design, including excessive camber or sag in the first span of the bridge, gaps forming between the backwall and roadway fill, additional stresses on the approach pavement, cracking of the backwalls, and cracking of the wingwalls can affect the magnitude of the bump.

Distress at the bridge approach has been noted to adversely affect the actual impact loading experienced by the end span. The magnitude of this increased impact loading has been estimated to be much greater than the maximum value of 30 percent estimated in design procedures. This impact overloading may have different effects on different deck and superstructure designs. Qualitative field observations (*21*) indicate that deck cracking under heavily loaded truck traffic is more pronounced on steel I-beam bridges than on prestressed concrete girder spans.

BRIDGE/ROADWAY JOINT

Joints and sealers in concrete pavements (*22, 23*) can contribute to motorist discomfort if they are not properly constructed and maintained. An expansion joint is sometimes used to allow for thermal changes that occur in the bridge and the approach system (Figure 6). An expansion joint that is properly maintained will cause few problems. However, if the seal in an expansion joint is allowed to deteriorate or is improperly installed, debris will collect in the joint and the structure will have no room to expand. This can cause distress to the bridge or the abutment.

Another problem with poorly maintained joints is that water can infiltrate through them into the fill material behind the abutment. This can erode the fill material or cause increased pressure on the abutment wall.

Integral abutments, discussed earlier, do not provide for an expansion joint between the bridge and the abutment. Thermal movement of an integral abutment does cause compression of the adjacent fill, creating a void, first behind the abutment and then beneath the approach slab (*18*). A joint will form at the bridge end if no provision is made for it.

Burke (*24*) explains that properly designed approach slabs used with integral bridges will eliminate some approach distress caused by the formation of the void, but the approach slabs will still experience cyclic movements that may eventually push the slab off its seat if not designed properly. To prevent this from happening, engineers have tied the approach slab to the integral bridge. This may improve the approach slab movement, but an expansion joint is still needed. If this expansion joint is not properly maintained, the problem is moved to the pavement end of the bridge approach. Bellin (*25*) maintains that integral bridges with approach slabs tied to the bridge show joint deterioration at both ends of the approach slab. Opinions vary concerning the effectiveness of approach slabs with integral bridges.

APPROACH SLABS

Approach slabs are reinforced concrete slabs used to span the problematic area between the approach pavement and the bridge abutment (Figures 1 and 6). They are used in 80 percent of new bridges (*18*). Approach slabs are designed to span various lengths, but 4 to 7 m (13 to 23 ft) is a typical range. However, Stark et al. (*26*) advocate the use of 20 m-long (66 ft) approach slabs because the observed cradle of settlement at approaches extends that far. The thickness of approach slabs also varies. Typically they are 225 to 305 mm (9 to 12 in.) thick. The slabs may be supported at both ends; the bridge end support is provided by the abutment and the pavement end support by a sleeper slab (Figure 1) or by the roadway embankment. A sleeper slab is a footing that extends the entire width of the roadway. Some approach slab details are presented in Appendix C.

The intended function of an approach slab is:

1. To span the void that may develop below the slab;
2. To prevent slab deflection, which could result in settlement near the abutment;
3. To provide a ramp for the differential settlement between the embankment and the abutment. This function is affected by the length of the approach slab and the magnitude of the differential settlement: and
4. To provide a better seal against water percolation and erosion of the embankment.

The portion of the embankment under the approach slab is difficult to construct to the same compaction standards as the major portion of the embankment and is more susceptible to live-load induced deformation. This is true whether an approach slab is used or not. Other than the availability of high-quality fill materials and well-controlled compaction, the approach slab appears to be the most important component in the bridge for reducing the bump at the approach. Survey replies confirm this with a consensus of respondents mentioning the positive aspects of approach slabs in preventing or minimizing the problem. A few comments, however, pointed out that approach slabs work only if bridge movements are provided for and expansion joints prohibit water from entering the approach fill and that approach slabs are expensive, often do not work, and are difficult to construct. Stewart presents a study of approach slab performance through case histories (*27*).

One different configuration for bridge approach slabs is to use a 50 m-long (152 ft) approach slab supported on piles of diminishing penetration. This provides a smooth transition from the bridge abutment, which is on long piles, and the pavement, which is a slab on grade. This solution is rated as "very promising" by Kemahli (*28*). While the concept of providing a gradual transition between two often very different types of support systems is sound, the cost of such a solution appears to be quite high.

The question of when to use an approach slab is a difficult one to answer (29). The decision should be based on the amount of calculated or anticipated differential settlement between the abutment and the embankment, the ability to achieve good compaction, and the ability to prevent erosion or loss of support due to water infiltration. Wahls (*4*) and Stark et al. (*26*) mention that a slope of 1/200 is acceptable from the standpoint of riding comfort. It seems that the change in slope, more than the slope itself, is critical. The statements by Wahls and Stark et al. may be interpreted to mean that a change in slopes of less than 1/200 is allowable (Figure 7).

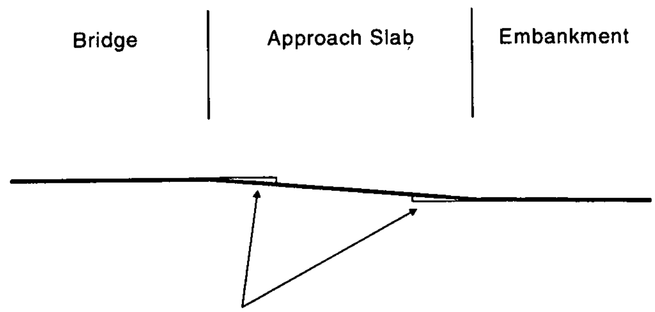


FIGURE 7 Allowable criterion for approach slab slopes (after *4* and *26*).

ROADWAY PAVING

There are three common types of roadway pavement: asphalt concrete (AC) pavement, portland cement jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP). The AC pavement is flexible and is placed on top of the subbase, base course, and sometimes the seal coat system. An AC pavement frequently deforms more easily, especially under high temperatures or high truck traffic. The JRCP and CRCP pavements are rigid pavements placed directly on a base layer. Reinforced concrete pavement lugs may extend into the base and fill to anchor the ends of the CRCP. Such lugs could also be used on JCRP slabs near bridges to minimize the movement at expansion joints. JRCP and CRCP pavements often experience some amount of pavement growth that can eventually close the expansion joints. These joints are designed to compensate for the thermal expansion and contraction of the pavement. Pavement growth, whether due to thermal expansion or alkali-silica reactions (ASR), can lead to severe abutment distress and increased likelihood of a bump at the approach (*30, 31*). Flexible pavements exhibit types of distress that differ from rigid pavements. For example, rutting of flexible pavements can result from improper compaction of the embankment backfill near the abutment.

CONSTRUCTION METHOD

Construction methods can play a significant role in the formation of the bump at the bridge end. The approach embankment can be constructed either before or after the bridge and abutment structures. This choice depends on the type of abutment used and sometimes on the type of structure. As stated previously, closed and spill-through abutments require the construction of the abutment first. Perched abutments are constructed after the embankment is placed. If the approach embankment is constructed first, post-construction settlement will be reduced. More recently, mechanically stabilized earth

(MSE) abutments have been used successfully and seem to reduce the bump problem, if piles are not required for seismic or other design concerns.

Another issue is compaction of the fill material. Inadequate compaction of the fill can lead to post-construction compression of the embankment and the formation of the bump. This can especially be a problem near the abutment. It is desirable to leave at least 3 m (9 ft) between the abutment wall and the embankment so that large equipment can compact the approach fill material near the abutment (7). In some states, heave of the embankment in relation to the abutment results from swelling soils.

CHAPTER THREE

LITERATURE REVIEW

For this synthesis, a literature search was performed through the Transportation Research Information Service (TRIS) files. The abstracts were ranked and those reports most directly related to the topic of the bump at the end of the bridge were chosen for review. They are all listed in the references. Several of these works were syntheses, which involved a literature search and a survey of transportation agencies. The reports pertaining to research performed commonly addressed the inspection of bridges and bridge sites. This chapter provides an overview of the findings.

Among the most notable recent studies are:

- Stark et al., 1995, "Differential Movement of the Embankment/Structure Interface—Mitigation and Rehabilitation" (*26*)
- Yeh and Su, 1995, "EPS, Flow Fill and Structure Fill for Bridge Abutment Backfill" (*32*)
- Hearn G., 1995, "Faulted Pavements at Bridge Abutments" (*13*)
- Chini et al., 1993, "Drainage and Backfill Provisions for Approaches to Bridges" (*33*)
- Schaefer and Koch, 1992, "Void Development Under Bridge Approaches" (*18*)
- James et al., 1991, "A Study of Bridge Approach Roughness" (*30*)
- Kramer and Sajer, 1991, "Bridge Approach Slab Effectiveness" (*29*)
- Laguros et al., 1990, "Evaluation of Causes of Excessive Settlements of Pavements Behind Bridge Abutments and Their Remedies—Phase II" (*11*)
- Whals, 1990, "Design and Construction of Bridge Approaches (*4*)
- Wolde-Tinsae and Aggour, 1990, "Structural and Soil Provisions for Approaches to Bridges" (*34*)
- Tadros and Benak, 1989, "Bridge Abutment and Approach Slab Settlement"(*17*)
- Snethen, D. R., 1997, (forthcoming) "Instrumentation and Evaluation of Bridge Approach Embankments. US 177 Bridges over Salt Fork River" (*35*)

This reference is a study by Oklahoma State University (Don Snethen, Civil Engineering) for the Oklahoma DOT on a detailed observation of the behavior of six bridge approach embankments built using five different techniques, including controlled low-strength backfill, geosynthetics-reinforced backfill, dynamic compaction, granular backfill, select material.

- West Virginia University, 1997 (forthcoming) "Study of Bridge Approach Behavior and Recommendations on Improving Current Practice" (*36*).

This reference is a study to be completed in the near future by West Virginia University for the West Virginia DOT. The project is studying the performance of poorly and well-performing approaches to assess the magnitude of the problem and develop recommendations for further action.

GENERAL FINDINGS

The percentage of bridges affected by approach settlement is not clear from reviewing the literature. Stark et al. (*26*) do mention that in a survey of 1,181 bridges in Illinois, 27 percent exhibited a significant bump. If few reports discuss the percentage of bridges affected, nearly all the reports come to similar conclusions about the possible causes of the bump. These include:

- Settlement of the natural soil under the embankment,
- Compression of the embankment fill due to inadequate compaction of the fill, and
- Poor drainage behind the bridge abutment and related erosion of the embankment fill.

Some reports also suggest that horizontal forces on the abutments could be a cause of the bump (*17, 37*). These horizontal forces are due to longitudinal pavement growth (*30, 31*) or soil pressures (*17*). James et al. (*30*) state that longitudinal pavement growth may influence approach roughness; they ranked 131 Texas bridges according to the severity of the bridge approach roughness. Those bridges with rigid pavements had more severe roughness than those with flexible pavements. Provision for bridge and roadway expansion/contraction may have a significant effect on the degree of roughness at the bridge end.

Another cause of approach problems mentioned was void development beneath the approach slab. This could be caused by thermally induced movements of integral abutments that compact the fill (*18, 13*) or, as mentioned before, by the erosion of the fill material aggravated by pumping. Laguros, Zaman, and Mahmood (*11*) found that higher embankments experienced greater amounts of settlement and therefore have more roughness problems. The Kramer and Sajer (*29*) study for the Washington State Department of Transportation discusses contributing causes of bump formation. Table 2 is a summary of their findings.

Schaefer and Koch (*18*) in South Dakota give specific recommendations for limiting the bump when it is caused by thermally induced movements of integral abutments compacting the backfill. They recommend that:

1. Shoulder areas of approach embankments should be capped with asphaltic concrete.

TABLE 2

CAUSES OF BRIDGE APPROACH PROBLEMS CATEGORIZED (after *29*)

Differential Settlement	
Compression of natural soils	Primary consolidation, secondary compression, and creep
Compression of embankment soils	Volume changes and distortional movements/creep of embankment soils
Local compression at bridge/pavement interface	Inadequate compaction at bridge/pavement interface, drainage and erosion problems, rutting/distortion of pavement section, traffic loading, and thermal bridge movements
Movement of Abutments	
Vertical movement	Settlement of soil beneath, downdrag, erosion of soil beneath and around abutment
Horizontal movement	Excessive lateral pressures, thermal movements, swelling pressures from expansive soils, and lateral deformation of embankment and natural soils
Design/Construction Problems	
Engineer-related	Improper materials, lift thickness, and compaction requirements
Contractor-related	Improper equipment, overexcavation for abutment construction, and survey/grade errors
Inspector-related/Poor quality control	Lack of inspection personnel and improper inspection personnel training
Design-related	No provision for bridge expansion/contraction spill-through design resulting in the migration of fill material from behind the abutment

2. Mudjacking should be performed when a void extends back 3 m from the abutment, or if the void reaches a height of 100 mm (50 mm in high traffic areas).
3. The reinforcement of the approach slab should be designed to minimize the transverse cracking that occurs near the abutment/approach slab interface.
4. The slope of the cut made for backfill placement be changed to measure between 4H:1V and 2H:1V.
5. The gradation of the backfill material be changed to a slightly finer, more well-graded material, and the requirement of fractured faces be dropped.
6. The use of the filter wrap should be continued to prevent erosion and raveling of the granular materials and as a separator for future mudjacking.

A 1994 study performed by Zaman et al. (*38*) for the Oklahoma Department of Transportation resulted in a statistical model that predicts problematic bridge approaches prior to construction. They identify several factors that may affect bridge approach performance, including age of the approach, embankment height, foundation soil thickness, skewness of the approach, traffic volume, embankment, and soil characteristics. The model calculates total bridge approach settlement. Any settlement over 25 mm is considered problematic by this model. Stark et al. (*26*) consider that a settlement of 50 to 75 mm would create serious riding discomfort. In their discussion of settlement gradient, they state that gradients of 1/100 or 1/125 create significant riding discomfort and agree with Wahls (*4*) that gradients of less than 1/200 are acceptable.

Hearn (*13*) gives a very detailed review of the bump problem including a summary of methods available to calculate settlement. He points out, as Moulton does (*12*), that there is essentially no difference in the settlement magnitude between abutments on piles and abutments on spread footings. This statement is based on the measured settlement of nearly 1,000 structures, including 350 bridges and 50 embankments. Hearn found a difference of only 10 mm between the median settlement of embankments and abutments with the embankments settling more. He indicates that bridges can tolerate more settlement than the present perception and gives a relationship between the differential settlement s_d between adjacent points and the mean total settlement s_m; the ratio s_d/s_m is about one third. His data lead to various relationships on settlement observations.

The studies give similar recommendations for preventing or repairing the problem. These recommendations can be classified into three categories of improvements that correspond to the major causes of the bump at the end of the bridge: improvement of the natural soil, improvement of the fill, and erosion reduction.

IMPROVEMENT OF THE NATURAL SOIL

The goal in improving the natural soil is to minimize the amount of settlement that will occur under the embankment and the abutment after construction. Improvement techniques include removal, densification, and soil reinforcement. Wahls (*4*) gives a good description of these various techniques. More recently, an ASCE Specialty Conference (*39*) and an FHWA demonstration project (*10*) give excellent details on the various techniques. Several reports (*4, 17, 40*) recommend performing time rate of settlement calculations to determine the severity of the problem. This will assist in choosing the most appropriate solutions for the situation. Hopkins and Scott (*40*) note that the amount of settlement that the natural soil experiences and

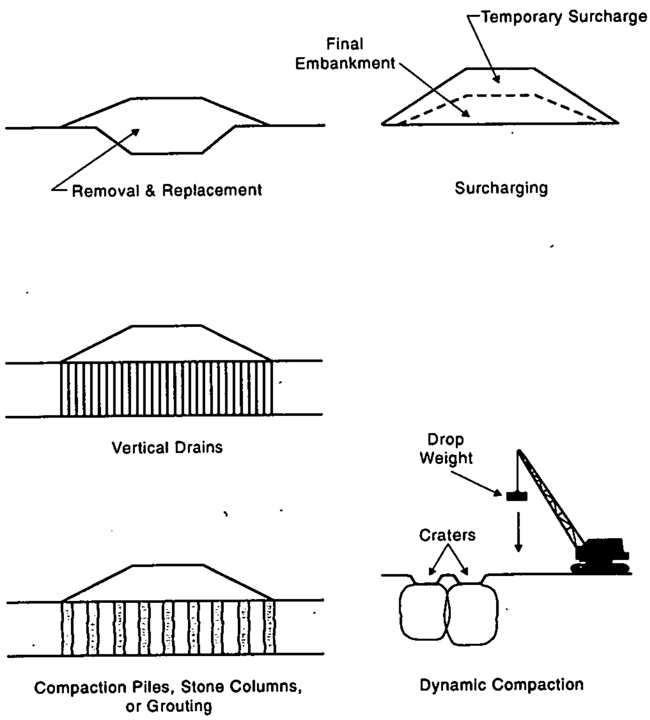


FIGURE 8 Roadway cross-sections illustrating densification methods.

contributes to the formation of a bump depends on when the approach pavement is placed.

Removal involves replacing the soft, compressible natural soil with one that will experience less settlement under the load of the approach embankment.

There are several methods of densification (*4*). They include waiting periods, surcharging, installation of vertical drains, dynamic compaction, compaction piles, and compaction grouting. Figure 8 gives an illustration of these methods. Waiting periods, or precompression, involves waiting until the rate of settlement has become small enough before completing construction. Surcharging consists of pre-loading the natural soil with an amount of embankment fill material greater than the final design fill height. This shortens the time period to reach the design settlement. In some subsurface conditions, vertical drains increase the rate at which water drains from the foundation soils, resulting in increased settlement rate and decreased time to final settlement. Dynamic compaction consists of dropping a heavy weight on the ground surface. Compaction piles are made of compacted granular backfill and are installed through the use of vibrocompaction or vibroflotation. Compaction grouting consists of forcing a viscous cement grout into the soil under pressure.

In situ techniques to reinforce the natural soil include stone columns, deep soil mixing, and embankment piles. Stone columns, similar to compaction piles, are created by backfilling cylindrical, vertical holes in the natural soil with compacted stone. Deep soil mixing involves combining lime, flyash, and cement with the natural soils using special mixing equipment. The third technique, embankment piles, uses timber or precast concrete piles to transfer the embankment load through soft soil deposits. The pile length decreases and pile spacing increases the greater the distance from the bridge. Many of the reports studied for this synthesis mentioned the above techniques for decreasing the amount of post-construction settlement of the natural soil.

Holmberg (*41*) cites several cases where embankment piles were successfully used in conjunction with an abutment resting in the embankment fill to minimize the bump at the end of the bridge. According to Shields et al. (*42*), using an abutment on a spread footing that rests in the embankment fill allows the bridge and the fill to settle together. Grover (*43*) noted in his 1975 study that spread footing abutments have less differential settlement and smoother rideability, but that they appear to have more total settlement from the original plan grade than deep foundations. Scour is also a more serious concern with spread footings.

Pre-cambering is a design technique used in some states (such as Nebraska) to compensate for small amounts of post-construction settlement. Figure 9 illustrates this method. Tadros and Benak (*17*) explain, "By constructing the approach pavement to a somewhat higher profile than the bridge, the approach can experience fairly small settlements without a deterioration of riding quality."

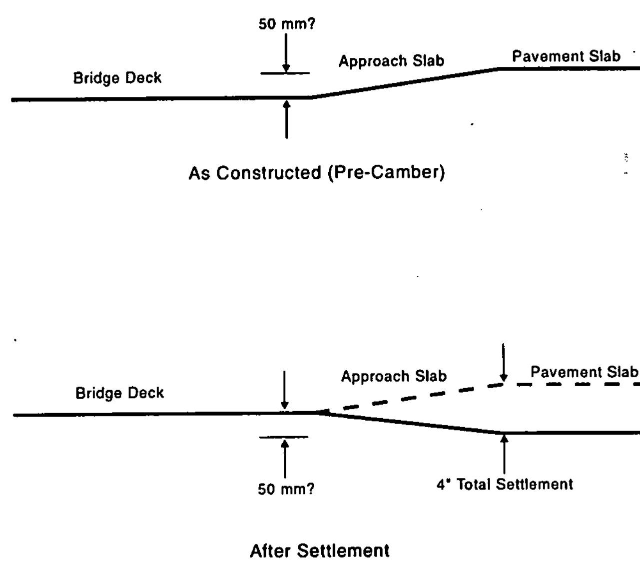


FIGURE 9 Precambering (after *17*).

EMBANKMENT FILL CONSIDERATIONS

The main concerns about the embankment material and, in particular, the abutment backfill (Figure 10) are the type of material used, how well it is compacted, and whether it is sensitive to erosion. The consensus of the reports studied is that a select material should be used behind the abutment to minimize compression. Chini et al. (*33*) cited select material specifications from the FHWA manual (*44*). These include requirements for gradation and soundness. The gradation is as follows:

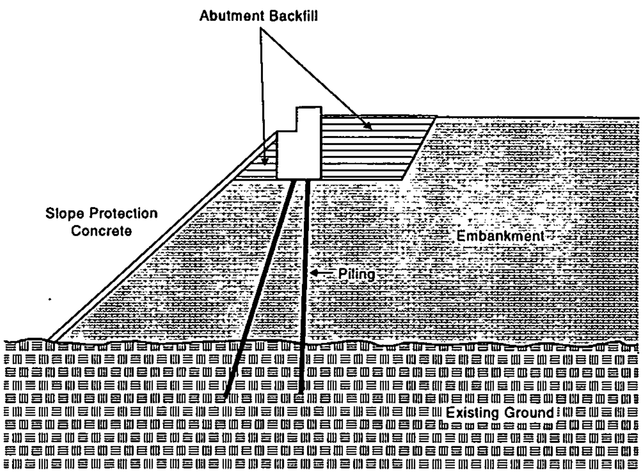


FIGURE 10 Distinction between abutment backfill and embankment (after *32*).

Sieve Size	*Percentage Passing by Weight*
100 mm (4 in.)	100
425 μm (No. 40)	0 to 70
75 μm (No. 200)	0 to 15

The soundness requirement states that the material shall be substantially free of shale or other soft, poor-durability particles. Wahls (*4*) cites specifications from California that require a maximum plasticity index (PI) of 15 and fewer than 40 percent fines within 45 m (150 ft) of an abutment wall. Several studies in England (*46, 47, 48*) show that fill specifications are not critical if proper care is taken when compacting the fill.

If select material is used, the major cause of fill compression is poor compaction. Kramer and Sajer (*29*) explore many reasons for this, including poor design criteria, inadequate equipment, and poor quality control. The literature frequently mentions that compaction is inadequate near the abutment because it is difficult for the compaction equipment to access this area. Figures 11 and 12 show examples of abutments with and without a corbel, which may be used to support an approach slab at the abutment. The presence of a corbel may hinder the compaction process. Because minimizing the compression of the embankment fill near the abutment is critical in preventing bump formation, more stringent compaction specifications are necessary near the abutment. California requires that the relative compaction be increased from 90 percent to 95 percent within 45 m (150 ft) of the abutment wall (*4*). Chini et al. (*33*) list maximum lift thickness and relative compaction used by several states for this situation. (These are shown in Table 3.) This statement applies to structurally retaining abutments. In the case of mechanically stabilized earth walls, these requirements and the equipment used may be quite different.

Stark et al. (*26*) recommend to reach 90 to 95 percent of the modified Proctor test maximum dry density, to compact dry of optimum in thin layers (0.15 to 0.2 m) of quality fill. They mention that the Ohio DOT requires that backfill contain less than 35 percent passing the U.S. Standard Sieve no. 200. They further suggest placing an additional layer of compacted fill above final grade to provide better compaction and higher confinement at final grade; this surcharge is removed before paving.

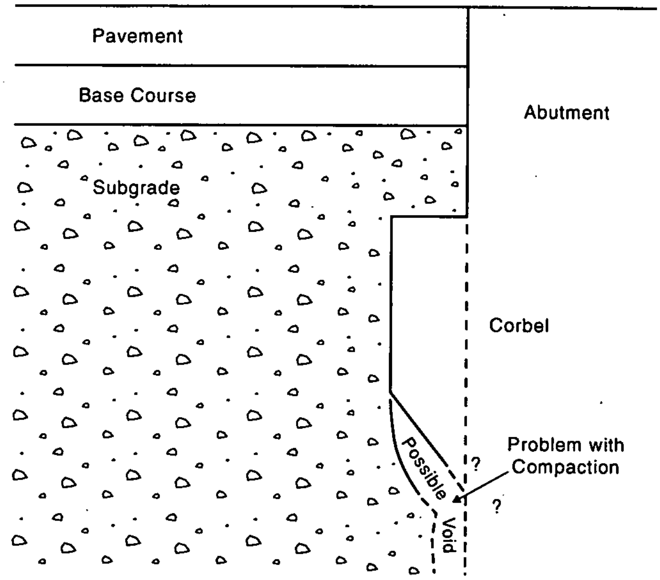


FIGURE 11 Abutment with a corbel as opposed to a vertical face (after *29*).

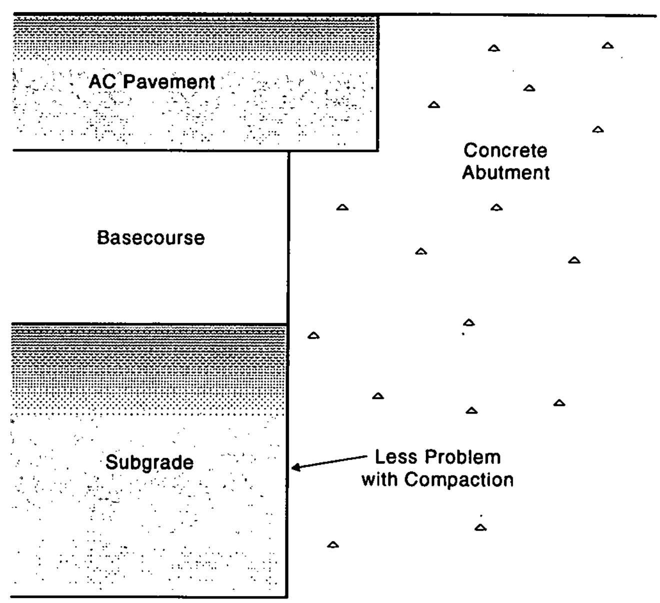


FIGURE 12 Abutment without a corbel (after *29*).

Another way to alleviate the problem of excessive fill compression or settlement of bridge approaches is to use jackable abutments or jackable approach slabs. The jackable abutments often placed on spread footings make it possible to counteract a bridge settlement larger than the approach settlement (*29*). This involves raising the bridge deck with hydraulic jacks. Tadros and Benak (*17*) suggest several solutions related to this idea; however, these solutions involve raising the approach slab and sleeper slab instead of the abutment. These solutions

TABLE 3
MAXIMUM LIFT THICKNESSES AND RELATIVE COMPACTION FOR EMBANKMENT MATERIAL AT ABUTMENTS (after *33*)

State	Maximum Lift Thickness (Loose Measurements)	Relative Compaction
Arizona	200 mm	95% AASHTO T99 (Standard)
Arkansas	100 mm	95% AASHTO T99 (Standard)
California	200 mm	95% *
Colorado	150 mm	95% AASHTO T180 (Modified)
Connecticut	150 mm	100% AASHTO T180 (Modified) D
Delaware	200 mm	95% *
Maine	200 mm	98% *
Michigan	220 mm	95% *
Missouri	-----	95% AASHTO T99 Method C
New Hampshire	200 mm	98% AASHTO T99 Method C
Ohio	-----	98% to 102 AASHTO T99
Rhode Island	250 mm	95% AASHTO T180 Method A or D
South Carolina	150 mm	95% *

* State Test Method ----- Not Specified 10 mm = 0.4 in.

include physical jacking of the slab, sleeper jacking, a pneumatic adjustable sleeper, and removable precast pavement panels. The raising of the slab is typically followed with mud-jacking. The removable panels allow more fill material to be placed beneath the slab to smooth the approach. The Nebraska study (*17*) also suggests the use of preformed grout holes in the approach slab to simplify mud-jacking. (While minimizing maintenance is a goal, some emphasize that the best approach is to solve the problem at the design stage, not later.) In the final analysis, the most economic and safest solution should be the best one.

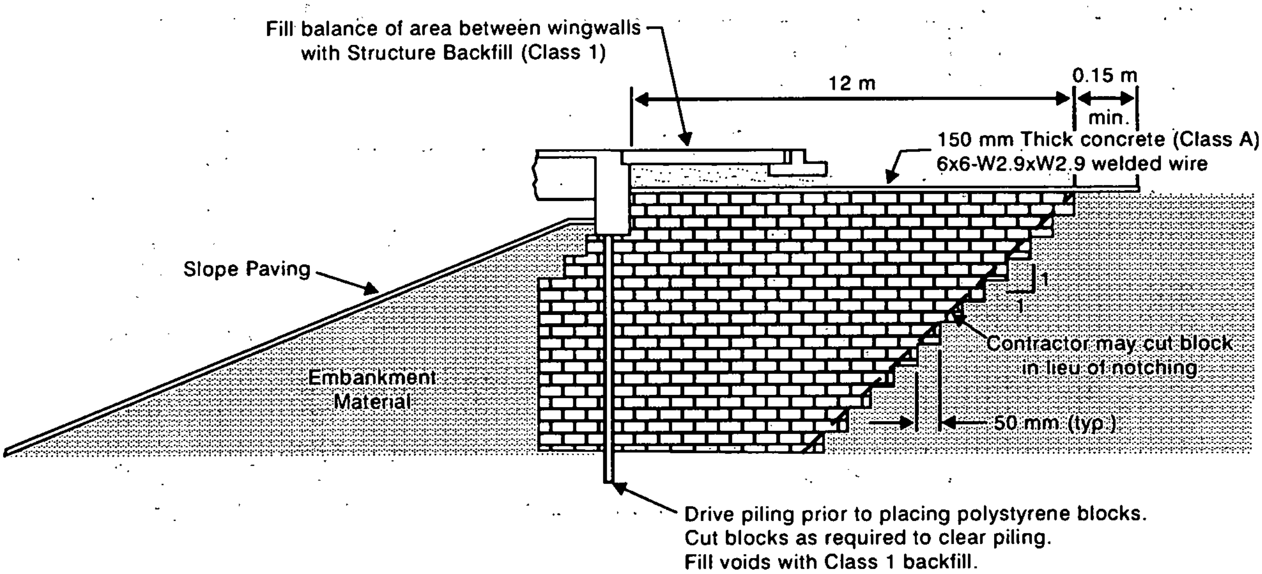
Using a lightweight fill for the embankment fill material is yet another method of dealing with approach settlement. Lightweight fill reduces the load carried by the foundation soil. This, in turn, reduces the amount of settlement that will occur but does not reduce the amount of time required for this settlement to take place. Lightweight materials include tree bark, sawdust, peat, fuel ash, slag, cinders, scrap cellular concrete, low-density cellular concrete, expanded clay or shale (lightweight aggregate), and expanded polystyrene. Some of these materials may introduce other problems, such as the consolidation of bark, sawdust, peat, or have deleterious effects on other elements (cinders around steel). It is essential to take great care in the selection of these materials. More details on lightweight fills can be found in Elias and Christopher (*10*) and in Magnan (*48*).

The use of mechanically stabilized earth (MSE) or mechanically stabilized backfill (MSB), in abutments has helped curb the problem of the bump (*49*). Mechanically stabilized abutments tolerate large deformations (*4*) and can accommodate the use of shallow foundations for abutments. In some states however, MSE walls create concern about seismic deformation of the soil mass. Some DOTs, such as New York, do not allow putting shallow foundations on MSE walls. Figure 5 illustrates the concept of mechanically stabilized abutments. Worrall (*50*), discussing the use of MSE in an abutment at Burton-on-Trent, states that "A Reinforced Earth abutment ensures that both the approach fills and bankseat settle together, eliminating the ever present bump." In the construction of the Bayou Louis Bridge in Louisiana, MSE was used to keep the embankment from placing pressure on the abutment wall (*51*). Christopher et al. (*52*) Wahls (*4*), and Mitchell and Villet (*53*) give thorough discussions on the topic of MSB. They include examples of the different wall types.

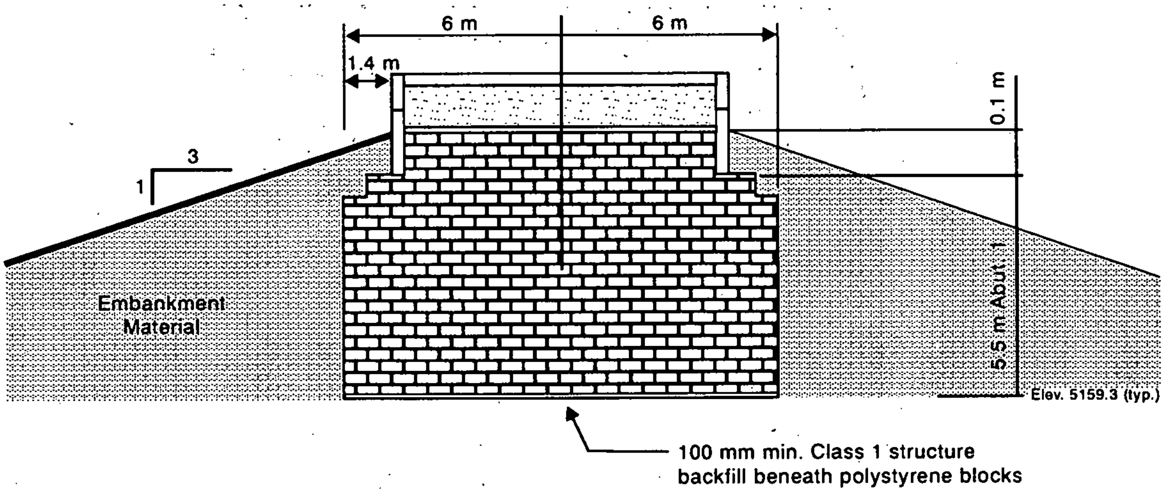
An interesting study was conducted by Yeh and Su (*32*) who used the following three abutment backfills (Figure 13) for six bridges in Colorado: expanded polystyrene (EPS), flow fill, and class 1 structure backfill. The EPS is a very lightweight fill that was placed in blocks (Figure 13). The unit weight of the blocks is 0.24 kN/m^3 (1.4 lb/ft^3). The flow fill is a low-strength concrete mix that is poured in place and has the advantage of strength without compaction (Figure 14). The class 1 structure backfill has a required gradation, 5 to 20 percent passing sieve no. 200, a liquid limit less than 35, and a plasticity index less than 6. It was compacted at a minimum of 95 percent of the maximum dry density (AASHTO T-180). On the basis of their movement and ride measurements, Yeh and Su conclude that the flow fill has the best performance among the three in controlling lateral pressure and movement behind the bridge abutments. Further, the flowfill shows the least post-construction compression and provides a better ride than the other two materials tested.

EROSION REDUCTION

The installation of appropriate drainage systems, which is very important at bridge approaches, keeps water from collecting behind the abutment or eroding the fill from behind the abutment. Both surface and subsurface drainage need to be considered. The surface run-off should be routed away from the bridge/approach joint. One recommendation toward an appropriate surface drainage system is to place the wingwalls beyond the bridge end panels (*54*). Another recommendation is to have a pavement wingwall assembly as shown on Figure 15. Either way, it is essential to keep water from infiltrating

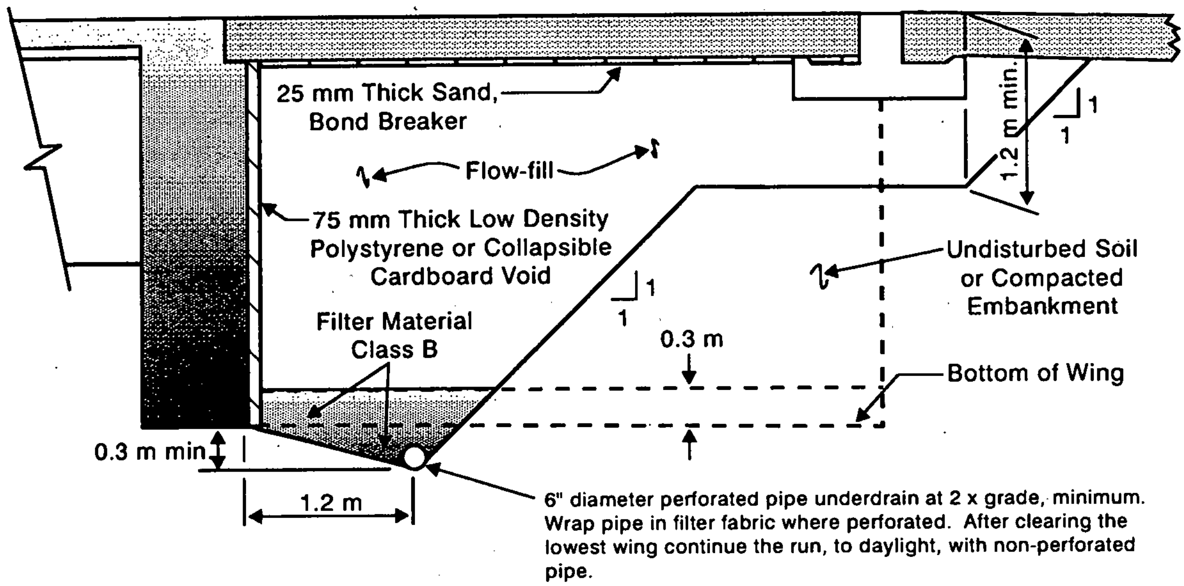


LONGITUDINAL SECTION

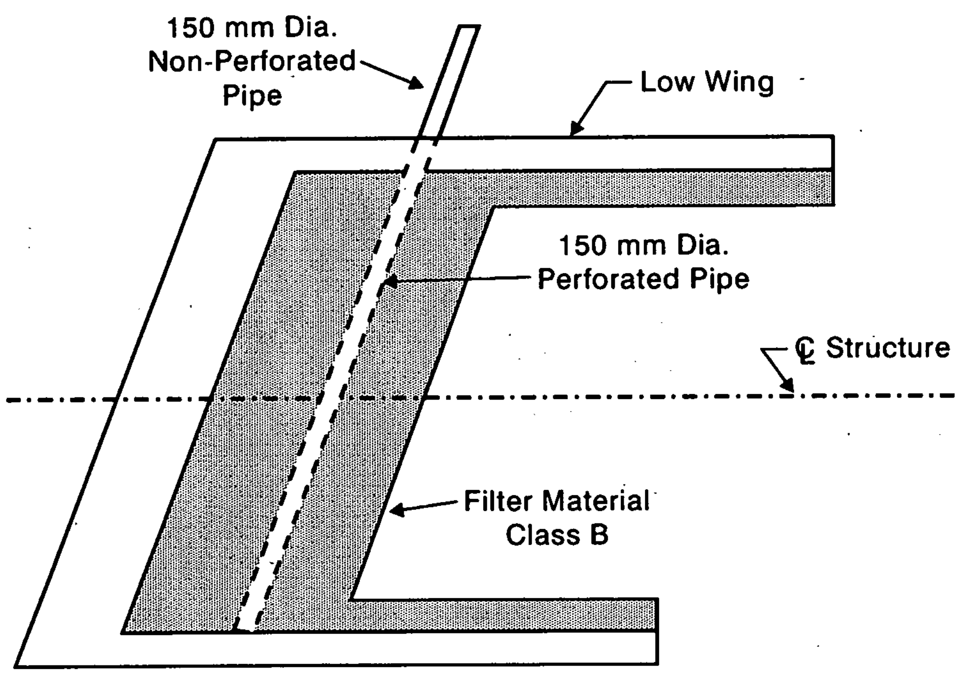


TRANSVERSE SECTION

FIGURE 13 Schematic of expanded polystyrene (EPS) embankment fill (after *32*).



Section Perpendicular to Abutment



Plan View of Abutment

FIGURE 14 Schematic of flow fill and abutment (after *32*).

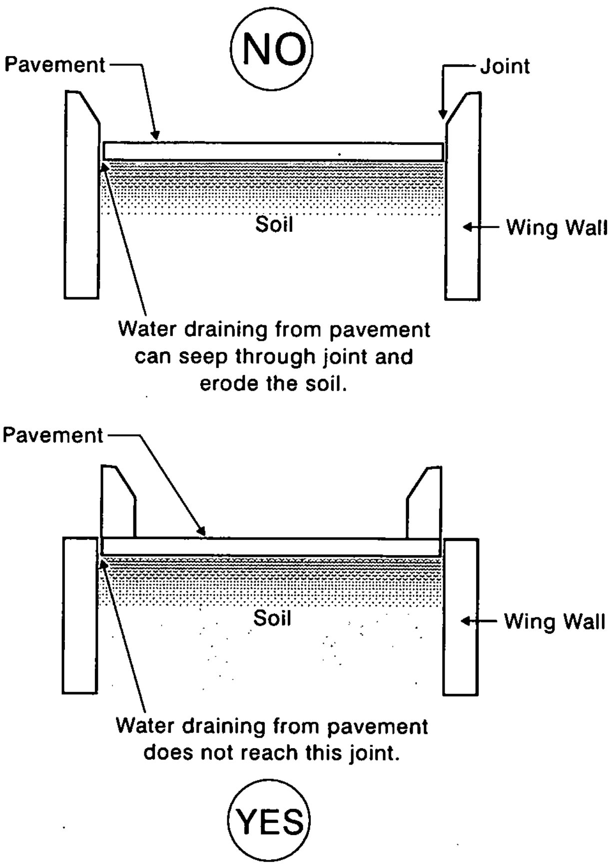


FIGURE 15 Cross-section showing wingwall and drainage detail.

the fill beneath the approach slab and behind the abutment. Reducing the amount of water flowing beneath the approach slabs will also reduce the amount of erosion occurring. Proper maintenance of approach slab joints will decrease the amount of water that infiltrates behind the abutment (*30*). Runoff should be directed away from the end of the bridge and should not be allowed to infiltrate the subgrade (*55*).

Chini et al. (*33*), Wahls (*4*), and Stark et al. (*26*) provide discussions about bridge approach drainage. Wahls suggests the use of gutters and paved ditches to direct surface water away from the bridge approach system. He also states that subsurface drains are needed only in the presence of impervious fill or natural soil. Chini et al. discuss the components of a subsurface drain. They include a drainage layer to direct the water away from the abutment and subsurface drainage pipe to collect the water from the drainage layer and send it to a collection point. Geotextile filters are also suggested to keep the pipes from becoming clogged. Both Chini et al. and Wahls mention the geocomposite drainage system, which is a prefabricated subsurface drainage system. Figure 16 shows a geocomposite drain. Another publication giving details on this topic is the report by Holtz et al. (*56*). Note that these types of drainage systems must be designed for site-specific conditions and they must be able to withstand the earth pressure.

Another technique for eliminating the erosion of the fill material is to wrap it with a geotextile to keep it from eroding (*18*). This also prevents the mixing of the fill material near the

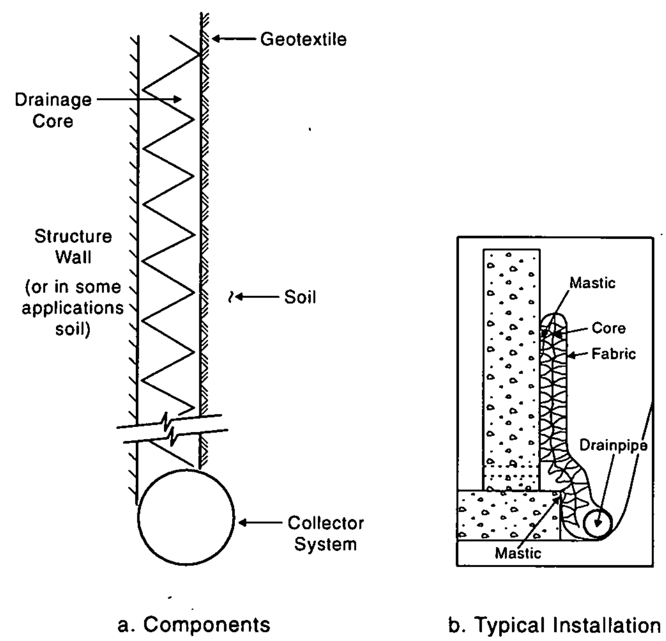


FIGURE 16 Geocomposite drain (after *4*)

abutment with the embankment soil. South Dakota includes this method in their specifications for bridge end backfill. A thorough discussion on the use of geosynthetics can be found in FHWA-HI-95-038 (*56*).

Embankments on sloping ground are susceptible to erosion resulting from seepage along the interface between the embankment and the natural soil. This flow of water can weaken the interface and trigger sliding of the embankment. Benching is a procedure used in this situation because it slows the flow of water, thereby decreasing erosion. Benching may also reduce the lateral movement of new embankments on natural soil. The natural slope is cut into a series of steps as seen in Figure 17 (*4, 17*). This technique also prevents failure at the interface between the embankment and the natural soil. Concrete slope facing also drastically reduces slope erosion (*26*).

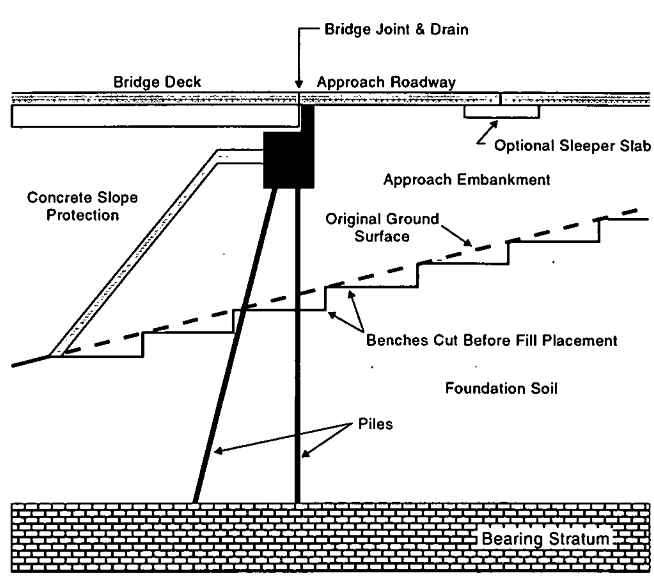


FIGURE 17 Benching to prevent sliding (after *17*).

CHAPTER FOUR

CURRENT PRACTICE

Current views about the causes of bumps at the end of a bridge and the practices used to address the problem are reviewed in this chapter. These views are based on discussions with DOT engineers and on survey responses received from state departments of transportation across the country. Seventy-two survey responses were received from 48 states (Table 4). This very high response rate shows that the problem is of concern to nearly all states. The questionnaire is presented in Appendix A and the survey results are summarized in Appendix B.

TABLE 4
STATES RESPONDING TO THE NATIONAL SURVEY

1. Alabama	25. Nebraska
2. Alaska	26. Nevada
3. Arizona	27. New Hampshire
4. California	28. New Jersey
5. Colorado	29. New Mexico
6. Connecticut	30. New York
7. Delaware	31. North Carolina
8. District of Columbia	32. North Dakota
9. Florida	33. Ohio
10. Georgia	34. Oklahoma
11. Hawaii	35. Oregon
12. Illinois	36. Pennsylvania
13. Indiana	37. Rhode Island
14. Iowa	38. South Carolina
15. Kansas	39. South Dakota
16. Louisiana	40. Tennessee
17. Maine	41. Texas
18. Maryland	42. Utah
19. Massachusetts	43. Vermont
20. Michigan	44. Virginia
21. Minnesota	45. Washington
22. Mississippi	46. West Virginia
23. Missouri	47. Wisconsin
24. Montana	48. Wyoming

Approximately 25 percent of the nation's 600,000 bridges (about 150,000 bridges) develop a noticeable bump. Estimating the cost of repairing the bump at the end of the bridge is very difficult. One way is to recall the numbers obtained by Schaefer and Koch (*18*) in their 1992 study: mudjacking $1,800, asphalt overlay $670, new approach slab $12,000. An estimate of the average repair cost may therefore be $1,000 per bridge end or $2,000 for the bridge. If such a repair occurs once every 3 years, then the cost per year per bridge with a bump is $667/year/bridge. A yearly national repair cost estimate is 600,000 x 0.25 x 667, or $100 million/year. Another way to obtain an estimate is to use the average yearly cost of repair obtained from the 30 states that responded to question 3 of the questionnaire (Appendix A). This average, based on a range of costs from $2/year/bridge affected to $2,626/year/bridge affected, is $398/year/bridge which leads to a national cost of $60 million/year. Some states (such as Colorado and Wyoming) have made a more detailed evaluation of this average cost and have quoted $1,250 and $1,600/year/bridge. The use of such numbers leads to a national yearly cost equal to $187.5 million. Therefore, a number of $100 million/year may be a reasonable lower bound of the cost of repairing the bump problem every year in the nation.

The cost of maintenance and repair is only one factor. Some state DOTs consider the public's perception of the bump at the end of the bridge to be quite a problem. Also, the intangible factor of safety benefits for drivers, snowplows, and maintenance activities must be considered when evaluating the magnitude of the problem.

The consensus across the departments of transportation appears to be that the bump is not a major problem, but is a nuisance that bears a significant cost, that requires regular maintenance, and for which a better solution would be welcome. Some cases are acknowledged to be serious and require more than just routine maintenance. The problem also occurs more frequently on older bridges. This is probably because newer bridges have improved drainage systems and approach slabs, while older bridges have had time for settlement of the fill and natural soil to occur and have been subjected to more traffic.

The following three sections describe factors associated with bump formation. The first section, Condition Factors, covers the factors associated with the components and materials involved as well as their behavior. The second section, Operational Factors, covers the factors associated with detection and maintenance of the bump. The third section, Design and Procedural Factors, covers the factors associated with design and construction.

CONDITION FACTORS

Of the many factors that can contribute to bump formation, the most common are compression of the fill, settlement of the natural soil under the fill, poor construction practices, poor drainage, poor fill material, and loss of fill material by erosion. These can be seen in Figure 2. The least common factors are the bridge type, having too rigid a bridge foundation, and settlement under the abutment. Table 5 lists these factors in order of importance based on the responses to the questionnaire.

Approach fill settlement refers to compression of the fill itself. It is one of the most common factors contributing to bump formation and is usually the result of poor compaction. Some states have an option between two compaction levels, ordinary compaction and controlled compaction. Examples of specifications are presented in Appendix D. Inadequate compaction can be caused by compacting the soil in lifts (Table 3)

TABLE 5

FACTORS CONTRIBUTING TO THE FORMATION OF THE BUMP RANKED IN ORDER OF IMPORTANCE BASED ON SURVEY RESULTS (48 states responded)

Ranking	Topic
1	Compression of the fill material
2	Settlement of the natural soil under the embankment fill
2	Poor construction practices
4	Others: ice lenses, freeze-thaw cycle, earthquake, changing moisture conditions, scour, high traffic load hits, frozen joints, poor design, lateral movement of fill
5	Poor drainage
6	Loss of fill by erosion
6	Poor fill material
8	Poor joints
9	Differential settlement between bridge and fill
10	Lateral movement of the bridge abutment
10	Temperature cycles
10	Pavement growth
10	Abutment type
14	Settlement of the natural soil under the bridge abutment
14	Poor construction specifications
16	A too rigid bridge foundation relative to the approach
17	Bridge type

that are too thick, or by not compacting the soil to a high density. When a high compaction density is not achieved, the embankment soil has a higher void ratio. This void ratio is likely to decrease due to traffic-induced vibrations; this creates compression of the fill. Long-term settlement is also possible; however, soils prone to long-term settlement, such as soft clay, typically should not be used for approach fill material. The above factors seem to become worse when the height of the embankment fill increases.

Poor fill material can be a contributing factor to the formation of the bump. Fill material that contains a significant percentage of clay particles is prone to time-dependent settlement. Clays with high plasticity can also heave when they experience moisture increases. Suitable fill material is granular in nature (sand and gravel) with a low clay and silt content for easier compaction. An example of acceptable fill is a soil with a liquid limit less than 45 percent, a plasticity index less than 15 percent, and a bar linear shrinkage more than 2 percent (Appendix D). Approach fill is also discussed in previous sections in chapters 2 and 3 of this synthesis.

Voids forming beneath the approach pavement have several causes; loss of fill material by erosion is one of them. This situation may go unnoticed until damage to the bridge approach is severe. The formation of this void can result in movement of the approach pavement, causing a bump, or distress of the approach slab due to insufficient support. Erosion of the fill material is caused by inadequate drainage at bridge approaches and runoff draining into the approach fill behind the abutment. Silts and fine sands are the most erodible types of soils (Figure 18).

Poor provisions for drainage, which causes fill erosion, and increased hydrostatic pressures on the abutment can result in damage to the bridge approach. Since erosion creates a void behind the abutment, increased lateral pressures due to water can push the abutment toward the bridge structure, allowing, in some extreme cases, the approach pavement to fall off the abutment. Water collects behind the abutment when impervious natural soils do not allow it to drain away. An associated problem in cold weather is ice lensing. Ice occupies 10 percent more volume than the same mass of water and generates heave and lateral deformation.

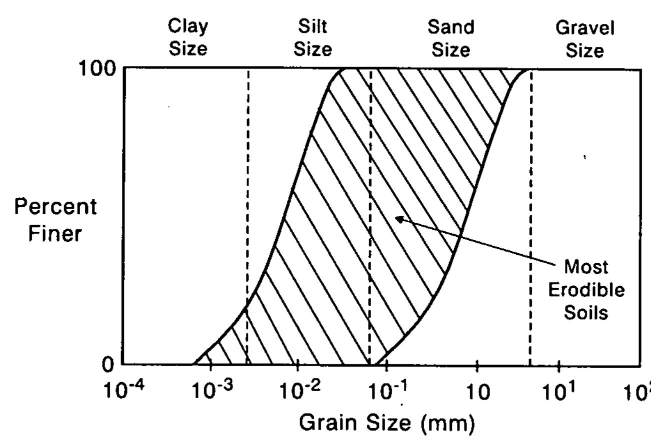


FIGURE 18 Example of range of most erodible soils.

Several drainage systems were discussed in chapter 3. Improved systems are used in current practice to successfully minimize the erosion problem and the resulting bump. Appendix E shows drainage system details.

The settlement of the natural soil under the approach fill plays a major role in bump formation. Of course, the higher the embankment fill, the larger the amount of settlement of the natural soil. If the natural soil beneath the bridge approach is clay (especially a soft clay), it is likely to experience time-dependent settlement due to the load of the embankment fill. This problem can be avoided by considering this settlement during design. The approach embankment designer and the bridge foundation designer should consult frequently with each other about the connection of the bridge to the bridge approach, comparing information about the expected settlement of the bridge and the expected settlement of the approach. If these two expected settlements are not nearly equal, a bump will form. Hopkins (*57, 58*) reports on case history studies of settlement of bridge approach embankments and compares measured settlements and predicted settlements. Schwider (*59*) studied the problem of estimating stresses and movements at a few bridges in Oklahoma. Figure 19 shows the difference in stress imposed by an abutment and an embankment. Note that the critical settlement occurs after the abutment is in place and the pavement is placed. This begins at time t_o in Figure 20. Part of this settlement is due to vibration and stresses from traffic loading. However, no method exists at present to predict traffic-induced soil settlement.

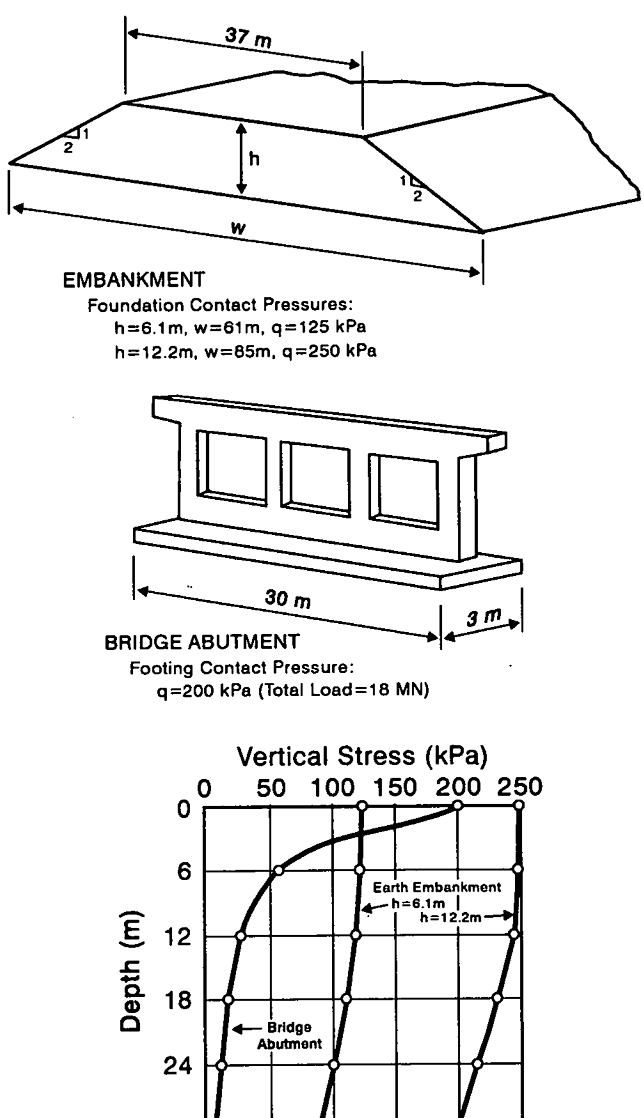


FIGURE 19 Differences imposed by stress in abutment and embankment (after *4*).

Techniques for reducing post-construction settlement of the natural soil are found in chapter 3.

Settlement of the natural soil under the bridge abutment is part of the problem, regardless of whether the bridge abutment is on piles or on spread footings. Many bridge engineers seem to consider this small settlement to be negligible. For this reason, this settlement is not calculated very often; yet it is essential to have an idea of its magnitude to compare it to the settlement of the top of the embankment.

A rigid bridge foundation can also be a contributor to the problem. A rigid foundation does not allow the bridge to settle, but the approach may settle a considerable amount. This results in a bump. A rigid bridge foundation is sometimes necessary when bridge spans are continuous and when proper clearance below the bridge is required. Under these circumstances, mitigation of the approach settlement is needed to minimize bump occurrence. Many engineers consider deep foundations necessary to offset scour potential.

Differential settlement between the bridge and the fill is another way of describing the bump at the end of the bridge (Figure 20); however, it has not been ranked as one of the most common causes. Differential settlement is similar to the problem of the rigid bridge foundation. Bridge settlement is typically very slight, the approach settlement is usually greater, and a bump occurs because of the difference in elevation.

If an approach slab is used and is designed to handle full traffic in free span between point A and point C on Figure 21, Wahls (*4*) and Stark et al. (*26*) have suggested that a slope of 1/200 is an allowable criterion. Figure 21 is an interpretation of this criterion. Note in Figure 21 that the criterion allows the required length of the approach slab to be determined as

$$L_{reg} \geq 200\,(s_c - s_a).$$

Poor construction specifications result in inadequate fill compaction and undesirable fill material, both of which contribute to settlement of the fill material. Use of appropriate specifications could minimize these problems (*60*). Poor construction practices are ranked as one of the most common causes of bump formation. Proper specifications need to be included and enforced. Typically, poor specifications are found in types of fill material, lift thicknesses, and compaction densities. Examples of compaction specifications used by several states are given in Table 3 and Appendix D. Several engineers state how difficult and expensive it is to enforce high-quality specifications. Often, inspectors do not have geotechnical knowledge and therefore do not know what to look for.

Lateral movement of the bridge abutment may directly contribute to the formation of the bump. It can cause serious damage to the bridge structure and/or the approach slab. Figure 22 shows lateral abutment movement. As previously mentioned, lateral movement can be caused by the collection of water behind the abutment. It can also be a result of lateral soil pressures and temperature fluctuations.

Bridge type seems to be the least common direct cause of the bump at the end of the bridge. The abutment type, however, plays a more significant role. The spill-through abutment type, described in chapter 2, allows fill material to wash out

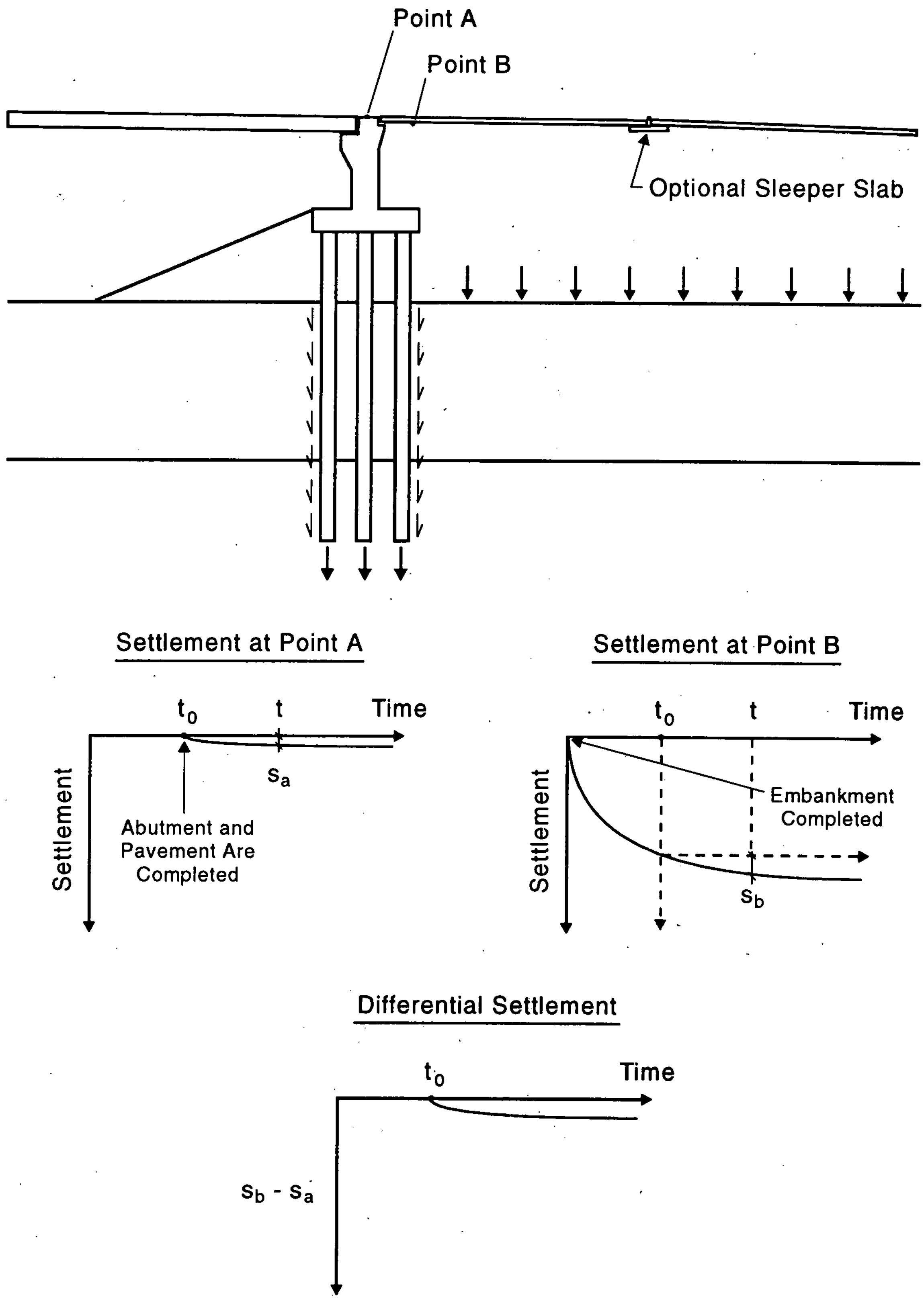


FIGURE 20 Settlement vs. time curves.

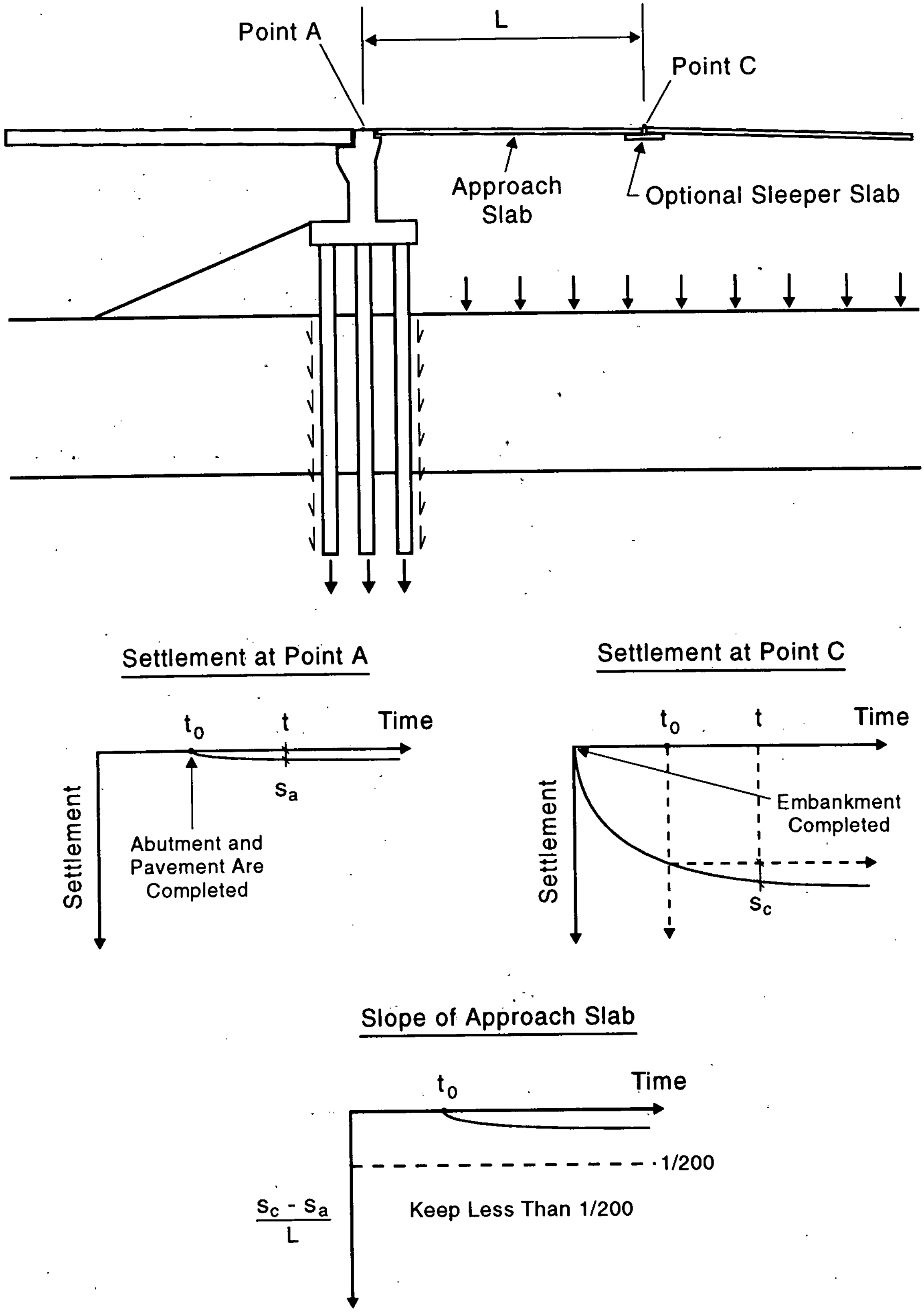


FIGURE 21 Interpretation of Wahls (*4*) and Stark (26) criterion for approach slab tolerable slope.

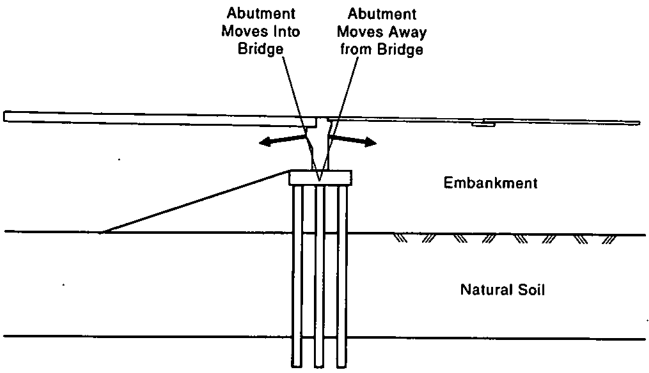


FIGURE 22 Lateral movement of the abutment.

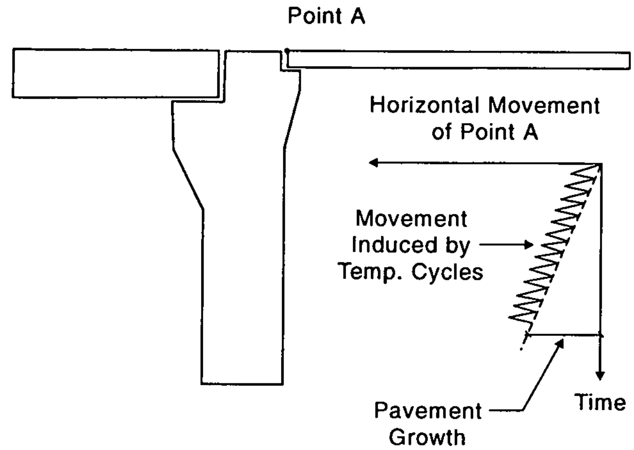


FIGURE 23 Pavement growth.

from below the abutment. Integral abutments experience thermal contraction and expansion in the longitudinal direction. These movements compact the fill material behind the abutment and create a void space. Though integral bridges have several advantages, many engineers responding to the survey believe the problem of the bump to be worse with integral abutments. One solution may be to use spill-through integral abutments.

The next three factors relate to pavement. They are pavement growth, poor joints, and temperature cycles. Temperature cycles can cause temporary elongation and permanent growth of pavement. When a rigid pavement expands and then contracts, it does not come back to its original position. There is a residual movement because the expansion is not completely elastic (Figure 23). Pavement growth results from the plastic strain that accumulates over the temperature cycles. Joints that are allowed to fill with debris cannot close when the pavement expands from high temperatures. This can cause buckling of the approach pavement or damage to the backwall, either of which can result in a bump.

Conditions causing bump formation (ranked according to survey results) are presented in Table 6. Table 7 ranks construction methods that minimize bump occurrence.

OPERATIONAL FACTORS

Many agencies inspect their bridge inventory every 2 years (informal maintenance inspections occur more frequently). During these inspections, problems such as the bump will be noticed and scheduled for maintenance. The two most common methods of detection are visual inspection and subjective

TABLE 6

CASES WHEN THE BUMP IS WORSE IN DECREASING ORDER OF NUMBER OF TIMES MENTIONED IN THE SURVEY RESULTS (48 states responded)

Ranking	Type	Number of Times Mentioned
1	Fill on soft compressible deposit or organic soil	13
2	Bridges with no approach slabs or too short approach slab	8
3	Poor fill material	7
4	Bad drainage	5
4	Severe erosion	5
4	Poor joint design/Poorly maintained joints	5
4	High embankments (>10 m)	5
4	Compressible fill	5
9	Heavy truck traffic	4
9	Abutment on deep foundations	4
11	Flexible pavements	3
11	Integral abutments with thermal cycles	3
13	Poor compaction	2
13	Steep approach gradients	2
13	Poor construction practice	2
16	Collapsible soils	1
16	Spill through abutments	1
16	Lack of soil investigation	1
16	Earthquakes	1
16	No effort to match settlements of bridge and road	1

TABLE 7

CASES WHEN THE BUMP IS MINIMIZED ACCORDING TO THE SURVEY (48 states responded)

Ranking	Type	Number of Times Mentioned
1	Abutment and embankment on strong soil	11
1	Approach slab (long enough and strong enough)	11
3	Well compacted fills or stabilized fills	8
4	Good fill material (well graded)	6
5	Good drainage	5
5	Low embankments (< 3 m)	5
7	Good construction practice and inspection	4
7	Adequate time period between fill placement and paving	4
9	Low truck traffic	3
10	Deep abutment walls that completely retain the fill	2
11	Carefully designed joints, kept clean	1
11	Water tight seals	1
11	Sleeper slab	1
11	Rigid pavement	1
11	Eliminate joint, continuous bridge	1
11	Expansion-contraction provided for	1
11	No lateral movement of abutment	1
11	Proper site investigation and geotechnical analysis	1
11	Bridge at crest of a vertical curve	1

rideability. Other methods used are subjective rideability, quantitative rideability, public complaints, and non-destructive testing (NDT).

Subjective rideability involves determining the ride quality onto and off the bridge. Inspectors driving across the bridges note whether a bump exists and how uncomfortable or dangerous it is. If the bump has unsatisfactory rideability or is a safety hazard, the bump will be repaired. Public complaints will also instigate bump repair, however, the repair is subject to funding and manpower constraints.

Non-destructive testing is rarely used to detect the problem of the bump. It is sometimes used to detect voids under the approach slab (some NDT methods are ground penetrating radar, ultrasonic testing, acoustic emission, and dye penetrant). Northern states can count on feedback from snowplow operators to determine when a bump needs to be fixed.

It is easier to choose an effective repair method when the exact cause of bump formation on a particular bridge is known; however in practice, it is rarely sought. If a bridge approach settled considerably more than others of the same type, it would be considered unusual enough to warrant an investigation. However, if the settlement is in line with all the other bridges, it will receive only routine maintenance. An exception to this is reported by Ardani (*61*) of the Colorado DOT. The report presents results of field and laboratory tests performed on 20 bridge approaches in Colorado to identify factors contributing to bump formation. Ardani concludes that the primary factors are: settlement of the natural soil and of the embankment, poor compaction of the embankment backfill, poor drainage, and erosion of the soil at the abutment face.

The current methods for repairing the bump at the end of the bridge (Table 8) include asphalt concrete (AC) leveling, mudjacking, drainage improvements, improving the properties of the fill, improving the properties of the natural soil under the fill, changing the joint, retrofitting the bridge with an approach slab, or removing and replacing the approach slab. Portland cement concrete is rarely used to repair a bump (*62*). The method most frequently used is AC leveling. This involves building up and smoothing the bump with AC mix, using hot or cold materials. Mudjacking, drainage improvements, and retrofitting with approach slabs are also used to repair the bump. Mudjacking raises the approach pavement and/or fills voids beneath the approach pavement through the injection of flowable grout. Schaefer and Koch (*18*) point out that this is only a temporary measure and that void development will continue under approach slabs that have been mudjacked until such time as the system reaches an equilibrium with the cyclic movement. Drainage improvements will reduce erosion of the fill material and lateral pressures on the abutment from water collected behind it. The use of approach slabs is relatively recent; therefore, older bridges tend not to have them. Many engineers believe that an approach slab greatly minimizes bump occurrence. For this reason, old bridges are sometimes retrofitted with approach slabs.

TABLE 8

MOST COMMON REPAIR METHOD IN DECREASING ORDER OF USE ACCORDING TO THE SURVEY (48 states responded)

Ranking	Method
1	Leveling with asphalt cement concrete
2	Mudjacking
3	Remove and replace approach slab
4	Improve drainage
4	Retrofit approach slab
6	Change joint
7	Improve the backfill
8	Improve the natural soil

Improving the properties of the fill material and the natural soil under the fill is a seldom-used repair method; it is better employed as a preventative measure before construction. Injection methods, however, can be used to fill gaps and strengthen the soil in place. The fillers used are grout cement or foam, such as a high-density polyurethane. Georgia and Oklahoma have experimented with this foam injection technique.

From the point of view of cost, Schaefer and Koch (*18*) give the following numbers in 1992 dollars: mudjacking—$1,800; asphalt overlay—$670; new approach slab—$12,000.

DESIGN AND PROCEDURAL FACTORS

At the design stage, current practice has shown that the following measures can decrease the magnitude and frequency of the bump problem:

- specifying better backfill
- using more rigorous compaction specifications
- allowing for more settlement under the bridge abutment
- placing the bridge abutment on spread footings
- designing the bridge abutment and approach fill so they settle by approximately the same amount
- improving cooperation between the roadway design and bridge foundation engineers
- using a properly designed approach slab
- improving drainage at the bridge end
- designing better joints
- calculating and allowing for pavement growth.

The most effective design considerations in current practice are specifying better backfill, using more rigorous compaction specifications, using a properly designed approach slab, and providing for drainage (Table 9). Most engineers believe that allowing for more settlement under the abutment, placing the abutment on spread footings, and designing the abutment and approach fill so they settle approximately the same amount are not very important design considerations. This does not mean that they may not function well. Vermont has successfully used abutments on spread footings in the fill material (see chapter 2).

TABLE 9

PROCEDURES TO REDUCE THE BUMP AT THE END OF THE BRIDGE ACCORDING TO THE SURVEY (48 states responded)

Ranking	Procedure
1	Specify better backfill
1	Use more rigorous compaction specifications
1	Use a properly designed approach slab
4	Improve drainage provisions
5	Better cooperation between geotechnical and structural engineer
6	Design better joints
7	Allow for pavement growth
8	Allow more settlement under bridge abutment
9	Place abutment on spread footings
10	Design bridge and embankment to have same settlement
Others	Better consolidation tests reliability
	Feedback from construction and maintenance
	Full-time inspection of contractor's work
	Complete settlement analysis for all bridges
	Recognize problem soils

A proper site investigation prior to bridge design will indicate whether there will be a problem with settlement of the natural soil. If settlement is a problem, the use of lightweight fill for the approach embankment may be considered. Strict backfill specifications for the fill next to the abutment and beneath the approach slab should be enforced and controlled by inspection during construction (*60*). An example of compaction specifications is given in Appendix D. Rigorous compaction specifications should result in minimum post-construction settlement of the fill material. The lift thicknesses and relative compaction used by several states are shown in Table 3. Another backfill provision used in many states for the past 20 years that increases the stability of the embankment is mechanically stabilized earth. MSE was mentioned and referenced in chapters 2 and 3.

Approach slabs are used extensively by many states (Figures 21 and 24). Several states install them on all bridges. They are usually 6 to 7 m long, 250 mm thick, and reinforced to be able to sustain the traffic load while spanning between the abutment and the sleeper slab or approach fill. Examples of approach slabs are shown in Appendix C. To improve drainage from an approach slab, the slab can be built as shown in Figure 15. Suggestions have also been made to tie reinforced concrete approach slabs to the abutment. However, this raises the question of where the expansion will occur. The most likely answer is at the roadway end of the panel.

The approach taken by the Wyoming DOT appears sound (*63, 64*). It consists of using fabric-reinforced soil (FRS) walls beneath each approach slab (Figure 25). Granular fill is placed

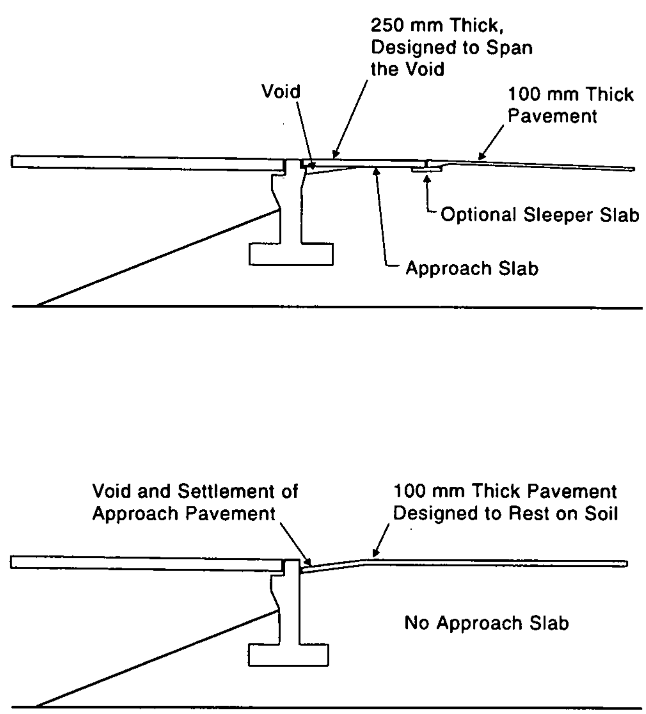


FIGURE 24 Purpose of an approach slab.

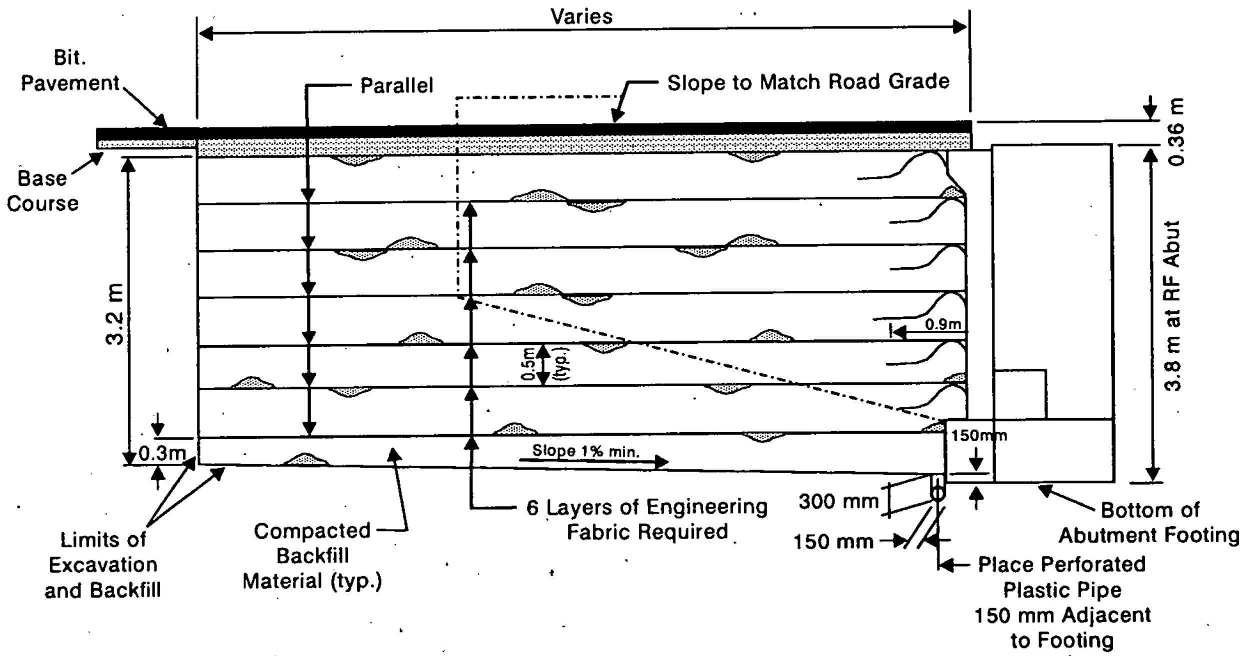


FIGURE 25 Fabric reinforced soil wall as used by Wyoming DOT (after *64*).

TABLE 10
GEOTEXTILE SPECIFICATIONS FOR FRS WALLS (after *64*)

Property	Test Method	Spec. Value
Resistance to mildew and rot	AATCC-30	100%
Resistance to insects and rodents	AATCC-24	100%
Grab strength at 20% elongation	ASTM D-1682	
Longitudinal Direction		2.22 kN
Transverse Direction		2.22 kN
Burst Strength	ASTM D-3786	2068 kPa
Trapezoid Tear Strength—Both Directions	ASTM D-1117	0.4 kN
Equivalent Opening Size—maximum value	CW 02215	0.3 mm
Water Permeability, K	WHD Test	0.005 cm/s
Secant Modulus at 10% Elongation	ASTM D-1682	4.45 kN

in 0.5 m-thick layers wrapped in a woven geotextile (Table 10). Price and Sherman (*64*) point out that the Wyoming DOT has not had to repair any of the bridges with the FRS walls for bump problems. They note that, in 1986, the Wyoming DOT spent $1,600 per year per bridge with end bumps (AC leveling) and that mudjacking has had limited success. Replacing an expansion joint damaged in large part by abutment rotation due to high lateral pressures costs approximately $25,000. The installed cost of the FRS wall was $6,000 per bridge end, compared to $3,200 for the conventional unreinforced embankment. The $2,800 difference can be quickly paid for by reducing or eliminating the $1,600 maintenance cost and the $25,000 joint replacement cost.

Construction stage measures that can minimize bump formation are better compaction control of the fill immediately behind the abutment and enforcing a waiting period after the fill construction prior to placing the pavement. Better compaction control can be achieved with improved compaction techniques and more thorough inspection. As stated earlier, many believe that the quality of construction inspection is poor. The use of a waiting period gives the fill and the natural soil time to settle before the final pavement is placed. This reduces the size of

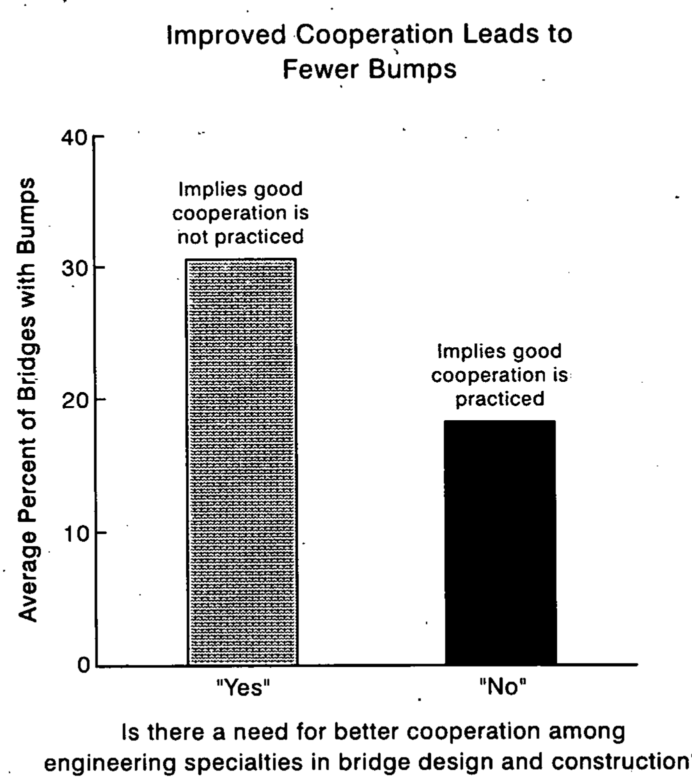


FIGURE 26 Implications of cooperation among civil engineering specialities in bridge design and construction.

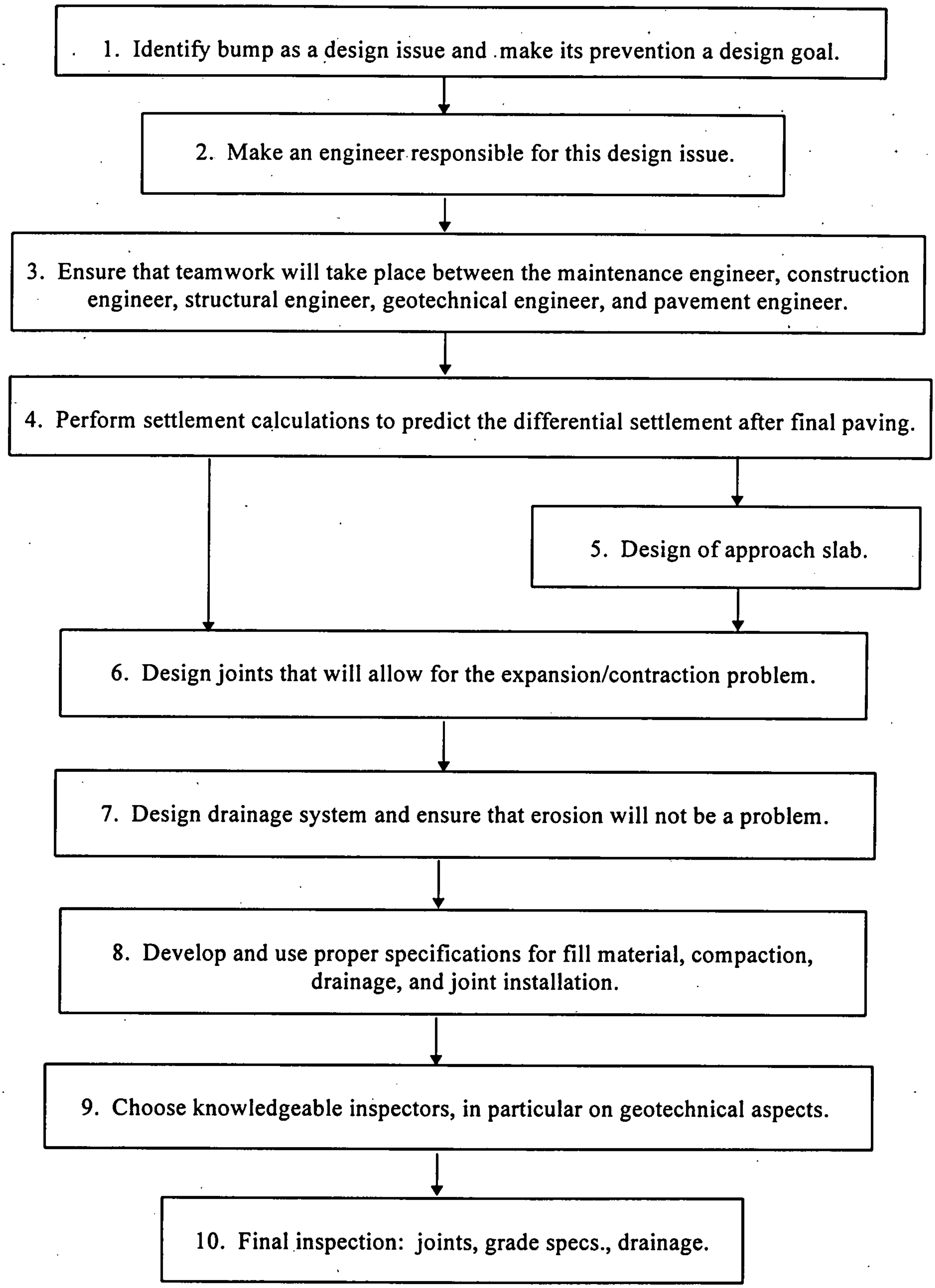


FIGURE 27 Flow chart to minimize bump from synthesis of practices.

the bump. Other techniques for minimizing this settlement are often used. Vertical drains are used in the natural soil to increase the settlement rate. There are also in situ methods of improving the natural soil: stone columns, deep soil mixing, and embankment piles (see chapter 3).

From a procedural or management perspective, the majority of state DOTs believe that the problem could be minimized by promoting better cooperation among the geotechnical, structural, pavement, and construction engineers. The survey results demonstrate this (Figure 26). One state commented that when their geotechnical group made recommendations, they were often rejected in an effort to save time. Even if cooperation exists among these groups, effective communication may not. Opportunities to improve communication, such as holding joint meetings and planning sessions, would bring each group's role in the overall success of the project into better focus. Figure 27 presents successful state practices at each step in the process to minimize bumps.

One engineer recommended performing a complete settlement analysis at each highway bridge site. Since this would identify the locations that would eventually cause trouble, the problem could be handled at the design stage of the bridge approach system. The settlement analysis might show that the difference in settlement between the abutment and the embankment would not be large (less than 50 mm), and that it would be more economical to routinely repair the bump with AC leveling. On the other hand, the settlement analysis would alert the engineers before construction to the expected differential settlement, which could result in damage to the bridge approach. The cost justification for a settlement analysis (saving later maintenance costs) is persuasive.

CHAPTER FIVE

CONCLUSIONS

The bump at the end of the bridge problem affects about 25 percent of the bridges in the United States. The estimated maintenance cost is at least $100 million per year nationwide, or approximately $667 per year per bridge affected. Many state DOTs consider this problem a nuisance that bears a significant cost, that requires regular maintenance, and for which a better solution would be welcome.

The problem is quite complex and very little rigorous information exists. This synthesis identifies some major causes of bump development (as noted in Table 5). They are 1) settlement of the top of the embankment greater than the abutment due to settlement of the natural soil under the embankment load and to the compression of the embankment fill, often because of insufficient compaction; 2) development of a void under the pavement due to erosion of the embankment fill brought about by poor drainage; 3) abutment displacement due to pavement growth, embankment slope instability, and influence of temperature cycles on integral abutments.

Generally, the bump tends to be most severe when one or more of the following conditions exist: high embankment, abutment on piles, high average daily traffic, soft clay or soft silt natural soil, high intensity rainstorms, extremes in temperature cycles, particularly with integral abutments, and steep approach gradient (Table 6).

The bump tends to be minimized when several of the following conditions exist: abutment and embankment on strong soil, a long enough and strong enough approach slab, well-compacted fills or stabilized fills, appropriate fill material, effective drainage, low embankments, good construction practice and inspection, and adequate waiting period between fill placement and paving (Table 7).

Survey results and a review of the literature demonstrate that better cooperation among the geotechnical, structural, pavement, construction, and maintenance engineers can be correlated to lower reported incidences of bumps. A second finding is that bridges with abutments on spread footings have fewer bumps than bridges with abutments on deep foundations. This may be expected since, in the case of spread footings, the combination of first span and abutment on spread footing plays a role similar to the combination of the approach slab and the sleeper slab.

The use of approach slabs minimizes or eliminates the problem of the bump. Some states use them on all new bridges. They are usually 6 to 7 m long, 250 mm thick, and should be reinforced to carry the full design load in free span between the abutment and the sleeper slab or the approach embankment.

Synthesis of discussions with DOT engineers and of the survey responses identified the following best current practice:

1. Treat the bump problem as a stand-alone design issue and prevention as a design goal.
2. Assign the responsibility of this design issue to an engineer.
3. Stress teamwork and open-mindedness among the geotechnical, structural, pavements, construction, and maintenance engineers.
4. Carry out proper settlement vs. time calculations.
5. If differential settlement is excessive, design an approach slab.
6. Provide for expansion/contraction between the structure and the approach roadway (fabric reinforcement, flow fill).
7. Design a proper drainage and erosion protection system.
8. Use and enforce proper specifications.
9. Choose knowledgeable inspectors, especially for geotechnical aspects.
10. Perform a joint inspection including joints, grade specifications, and drainage.

The best approach for the DOT engineer is one that strikes a balance between proper design, proper construction, and acceptable maintenance, while satisfying budget constraints and safety levels. While this synthesis of best current practice can improve the current status of the bump at the end of the bridge, there will still be some bumps at the end of some bridges.

The following are suggested topics for further research.

1. Evaluate the best current practice by scientific observation of case histories across the country. State DOTs could be invited to propose candidate sites, some with severe problems, some with successful performance, including fabric reinforcement and flow fills. Selected sites would be instrumented and studied in detail. The analysis would allow the preparation of an updated best current practice.
2. Build scaled models that focus on the major factors for the bump under simulated traffic and controlled conditions. For example, settlement of the subsoil could be eliminated by building the model on a concrete floor, or eliminate erosion by mixing some cement with the backfill. Model tests could also be used to study the comparative effectiveness of repair alternatives.
3. Perform a cost/benefit analysis of various solutions. This analysis could be done from the design-construction standpoint and from the repair standpoint. In both cases, real costs from DOTs would be collected and compared.
4. Determine what is a tolerable bump. This would consist of establishing criteria for the approach slope that would be acceptable for cars and trucks. A slope of 1/200 appears safe; some say that 1/50 is acceptable. Factors to be considered include traffic speed and traffic volume.
5. Establish the current national level of usage for spread footings versus piles. Many conflicting reports exist. Some say spread footings work well, decrease the bump, and save money; others say they settle more and provide little savings.

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APPENDIX A

Survey Questionnaire

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Project 20-5, Topic 26-10

Settlement of Bridge Approaches
(The Bump at the End of the Bridge)

QUESTIONNAIRE

Name of respondent: ________________
State DOT: ________________
Title: ________________
Phone and FAX No.'s: ________________

GENERAL INFORMATION:

1. How many bridges are there in your state? ________________

2. a.) Have you encountered the problem of the bump at the end of the bridge?

☐ YES ☐ NO

b.) If the answer to the above is YES, please estimate the percentage of bridges in your state that are affected by this condition:

☐ 10% ☐ 20% ☐ 30% ☐ 40% ☐ 50% ☐ OTHER

c.) If OTHER, please provide an estimate of the percentage: ________________ %

3. What is your estimate of the total maintenance cost per year in your state for this problem including both internal and contracted maintenance?

Total Maintenance Cost (per year): $ ________________

Estimate of Percent Cost Internal ______ %

Estimate of Percent Cost Contracted Maintenance ______ %

4. Do you have any further comments on the extent of the problem in your state?

____
____
____

NCHRP Project 20-5, Topic 26-10
Agency: ________________

CONDITIONS INFORMATION:

5. What are the common causes of the problem in your state?

Please rank using: 1 = most common, 2 = frequent, 3 = seldom a factor, 4 = never a factor

____ settlement of fill
____ loss of fill by erosion
____ poor fill material
____ poor drainage
____ settlement of natural soil under the fill
____ settlement of natural soil under the bridge abutment
____ too rigid a bridge foundation
____ differential settlement between bridge and fill
____ poor construction specifications
____ poor construction practices
____ lateral movement of the bridge abutment
____ bridge type
____ abutment type
____ pavement growth
____ poor joints
____ temperature cycle
____ OTHER **If OTHER, please explain:**

____
____
____

6. In what cases does the problem appear to be worse? **PLEASE COMMENT:**

____
____
____

7. In what cases does the problem appear to be minimized? **PLEASE COMMENT:**

____
____
____

8. Are there any organizational or procedural obstacles (impediments) which could be considered as contributing factors to the problem?

☐ YES ☐ NO; If YES, please explain below

____
____
____

OPERATIONAL INFORMATION:

9. What methods do you use to detect the problem and how often do you use those methods?

Please use the following scale: 1 = often, 2 = sometimes, 3 = rarely, 4 = not at all

____ visual inspection
____ ridability (subjective)
____ ridability (quantitative)
____ public complaints
____ non-destructive tests (NDT), please explain the test(s) used:

____
____
____

____ OTHER; if OTHER, please explain:

____
____
____

10. How and when do you decide to perform maintenance on a bridge with this problem?

____
____
____

11. Does someone try to find the exact cause of the problem for a given bridge?

☐ YES ☐ NO Please comment:

____
____
____

12. What method do you use to repair the problem and how often do you use these methods?

Please use the following scale: 1 = often, 2 = sometimes, 3 = rarely, 4 = not at all

____ leveling with Asphalt Cement Concrete (ACC)
____ mud jacking
____ drainage improvements
____ improve the properties of the fill
____ improve the properties of the natural soil under the fill
____ change the joint
____ retrofit with an approach slab
____ remove and replace approach slab
____ OTHER, please explain below:

____
____
____

PROCEDURAL INFORMATION:

13. What can one do at the design stage to decrease the magnitude and frequency of the problem and how important is each recommendation?

Please rank by using: 1 = most important, 2 = important, 3 = not very important, 4 = not used

____ specify better backfill
____ use more rigorous compaction specifications
____ allow for more settlement under the bridge abutment
____ place the bridge abutment on spread footings
____ design the bridge abutment and approach fill so they settle by approximately the same amount
____ better cooperation between the geotechnical and structural engineer
____ use a properly designed approach slab
____ improve drainage provisions
____ design better joints
____ calculate and allow for pavement growth
____ OTHER, please explain below:

____
____
____

Agency: ____________________

14. a.) What can be done at the construction stage to decrease the problem and how important is each recommendation?

Please rank by using: 1 = most important, 2 = important, 3 = not very important, 4 = not used

____ better compaction control of the fill
____ waiting period after the fill construction prior to pacing the abutment
____ other unique or innovative methods to handle the problem

b.) If you use other unique or innovative methods to handle the problem please explain below:

c.) Would you be willing to share specifications or drawings pertaining to your solutions if requested?

☐ YES ☐ NO

15. What can be done from a procedural or management perspective to minimize the problem?

better cooperation between the geotechnical, structural, roadway, and/or construction engineer ☐ YES ☐ NO

OTHER ☐ YES ☐ NO if YES please explain below:

CONCLUDING INFORMATION:

16. Has your agency performed or sponsored any research, development, or training efforts in this area?

☐ YES ☐ NO; if YES, please briefly describe these efforts and enclose copies of any available reports:

17. What research do you feel would help in minimizing the problem?

Agency: ____________________

18. What states lead the way when it comes to avoiding or solving this problem?

19. For purposes of cross-referencing responses between state DOTs please answer the following:

Are you a? (please check one)	Years Experience
☐ structural engineer	____
☐ geotechnical engineer	____
☐ roadway design engineer	____
☐ construction engineer	____
☐ maintenance engineer	____
☐ bridge engineer	____
☐ OTHER, please explain ____________	____

THANK YOU FOR YOUR ASSISTANCE!

Please send your response to:

Professor J.-L. Briaud
Department of Civil Engineering
Texas A&M University
College Station, TX 77843-3136

If you have any questions, please call Professor Briaud on (409) 845-3795 or contact him on E-mail at BRIAUD@TAMU.EDU. If you would like to submit your questionnaire response by facsimile, please do so on (409) 845-6554.

We would appreciate your response by March 10, 1995

APPENDIX B

Summary of Survey Responses

States who responded to the national survey.

1. Alabama
2. Alaska
3. Arizona
4. California
5. Colorado
6. Connecticut
7. Delaware
8. District of Columbia
9. Florida
10. Georgia
11. Hawaii
12. Illinois
13. Indiana
14. Iowa
15. Kansas
16. Louisiana
17. Maine
18. Maryland
19. Massachusetts
20. Michigan
21. Minnesota
22. Mississippi
23. Missouri
24. Montana
25. Nebraska
26. Nevada
27. New Hampshire
28. New Jersey
29. New Mexico
30. New York
31. North Carolina
32. North Dakota
33. Ohio
34. Oklahoma
35. Oregon
36. Pennsylvania
37. Rhode Island
38. South Carolina
39. South Dakota
40. Tennessee
41. Texas
42. Utah
43. Vermont
44. Virginia
45. Washington
46. West Virginia
47. Wisconsin
48. Wyoming

Respondent Details

The following are responses 1 and 19, to qualify the experts surveyed. Respondents names have been removed.

Agency	No. of Bridges	Classification	Years experience
AK DOT	844	Bridge Engr.	20
AL DOT	3449	Main. Engr. Asst.	32
AR DOT	6481	Bridge Engr.	26
CA DOT	24000	Maint. Engr.	5
CA DOT			
CA DOT	25000	Pvmt. Mgmt. Engr.	
CO DOT		Research Engr.	17
CO DOT	8000	RW/Con/Br. Engr.	8
CO DOT	8000	Str. 45;Br 40	42
CT DOT	5113	St 20+;Main20+;Br20+	20
DC DPW	340		
NE DOT	1250	Str. Engr.	25
FL DOT	6100	Str. Engr.	20
GA DOT	14400	Br./Br. Maint.	12
HI DOT	1098	RW/Con/Main. Engr.	6
IA DOT	3900	Roadway Des. Engr.	38
IL DOT	5800	Str. Engr.	21
IN DOT	18000	Geotech. Engr.	
IN DOT	5581	Constr. Engr.	30
KS DOT	5000	Geologist, Gt unit	37
LA DOTD	14000	Br. Engr.	
LA DOTD		Geotech. Engr.	
LA DOTD		Geotech. Engr.	14
LA TRC	13821		
MA DOT	5000	S12,G14,C6,M2,B13	9
MA HD	2910	Maint. Engr.	8
MA HD		Geotech. Enrg.	10
MD DOT	4850	Geot 35/Br 44	39
ME DOT	3600	Br./Str./BMS Engr	18
MI DOT	4500	Br. Engr.	10
MN DOT	20000	Br. Engr.	30
MO HTD	23200		
MO HTD	24000	Geotech Engr 4&11	8
MO HTD	23200	Const. Engr.	30
MO HTD	6911	Maint. Engr.	18
MS DOT	5000	StGtConMaiBrOther	10
MT DOT	4466	Br. Engr.	18
NC DOT	13651	Maint. Engr.	
ND DOT	5900	Br. Engr.	1
NE DOR	15742	Maint 35;BrEn 12	24
NH DOT	2334	Br. Engr.	17
NJ DOT	6367	Br. Engr.	35
NM DOT	3000		
NV DOT	1209	Br. Engr.	20
NY DOT	20000	Geotech. Engr.	24
OH DOT	41000	Geotech/Br. Engr.	25

Respondent Details (continued)

Agency	No. of Bridges	Classification	Years experience
OK		Engrg. Geologist	30
OK DOT	4138	Maint. Engr.	8
OK DOT	6700	Br. Engr.	30
OK DOT		Geotech. Engr.	22
OK DOT	22901	Br. Maint. Engr.	10
OK DOT		Geotech. Engr(BrDiv)	3
OK DOT	23000	Br. Engr. (Asst.)	3
OK DOT	22300	Const. Engr.	35
OK DOT	23000	Br. Engr.	25
OR DOT	6500	Str 35;Con 24;Br 30	30
PN DOT	23000	Str. Engr.	20
RI DOT	750	Br. Engr.	
SC DOT	9000	Br. Engr.	21
SC DOT	7000	Con 19;Maint 23	21
SD DOT	6394	Res. Engr. & 4 oth.	23
TN DOT	19000	Str/Br. Engr.	30
TX DOT	46000		
UT DOT	2224	Str. Engr.	24
VA DOT	9000	Br. Engr.	21
VA Dist	3200	Br. Engr.	28
VA Dist	20000	Br. Engr.	35
VT AOT	2352	Maint. Engr.	38
WA DOT	3000	Geotech. Engr.	9
WA DOT	3000	Struct. Engr.	28
WI DOT	13166		
WV DOT	6200	Geotech. Engr.	
WV DOT	6200	Br. Engr.	32
WV DOT	6200	Const. Engr.	
WY DOT	3000	Gt En.19, BrEn 23	

No. Responses	Avg. No. Bridges	Avg. Yrs. Experience
75	10544	21

Estimated Costs

The following are responses to questions 1, 2, and 3.

Agency	Number of Bridges	Percent Affected	No. Affected Bridges	Est. Annual Maint. Cost	Annual Cost per Affected Bridge
AK DOT	844	50	422	40,000	95
AL DOT	3,449	75	2,587		0
AR DOT	6,481	20	1,296		0
CA DOT	24,000	4	960	25,000	26
CA DOT			0		0
CA DOT	25,000	20	5,000	1,068,000	214
CO DOT		10	0		0
CO DOT	8,000	70	5,600	1,500,000	268
CO DOT	8,000	30	2,400	3,000,000	1,250
CT DOT	5,113	20	1,023	75,000	73
DC DPW	340	20	68	60,000	882
DE DOT	1,250	10	125		0
FL DOT	6,100	10	610	800,000	1,311
GA DOT	14,400	10	1,440	300,000	208
HI DOT	1,098	10	110	55,000	501
IA DOT	3,900	10	390	1,024,000	2,626
IL DOT	5,800		0		0
IN DOT	18,000	40	7,200	50,000	7
IN DOT	5,581	30	1,674		0
KS DOT	5,000	50	2,500	100,000	40
LA DOTD	14,000		0		0
LA DOTD		30	0		0
LA DOTD		50	0		0
LA TRC	13,821		0		0
MA DOT	5,000	30	1,500		0
MA HD	2,910	10	291		0
MA HD			0		0
MD DOT	4,850	30	1,455	1,500,000	1,031
ME DOT	3,600	20	720	100,000	139
MI DOT	4,500	50	2,250		0
MN DOT	20,000	30	6,000	300,000	50
MO HTD	23,200		0		0
MO HTD	24,000	30	7,200		0
MO HTD	23,200		0		0
MO HTD	6,911	35	2,419	150,000	62
MS DOT	5,000	30	1,500		0
MT DOT	4,466	40	1,786	110,000	62
NC DOT	13,651	10	1,365	200,000	147
ND DOT	5,900	30	1,770		0
NE DOR	15,742	75	11,807	20,000	2
NH DOT	2,334	40	934	100,000	107
NJ DOT	6,367	10	637	200,000	314
NM DOT	3,000	10	300	200,000	667
NV DOT	1,209	20	242		0
NY DOT	20,000	10	2,000	50,000	25

Estimated Costs (continued)

Agency	Number of Bridges	Percent Affected	No. Affected Bridges	Est. Annual Maint. Cost	Annual Cost per Affected Bridge
OH DOT	41,000	2	820		0
OK		20	0	200,000	0
OK DOT	4,138	30	1,241	500,000	403
OK DOT	6,700	20	1,340		0
OK DOT		40	0		0
OK DOT	22,901	30	6,870		0
OK DOT			0		0
OK DOT	23,000	30	6,900		0
OK DOT	22,300	30	6,690		0
OK DOT	23,000	70	16,100		0
OR DOT	6,500	51	3,315		0
PN DOT	23,000	20	4,600		0
RI DOT	750	1	8		0
SC DOT	9,000	30	2,700	100,000	37
SC DOT	7,000	50	3,500		0
SD DOT	6,394	20	1,279	25,000	20
TN DOT	19,000	50	9,500	300,000	32
TX DOT	46,000	30	13,800		0
UT DOT	2,224	20	445	50,000	112
VA DOT	9,000	99	8,910		0
VA Dist	3,200	20	640	250,000	391
VA Dist	20,000	1	200		0
VT AOT	2,352	10	235	27,000	115
WA DOT	3,000	40	1,200		0
WA DOT	3,000	20	600		0
WI DOT	13,166	30	3,950		0
WV DOT	6,200		0		0
WV DOT	6,200		0		0
WV DOT	6,200	70	4,340		0
WY DOT	3,000	50	1,500	2,400,000	1,600
TOTAL	704,242		178,262	14,879,000	
AVERAGE		25			398

Most Common Causes

The following are responses to the survey question 5, about the most common causes of the bump at the end of the bridge.

Setl of Fill	Loss of Fill	Poor Fill Matl	Poor Drainage	Setl undr Fill	Setl undr Abut	Too Rigd foun	Diff Setl	Poor Con Spec	Poor Con Prac	Lat. Movement	Brid Type	Abut Type	Pvmt Grth	Poor Jts	Temp Cycl	Othr Caus
1	2	2	2	2	2	3	2	4	3	3	3	3	4	3	2	2
1	2	2	2	3	3	3	3	3	2	3	3	2	2	1	2	
1	2	2	2	1	3	4	1	1	1	3	2	2	3	2	2	1
1	2													2		
1	4	3	1	2		4		3	2	4	1	1	4	3	4	
1	3	2	3	3	3	3	3	4	1	4	3	3	4	4	3	
2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2
2	2	3	2	3	3	2	2	3	2	2	2	2	2	2	2	
1	3	4	3	2	2	1	2	4	2	2	4	3	3	3	4	
1	3	2	2	3	2	4	3	3	2	4	2	3	2	3	3	
2													1			
2	4	2	4	2	3	3	4	4	2	4	4	4	4	1	3	
2	3	2	3	1	2	3	1	2	3	2	4	3	3	1	4	
1	3	3	3	1	1	4	1	4	3	3	3	2	3	2	3	
1	4	3	4	2	3	4	2	3	3	3	4	4	4	4	4	4
2	3	3	3	2	3	3	1	3	2	3	2	2	2	3	3	
1	3	3	2	3	3	3	2	2	2	3	3	3	3			
1		1	1	1		1				3						
1	2	1	2	3	4			2	1	2	2	2	2	2	2	
2	2	2	2	1	4	3	1	2	2	2	3	3	2	2	2	
1	1	2	1	2	3	3	1	4	2	3	3	3	3	2	3	2
1	1	2	2	3	4	3	1	3	2	3	4	3	3	3	2	
2	2	2	2	2			2									
1	3	3	2	2	4	4	4	3	3	3	4	4	3	3	3	
1	3	4	3	4	4	1	1	2	1	3	3	3	3	3	2	
1	2	3	2	3	4	4	2	3	3	3	3	3	2	1	1	
3	2	3	4	2	3	4	1	4	3	2	3	3	3	2	4	2
1	2		2													
2	3	3	3	1	3	3	2	4	3	3	3	3	3	3	3	
1	3	3	2	3	4	4	2	3	3	3	4	4	3	3	3	
1	3	3	3	3	3	3	2	3	2	4	4	3	3	2	3	
1	3	1	2	2	3	3	1	3	3	3	3	3	3	2	1	
2	3	2	3	2	2	4	3	2	2	3	4	3	3	2	2	
1	1			1			1									
3	2	3	2	1	2	4	*	4	3	4	4	3	3	4	1	
2	3	3	3	2	3	2	1	3	3	3	3	3	3	3	3	
1	3	3	2	3	3	3	1	3	2	4	3	3	4	3	4	
1	3	2	3	2	3		1	2	3	4	4	4	4	4	4	
1	1	3	1	3	3	3	3	3	3	3	3	3	3	3	3	
2	3	3	3	1	4	2	1	3	2	3	4	4	4	3	4	
2		2		2	2		2		2							

Most Common Causes (continued)

Setl of Fill	Loss of Fill	Poor Fill Matl	Poor Drainage	Setl undr Fill	Setl undr Abut	Too Rigd foun	Diff Setl	Poor Con Spec	Poor Con Prac	Lat. Movement	Brid Type	Abut Type	Pvmt Grth	Poor Jts	Temp Cycl	Othr Caus
1	1	2	2	1	3		2	3	1	2	3	3	3	3	3	
2	2	3	3	3	3	3	3	1	2	3	3	3	3	3	3	2
1	1	1	2	2	2	1	4	3	3	3	3	3	3	3	4	
1																
1	2	2	3	3	3	3	2		2	3	3	3	2	2		
3	3	3	3	3	3	4	1	3	2	4	4	3	3	4	4	
1	2	2	3	2	4	4	1	2	2	3	4	4	3	3	3	
2	2	1	1	2	2	4	1	2	2	3	4	4	2	2	2	
2	2	2	2	1	3	1	1	3	2	2	4	1	3	2	3	
1	3	3	3	2	3	3	1	2	1	3	2	2	2	2	2	
1	3	1	1	3	3	4	3	4	2	2	3	2	3	4	4	2
1	2		2											2		
1	3	3	1	1	3	4	3	3	2	4		3	4	2		
3	3	4	3	3	3	4	3	3	2	1	2	2	3	3	2	
1	2	2	2	1	1	4	2	3	2	3	4	3	4	3	3	
1		1							2							
1	1	3	1	4	4	3	3	3	3	3	3	2	3	4	4	
1	3	3	3	2	3		1	3	2	3	3	3	3	4	3	
2	2	2	2	2	3	3	3	3	3	3	3	2	3	2	3	
1	4	1	4	3	4	4	1	4	1	4	4	4	4	4	4	
1	2	3	3	1	4	1	4	2	2	3	3	2	4	2	4	
1	2	3	3	2	2	3	1	3	2	2	3	2	2	2	2	
2	3	3	3	3	3	4	1	3	3	3	4	3	3	3	4	
1	4	3	3	1	3	4	2	3	2	3	3	2	3	3	2	
1	3	3	3	1	3	2	1	4	3	3	4	4	3	4	4	
1	3			2		2	2			2			3			
1	2	3	2	3	3	3	2	3	2	2	2	2	3	2	3	
1.4	2.5	2.4	2.4	2.1	2.9	3.1	2.6	2.9	2.2	2.9	3.2	2.8	3.0	2.7	2.9	2.1

Averages for each column
(low values are most common; high values are least common)

Comments Related to Causes of Bumps

The following comments are responses to questions no. 4, 5, 6, and 7.

Extent comments:	Older bridges (built in 1950's or before) suffer more of this problem than our newer construction.
Other cause explanation:	Melting permafrost & ice lenses
Worst cases:	Spill thru abutments
Minimized cases:	Deep enough backwalls to prevent spill thru, well compacted fill behind the abutments & good drainage.
Worst cases:	Sandy fill material and leaking joints with non cohesive fill material
Minimized cases:	Select fill material with surface drainage away from bridge structure
Other cause explanation:	Approach slab configuration
Worst cases:	Deeper superstructures on high fills
Minimized cases:	Shallow superstructures on minimal fills
Extent comments:	Following major earthquakes, the frequency of this problem is greatly increased
Other cause explanation:	Settlement during earthquake
Worst cases:	The magnitude of settlement from earthquakes is the most severe, but erosion of the fill is a "hidden" problem until it has advanced.
Minimized cases:	Joints
Extent comments:	Some of the rough riding bridge approaches and departures are corrected as part of roadway rehabilitation projects. Most of the rehabilitated bridge approaches are part of a larger rehabilitation project which encompasses bridge approaches
Worst cases:	In cases of consolidation within approach embankment, poor compaction of backfill material due to restricted access of compaction equipment. Overall, poor embankment materials.
Minimized cases:	When approach slab is used, good structural backfill material and when bridge abutments & wings are keyed into the approach fill to prevent erosion of the fill under the abutment.
Extent comments:	The problem extend varies from slight to extreme. Moderate to extreme cases cause snow plow damage. Colorado spent $250,000 in 1994 for flow fill (a poured, cement treated granular backfill) at new bridge abutments to mitigate these probl
Other cause explanation:	Frost heave. There are some instances of approach pavement and approach slabs moving from probable frost heave and/or soil swelling.
Worst cases:	Concrete approach pavements on higher fills.
Minimized cases:	Asphalt approach pavements on no fill or low fill of coarse granular material on coarse granular natural ground (Mountain areas). Most box culverts.
Extent comments:	The 3.0M estimates approx 1% of the maint. budget for structures and 1/3 that for joint repair and bump at end of bridge problems--no records of actual costs are available in the precise detail requested.
Worst cases:	Differential settlement between bridge and fill and there seems to be underlying materials subject to consolidation with minimal investigation of this feature.
Worst cases:	Settlement of fill
Minimized cases:	On rock--in a cut
Extent comments:	No
Worst cases:	Fill on organic deposit at approach slab
Minimized cases:	In areas where proper drainage is naturally occurring.
Extent comments:	No.
Worst cases:	Heavy Truck Traffic
Minimized cases:	Low Truck Traffic
Worst cases:	Poorly maintained joints and poor fill material
Minimized cases:	Good construction practices when placing fill.
Worst cases:	Settlement of natural soil under the fill.
Extent comments:	West and East borders of state: major river bridges on Missouri and Mississippi Rivers
Worst cases:	Approach fill not allowed time to settle.
Minimized cases:	PCC paved approach with special double reinforced panels, dowelled pavement joints, drilled bentonite treatment, special drainage system, and subbase w/geogrid
Extent comments:	This is a common problem but it is usually a minor problem.
Worst cases:	High embankments and heavy truck traffic
Minimized cases:	Low embankments and light truck traffic
Extent comments:	*(Comment on percentage) "Almost all of the strs exhibiting this problem are over 10 yrs"
Worst cases:	Poor approach soils
Minimized cases:	Replacement structures where fills have been stabilized.
Extent comments:	Most approach slabs in Louisiana range between 20 to 40 feet long--In projects where we placed pile supported approach slabs with draduating pile length we do not seem to have any better results with the bump issue.
Worst cases:	(1) Shorter approach slabs
Minimized cases:	When natural soil is strong & when we have a sleep slab constructed at the joint between the approach slab and the pavement.
Extent comments:	Varies from bridges that are not yet open to traffic to old timers.
Other cause explanation:	The overall problem is changing moisture conditions within the approach embankment. Fix that and no more problem
Worst cases:	Use of heavy clay as an approach, overcompaction of the heavy clay, no moisture control within the embankment, (Lime treatment, sealing the exterior walls, directing bridge runoff away from soil embankment (approach)).
Worst cases:	The delta region of Louisiana is abundant with normally consolidated, high organic natural soils. More time is spent designing for subsurface settlement than was done 10-15 years ago.

Minimized cases:	Many of the causes mentioned in question 5 have been addressed in new designs and specifications.
Other cause explanation:	Moisture cycles
Worst cases:	a. Long-term settlement due to normally consolidated soils, regardless of fill type. b. Erosion due to lack of drainage behind the abutments, when low PI fills are used. c. Nearly all MDOT bridges are constructed on pile foundations and do not settle.
Minimized cases:	a. When well-compacted cohesive fills (10<=PI<=20) are placed on incompressible natural soils. b. Bridge ends fills constructed on good base soils with good fill material with proper compaction and adequate drainage.
Extent comments:	Costs are difficult if not impossible to estimate. Overlays of Bit. Conc. approach are usually done with resurfacing contracts, bridge betterments (which address other difficencies (sic), & pot-hole patching.
Other cause explanation:	Respondent noted with respect to responses above
Worst cases:	Older bridges withoud approach slabs, possibly with poor backfill material and/or poor drainage
Minimized cases:	Approach slabs reduce the occurence...
Worst cases:	Where no approach slab is provided and where erosion (by either rain or river) is starting also.
Minimized cases:	Probably good slab and transition construction.
Extent comments:	[Respondent estimated total maintenance costs to be "$1-2 Million"; $1.5 is used here]
Worst cases:	Roadway section for approaches are composed of flexible pavement section
Minimized cases:	Roadway section for approaches are composed of rigid pavement section
Worst cases:	Poor compaction of backfill granular material and/or no approach slab.
Minimized cases:	Proper compaction, use of buried approach slabs, or use of buried structures.
Extent comments:	Michigan FHWA is pushing for ride quilty (sic) spec in Departments construction contracts.
Other cause explanation:	Frozen Pin & Hanger; scour; deck cracking; high load hits; tilted rockers buckled beam ends due to corrosion; abutment spalls due to frozen joints.
Worst cases:	Leaking joints causing deterioration of steel and concrete.
Minimized cases:	Eliminating the joint by making bridge continious (sic).
Extent comments:	The "bump" is not major in most cases and may not require any action other than routine maintenance.
Other cause explanation:	Frost heave in approach
Worst cases:	Areas of poor natural soils under approach
Minimized cases:	Concrete approach panel plus special granual (sic) treatment under panel
Worst cases:	Soft foundation soils under bridge approaches
Minimized cases:	Good foundations soils, little or no fill, or an adequate delay between fill placement on bridge approaches and paving.
Extent comments:	*% not known, high percentage probably
Other cause explanation:	The design of our backwalls on abutments have a slab haunch for the approach pavement to set (sic) on. These haunches have broken off. This design is now changed.
Worst cases:	There was more of a problem with asphalt approaches to the bridge.
Minimized cases:	Our current design of providing a concrete approach slab has reduced the problem by bridging the worst settlement area.
Worst cases:	High Traffic
Minimized cases:	Low Traffic
Extent comments:	(note--cited costs are for"mudjacking only, other costs are not identifiable")
Worst cases:	When little effort is made matching the profile grade of the pavement and the bridge.
Minimized cases:	When proper compaction behind the abutment is achieved. Good profile grade set by contractors.
Extent comments:	Problems less on newer structures due to drainage improvements at ends of bridges.
Worst cases:	Settlement of natural soil under the fill
Minimized cases:	Use of surcharges and wick drains
Extent comments:	ND DOT does not maintain cost record to this detail.
Worst cases:	Tall abutments and abutments on piles
Minimized cases:	Buried structures (Concrete frames, culverts and arches)
Extent comments:	Not a serious problem overall.
Worst cases:	Settlement of the fill despite good construction specifications seems to take place over a period of time
Minimized cases:	(word not clear) good drainage, settlement seems to be minimal. Except a very few cases where the settlement was caused by loss of material due to embankment scour--Poor drainage or spill-through abutments.
Worst cases:	The problem appears to be worse when approach fills exceed 20'
Minimized cases:	There is less likelihood of a problem developing when approach fills are shallow and natural soil has no tendancy to consolidate.
Extent comments:	Percentage accomplished by internal and contract is unknown, this maintenance is not broken out.
Worst cases:	Poor details which allow deck drainage to flow into joints constructed to break bond. Example: Joint to separate approach slab from wingwall. Asphalt impregnated fiber board is usually used.
Minimized cases:	Where the select borrow approach fill has been placed correctly and the approach slab is located above the wingwalls instead of along side. This means no joint for water to enter.
Extent comments:	It is considered an annoyance to a quality ride, but not a great cost to maintenance operations.

Other cause explanation: Most cases are either settlement or foundation soils under approach or problems compacting backfill in confined areas behind abutment.
Worst cases: Abutments supported on deep foundations: abutments don't settle, some long term consolidation of foundation soils under approach.
Minimized cases: At sites where embankment construction & final paving were separated by a lot of time.

Worst cases: Poor construction practices
Minimized cases: Good compaction

Extent comments: For "How many bridges are there in your state?" respondent answers "Too many".
Other cause explanation: By "Too rigid a bridge foundation" respondent has pencilled "?--We design for 0.0 settlement here"
Worst cases: E. Okla where soils collapse, silty sands, high water tables
Minimized cases: W. Okla sands, gravels, thin soils, & alluvium, low embankments

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Other cause explanation: Poor design

Extent comments: It is severe on some bridges
Worst cases: High fills 35'-40' over poor natural soils.
Minimized cases: Small fills <15 high

Other cause explanation: Respondent has rank ordered these items from 1 to 16. Data disregarded, except for number 1.
Worst cases: Case No. 4,1,2,3,5 (respondent is apparently referring to above causes)
Minimized cases: Cases 11,12,13,15

Worst cases: Poor construction practices through compactions behind bridge abutment difficulties. (sic)

Extent comments: No
Worst cases: Settlement of the natural soil under the fill requiring overlays every year or loss of fill by erosion forming huge voids.
Minimized cases: When the approach slab is long, reinforced and hinged at the abutment.

Worst cases: Large fills
Minimized cases: Few cases

Extent comments: Causes of the bump at bridge ends are: fill settlement, subsurface settlement, compaction from thermal cycling of deep integral abutments, approach slabs tied to the bridge without provision for expansion, poor or no expansion joints and p
Worst cases: With integral abutments where thermal cycles compact the backfill
Minimized cases: When expansion/contraction is provided for and the end fills are not compacted by structure movement

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Extent comments: 99% of approach slabs placed as part of construction project (bridge rehab/replacement or pavement)
Other cause explanation: Poor grade control
Worst cases: Gravity abutment with flexible pavement
Minimized cases: PDT Standard R.C. Approach Slab (16" thick) on open-graded sub-base and granular backfill

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Extent comments: No
Worst cases: Bridges with no approach slabs and bridges with pavement crack or unsealed joint at bridge end
Minimized cases: NA

Extent comments: None
Worst cases: Interstate Projects with Heavy Truck Traffic

Extent comments: This is a real and a perceived problem. Estimate of % depends upon if it is by traveling public, bridge engineer, geotechnical engineer, highway commissioner, etc. of the bridges affected, about 20% are a serious problem.
Worst cases: Integral Abutment Structures; Structures without approach slabs; High fills with short approaches; specific soil & climatic conditions
Minimized cases: Opposite of #6

Worst cases: The higher the fill, or the softer the natural soil under the fill, the greater the propensity for significant settlement
Minimized cases: Well compacted shallow to medium fill height, over insitu rock

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Worst cases: In those areas of the state not having good fill material
Minimized cases: Where a high quality, well graded backfill is used.

Extent comments: The internal cost is for filling the depression with asphalt by Maintenance personnel to maintain a smooth riding surface, not for repairing the problem.
Worst cases: Poor drainage, loss of fill by erosion and settlement of the fill.
Minimized cases: Latteral (sic) movement of the bridge abutment. Settlement of natural soil under the abutment.

Extent comments: *(comment on total maintenance cost) "Very Little"
Worst cases: On bridges without approach slabs
Minimized cases: On bridges with approach slabs

Extent comments: * by 20% above ("of interstate & primary bridges')
Other cause explanation: Due to lateral movement of fill materials in large fills.
Worst cases: Erosin (sic) of fill beneath approach slabs due to poor drainage beneath &/or to loss of joint material between approach slab & backwall.
Minimized cases: When abutments completely retain the fill.

Extent comments: It is an exaggerated problem. The typical cure is more expensive and worse than the illness, not cost effective.
Worst cases: Air flaking approach fills cannot be consolidated without a time factor of about 3-years.
Minimized cases: With a reliable fill material which can be compacted well, or rock fills.

Extent comments: Problem is minimal.
Worst cases: Approach fill constructed on compressible soils and bridge supported on piling. Also, skeleton style abutments contribute to problem by fill loss under abutment.

Minimized cases:	When preloading, or surcharge construction techniques are used. Design based on foundation investigation, testing and geotechnical analysis.
Extent comments:	No cost data, see page 46 of enclosed report
Other cause explanation:	See enclosed report pages 49-52 & 56-59.
Worst cases:	Deep foundations supporting bridge--differential settlement between bridge and approach fill. Soft foundation soils. Integral bridge abutments--thermal expansion/contraction.
Minimized cases:	Good control on contraction inspection--compaction, fill gradation, etc.
Extent comments:	No
Worst cases:	Fill that continues to consolidate with time.
Minimized cases:	Use of approach slabs eliminates the problem.
Worst cases:	On steep approach gradients
Minimized cases:	Where natural soils are of granular material.
Other cause explanation:	For a majority of bridges in WV, the abutments and piers are either constructed on rock or on end bearing piling driven to rock. This allows almost zero settlement of the substructure units.
Worst cases:	Deeper in place soils provide the potential for move settlement. Fills constructed of clay soils have creep potential.
Minimized cases:	Abutments on rock.
Extent comments:	Seems to be a common problem
Other cause explanation:	1) Differential settlement due to a fill built & this surcharge causes uncalculated settlement.
Worst cases:	1) Vertical geometry appears to be a factor in that it appears to be worse in the sag of a vertical curve.
Minimized cases:	1) Bridge located in the crest of a vertical curve
Worst cases:	The greater toe fill height behind the abutment, the greater the potential for problems. Ditto with the depth of roadway fill at the bridge end(s).
Minimized cases:	Inverse of above, and with bridges with integral abutments.

Inspection and Detection Methods

The following are the responses to question 9 about inspection and detection methods most commonly used by the departments of transportation.

Vis. Insp	Subj Ride	Quan Ride	Publ Comp lain	NDT	Othr
1	1	1	3	4	
1	1	3	2	4	
1	1	2	2	4	
1			2		
1	3	3	3	4	
1	1	2	1	3	
1	1	3	2	3	
2	1	1	2	4	
1	4		2		
1	2	2	1	4	
2	2	2	1	4	
1	1	2	3	4	
2	1	4	4	4	
1	2	3	2	4	
1	2	4	3	4	
	1				
1	1	2	2	4	
1	1	3	1	4	
1	1			3	
1	2	4	3	4	
1	1	4	2	4	
1	3	3	1	2	
1	1	3	2	3	
2	1	4	4	4	
2	1	2	2	4	
1	3	2	4		
2	1	2	2	4	
1	2	3	3	4	
1	1	4	2	4	
1	1	2	2	4	
1	1	4	2	4	
1	2	3	1	4	
2	1	3	2	4	5
1	1				
1	1	2	2		

Vis. Insp	Subj Ride	Quan Ride	Publ Comp lain	NDT	Othr
1	1	2	2	4	
1	3	4	2	4	
1	2	3	1	4	
1	1	3	2	4	
2	1	2	3	4	
1	1	1	1		
1	1	3	1	4	
1	1	2	3	4	
1	1	3	2	4	
1	2	3	1	4	
1	1	3	2	4	
1	1	2	2	3	
1	1	4	3	4	
1	1	3	3	4	
4	1	4	1	4	
1	1		3		2
2	1	4	2	4	
1	1	4	1	4	4
1	1	1	2	3	
1	1	3	1	4	
1	1	3	2		
1	1	3	2	3	
1	1				
1	1	4	3	3	
1.2	1.3	2.8	2.1	3.8	

Averages for each column
(low values are most common;
high values are least common)

Comments Related to Dectection and Maintenance

The following comments are responses to questions no. 9, 10, and 11.

How and when maintained:	Depends on severity, available money & manpower. Safety to traveling public would be #1 priority.
Try to find problem?:	We determine probable cause during bridge inspections. In some cases we do extensive research to determine the exact cause.
How and when maintained:	Usually at time of roadway resurfacing unless condition worsens to the point of a safety problem.
Try to find problem?:	Yes if severe--Followup with geotechnical investigation for cause.
How and when maintained:	When the problem begins to show that traffic impacts to the bridge end are significant--and on public complaint.
Try to find problem?:	The exact cause is never apparent due to the complex combination of variables involved.
How and when maintained:	Frequently
Try to find problem?:	Bridge maintenance entineers will try to determine the cause to actually fix the driving mechinism (sic)--settlement is sometimes a sign of bigger problem (ie slope instability)
How and when maintained:	When it pose (sic) a hazardous condition for the travelling public
Try to find problem?:	I have conducted a research study to identify the causes of bridge app. settlement.
NDT explanation:	Every 2 years thru the nbis inspection program. The information obtained in not especially usefull (sic).
How and when maintained:	It is prioritized at the maintenance patrol level with respect to available funds, availablity of repair methods, and competing maintenance needs.
Try to find problem?:	Not on a program level. This is not a funded activity. As occasionally required by normal project and work design, construction and maintenance personnel do this.
How and when maintained:	Pretty much left to personnel and financial resources of maintenance. Probably in response to complaints.
Try to find problem?:	Not generally; however on several occasions we have done drilling and excavation to determine apparent causes and proposed corrective actions.
How and when maintained:	As a result of complaints.
Try to find problem?:	(No, but...) Individual bridges sometimes merit investigation if problem is severe.
How and when maintained:	Private contractor with consultant engineer recommendation.
Other detect. explan:	Respondent has checked, but not rated, visual inspection, rideability (subjective), and public complaints.
How and when maintained:	As Maintenance forces become available or the complaints become louder.
Try to find problem?:	We feel it is caused by pavement growth. We dont have any better joint details to address growth of these bumps.
How and when maintained:	Inspect bridge once every two years. Will perform maintenance if problem occurs. Try to reseal joints once every 5 years.
Try to find problem?:	Will look for leaky joints
How and when maintained:	As often as any complaints are received
Try to find problem?:	Highway Bridge Structural Engineers review the problem together with Soil Engineers from Highway Research and Materials Testing Laboratory.
How and when maintained:	Problem becones severe enough to provide an impact loading on bridge, or differential settlement at end of bridge, or doing other work on bridge.
How and when maintained:	Subjective judgement. When the bump seems to cause a significant traffic hazard.
How and when maintained:	When complaints are recd from public.
Try to find problem?:	Not normally
How and when maintained:	Maintenance forces inspect road regularly and repairs are made when bump is significant enough to require repair.
Try to find problem?:	If settlement occurs rapidly and does not appear to be routine, it will be investigated by Geotech unit.
How and when maintained:	?
Try to find problem?:	Usually try to fix at District level with hot mix (or cold mix) band aid.
How and when maintained:	When ridability becomes objectionable.
Try to find problem?:	Construction, Geotechnical, and Structural personnel meet and discuss each site to be repaired. The reason for the problem is usually obvious.
NDT explanation:	Respondent has noted by "visual inspection" --Yearly bridge inspections
How and when maintained:	When rideability suffers--steps are usually taken to level the roadway with a patching material.
Try to find problem?:	Respondent pencilled in "sometimes" above.
NDT explanation:	Ground Penetrating Radar to detect voiding, approach slab and conditions of fill.
Try to find problem?:	In some specific cases and sites.
Other detect. explan:	[Respondent has indicated "biennial" visual inspections are performed]
How and when maintained:	Evaluate need based on biennial inspection report and feedback from district maintenance officer--done annually
How and when maintained:	When it's a safety concern. Bridge Inspectors or Bridge Maintenance Managers will discover the problem and will alert maintenance crews.
Try to find problem?:	Yes, particularly if it's related to abutment movement.
NDT explanation:	Ultrasonic testing, acoustic emission and dye peneterant (sic)
Try to find problem?:	As soon as a problem is found out an effort is made to take care of the problem and find the cause. Repairs are not effective unless the cause of the problem is also corrected.

NDT explanation: Only NDT would be ride roughness measuring equipment or survey profiles
How and when maintained: Judgement based on rideability (subjective)
Try to find problem?: Investigation only when problem is severe requiring major maintenance

How and when maintained: If the approach settles to the point the ridability becomes unsatisfactory then repairs are scheduled by maintenance forces.
Try to find problem?: Not necessarily. For asphalt approaches a new asphalt wedge is added and on concrete slabs we first attempt to raise the slab by mud-jacking.

How and when maintained: Maintenance sections place asphalt when bump becomes pronounced

How and when maintained: When bump becomes dangerous.
Try to find problem?: Seems we just fix with mudjacking.

How and when maintained: No set policy; action taken when problem is detected and warrants corrective measures.
Try to find problem?: When multiple problems occur such as slope protection erosion and erosion around end bents as well as settlement of approach slabs.

Other detect. explan: Respondent has checked, but not rated, three items: visual inspection, ridability(subjective), and public complaints.
How and when maintained: When ride becomes objectionable

How and when maintained: If there is a project in area or is a severe problem
Try to find problem?: Sometimes, however is hard to find one single cause

How and when maintained: Most recommendations are made after NBIS biennial inspections are accomplished--however, if there is a citizen complaint it is verified and taken care of immediately.
Try to find problem?: During biennial inspections every effort is made to determine the cause and correct it as much as possible.

How and when maintained: When ridability deteriorates to a point where maintenance is required.
Try to find problem?: The bridge design section and the geotechnical section try to determine the cause for the more serious cases.

How and when maintained: When the safety of the traveling public is compromised and/or the structural integrity of the slab is threatened.
Try to find problem?: If it is an erosion problem, how is the drainage causing the erosion and how can it be remedied? If settlement is the cause, is something causing extraordinary settlement.

Other detect. explan: The snow plow operators usually have direct feedback when conditions are bad.
How and when maintained: 1. Ride becomes intolerable.
Try to find problem?: If the problem occurs shortly after structure construction or re-construction and is severe, a review or investigation is generally undertaken.

How and when maintained: Ridability concerns

Other detect. explan: Respondent has checked, but not rated, "visual inspection".
How and when maintained: Severity of bump.
Try to find problem?: Usually, unless (word hard to read, may be "severe" or "reversed") worst cases are nearly catastrophic due to dispersive soil erosion.

How and when maintained: If the problem is such that either the safety of the motorist is in question or further damage to the roadway facility or bridge is inevitable then maintenance is performed.
Try to find problem?: Sometimes

How and when maintained: When it becomes very severe. Public comment etc.
Try to find problem?: Our Geotech Branch usually studies the problem and recommend a solution.

How and when maintained: Varies

How and when maintained: When we receive complaints, or when pavement growth begins to cause problems with the bridge components, i.e., breaking backwalls, rocking over bearing devices, breaking pedestals, etc.
Try to find problem?: In some cases we have performed soil/foundation testing to determine causes.

Try to find problem?: Sometimes, depending on the severity of the problem

Try to find problem?: On occasion we have done soil studies in an attempt to determine the cause of the settlement

How and when maintained: As soon as it is detected

How and when maintained: When the public complains.

Other detect. explan: (Visual Inspection--every 2 years w/ bridge inspection)
How and when maintained: Defer until bridge work is done

How and when maintained: When complaints are received or thru normal maintenance scheduling otherwise
Try to find problem?: The best method ofr repair can be best determined if the cause of approach settlement at a particular bridge site is known

How and when maintained: Rideablility (subjective) is used to determine when the problem is severe enough to repair
Try to find problem?: Bridge Inspection Teams

How and when maintained: Region Bridge Maintenance Engineers make the decision based on ridability and traffic levels. Central Office Engineers assist if approach slabs are added or replaced.
Try to find problem?: Observations are made during bridge inspections. A serious problem may result in field asking central office for assistance, but it is rare for geotechnical staff to become involved. Sometimes geotechnical design recommendations are rejec

How and when maintained: a) when rideability becomes intolerable
Try to find problem?: Occationally (sic) study extreme cases

How and when maintained: When the settlement at the end of the approach slab is more than 4-5 inches.
Try to find problem?: Problems are usually inspected and evaluated by the bridge inspectors. Unusual cases are inspected by an experienced bridge design engineer.

How and when maintained:	When the ride quality becomes intolerable or when the approach roadway receives a scheduled overlay
Try to find problem?:	Seldom
Other detect. explan:	Check by coring consolidation of materials beneath approach slabs.
How and when maintained:	By prioritizing our bridge maintenance repair work based on conditions normally gathered through Bridge Safety Inspection Reports.
Try to find problem?:	Yes, we often ask recommendations from those in Hydraulics & Material Secitons.
How and when maintained:	When ridability is significantly affected, usually within 3 years after construction. Correction is scheduled with typical other pavement settlements in the area.
Try to find problem?:	It's pretty well known, non-quantitatively, that new fills will settle some and the subsurface of original ground under high fills also.
Other detect. explan:	When bump at ent of bridge poses a hazard to snowplowing activities.
How and when maintained:	When bump (ridability) becomes objectionable. Also if hazard to snowplowing activities.
Try to find problem?:	Existing problems are referred to soils and foundations unit for investigation and recommendation.
NDT explanation:	Shallow excavation at pavement seat.
How and when maintained:	N/A
How and when maintained:	Regional maintenace (sic) crews make the decision.
Try to find problem?:	Only if unusual movements are detected will a study be conducted.
Try to find problem?:	Formal reports based on subsurface data are rarely generated.
How and when maintained:	Const. Div will only perform "maintenance" on this type of problem if it shows up prior to project completion
NDT explanation:	Ground penetrating radar
How and when maintained:	Unless it's a safety concern, we usually correct it along with other rehab. work.
Try to find problem?:	Inspection by design personnel, and investigation by geotechnical personnel/equipment.

Most Common Repair Methods

The following are the responses to question 12, about the methods used most often to repair the bump at the end of the bridge.

A/C Levling	Mud Jack	Dran Impvmts	Fill Impvmts	Soil Impvmt	Chng join	Rtro Ap Slab	R/R Ap Slab	Othr Repr
1	4	2	3	4	3	3	4	
1	3	2	3	3	2	2	3	
1	2	2	2	3	2	3	2	
1	1	2				2		
1	3	2	3	3	4	3	2	
1	2	1	3	4	2	2	2	2
3	1	2	3	3	1	2	3	
1	4	3	4	4	3	2	4	
1							2	
4	2	3	3	4	1	2	2	
1	4	1	3	2	2	3	4	
1	3	2	3	3	2	2	2	1
1	2	4	4	4	4	4	3	4
2	2	3	2	3	3	3	2	
1	2	2	3	3	3	2	2	
1	2	2	4	4	2	2	2	
1	1	2	4	4	4	2	2	
1	2	2	1	1	3	1	2	
1	4	2	4	4	2	2	2	
1		2	2	8	2	2	2	
1	4	3	3	3	2	3	3	
4	4	3	3	4	3	3	3	1
1	2	2	3	3	1	1	1	
1	1	3	2	4	2	2	2	
	1	2			2	2		
2	1	3	3	3	3	2	2	
1	2	2	3	3	3	2	2	
1	1	3	4	4	3	3	3	
1	2	2	2	4	2	2	2	
1	3	4	4	4	2	3	2	
2	1	2	3	4	3	3	3	
1	3	2	1	1	2	1	3	
1	3	3	3	3	3	3	3	
1	1	2	4	4	3	3	3	
1	3	2	2	2	4	2	2	
1	3	1	2	2	2	2	3	
1	3	2	4	4	4	3	2	
1								
1	1	2	2	4	3	2	2	2

Most Common Repair Methods (continued)

A/C Levling	Mud Jack	Dran Impvmts	Fill Impvmts	Soil Impvmt	Chng join	Rtro Ap Slab	R/R Ap Slab	Othr Repr
2	1	3	4	4	3		3	
1	1	2	3	3	4	2	2	
1	2							
1	2	3	3	4	2	3	3	
1	2	4	4	3	4	4	2	
1	1	3	3	4	4	3	2	
1	1					2	2	
1	3	2	4	4	2	2	3	
2	4	3	4	4	2	1	1	1
1	2	2	4	4	2	2	2	
1	1	3	4	4	4	3	3	
1	1	2	3	4	3	3	2	
1	3	3	4	4	3	3	3	
1	2	1	3	3	3	3	2	
1	3	4	3	4	4	4	2	
2	3	2	3	4	2	2	2	
1	4	4	4	4	4	4	4	
1	4	3	4	4	2	3	3	2
1	3	4	4	4	4	2	2	
1	3	2	3	3	3	2	2	
1	3	3	3	3	3	3	3	
1	2	3	3	4	4	3	3	
2	3	1	1	4	1	1	1	
1.2	2.3	2.4	3.1	3.6	2.7	2.4	2.4	1.9

Averages of each column
(low values are most common,
high values are least common.)

Most Common Design Procedures to Reduce Bump at End of Bridge

The following are responses to question 13, about what can be done at the design stage to reduce the occurrence of the bump at the end of the bridge.

Spec Betr Fill	Use More Comp	Allo for Setl	Sprd Foot ings	Dsgn for Setl	Coop erat ion	Use Ap Slab	Use Imp Dran	Betr Jnts	Ant. Pvmt Grth	Othr Desn
1	1	1	2	2	2	2	2	3	4	
1	1	2	3	2	2	2	1	1	2	
2	1	3		4	2	2	2	2	3	1
2	1	3	3	3		2	2	2	3	
2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	3	1	2	2	1	2	
1	1	1	2	2	2	4	3	4	4	
3	3	4	3	3	1	2	1	1	2	
	2		2			3		1		
2	2	4	4	4	2	2	2	1	2	
2	2	2	1	1	3	3	1	1	4	
1	1	3	3	2	2	2	2	2	3	2
1	1	4	4	4	4	4	4	4	4	4
2	2	3	3	2	2	2	3	3	2	
1	1	4	3	4	2	2	2	2	2	
1	1		4		2	2	2		4	
1	1	4	4	4	1	2	2	4	4	
1	2	2	2	2	2	2	1	2	2	
1	2	3	3	3	4	1	2	2	3	
2	2	3	3	4	2	2	2	2	3	
2	2	4	3	4	3	2	2	2	2	
1	1	4	4	3	3	1	1	3	3	
2	1	3	2	1	3	2	3	3	1	
1	4	4	4	3	4	1	2	2	1	
						1	1	1		
2	2	4	4	4	2	2	2	2	2	
2	3	3	4	4	2	1	2	2	4	
1	1	4	3	4	1	2	1	2	2	
1	1	2	3	2	2	1	2	2	2	
						1				
1	1	1	2	3	2	1	2	1	2	
3	3	3	3	2	2	1	2	3	4	
1	1	3	3	3	2	2	1	2	2	
1	1	4	4	4	2	1	2	3	3	
2	2	4	3	3	1	1	1	1	4	
3	2	1	2	1	2	2	3	4	4	
2	2									
1	2	4	4	4	3	2	1	3	3	
2	1				2					

Most Common Design Procedures to Reduce Bump at End of Bridge (continued)

Spec Betr Fill	Use More Comp	Allo for Setl	Sprd Foot ings	Dsgn for Setl	Coop erat ion	Use Ap Slab	Use Imp Dran	Betr Jnts	Ant. Pvmt Grth	Othr Desn
2	1	2	3	1	1	1	2	2	3	
				1						
1	1	2	3	2	2	3	2	2	2	
1	1	2	3	5	3	2	1	2	2	
1	2	2	3	2	2	2	2	2	2	
1	1					1				
1	1	4	4	4	2	2	2	3		
2	1	4	2	1	1	1	1	1	2	
1	1	4	4	4	2	1	1	2	2	1
						1	2	2	2	
2	1	3	3	3	2	1	2	2	4	
3	2	4	4	2	2	1	2	2	2	
1	3	4	4	4	3	3	3	3	4	
1	2					1				
2	1	1	4	4	2	1	1	3	4	
4	4	4	4	4	4	1	4	4	4	4
2	2	3	2	3	3	2	2	2		
4	2	4	4	4	4	4	4	4	4	
2	2	4	2	2	1	1	2	2	4	
2	2	2	3	3	2	2	2	2	3	
						1				
1	1	2	3	4	1	2	1	2	2	
2	2	2	2	1	1	1	2	3	3	
3	3	3	2	2	3	1	4	4	3	
1	3	4	3	4	1	1	1	1	2	
1.7	1.7	3.0	3.0	2.9	2.1	1.7	1.9	2.3	2.8	2.3

Averages for each column
(low values are most common; high values are least common)

Most Important Construction Controls to Reduce Bump at End of Bridge

The following are responses to question 14, about what can be done at the construction stage to decrease the problem.

Betr Comp Cntl	Wait Per- iod	Inno vatv Meth
1	1	5
1	2	2
1	2	2
1		
1	1	2
2	2	2
2	2	
1	2	2
1	2	
2	1	
1	1	
1	2	4
1	1	3
1	2	4
2	2	2
1	1	
1	2	2
2	1	1
2	2	2
1	3	4
2	2	2
1	3	2
1	2	
1	3	2
3	2	1
2	1	3
2	3	1
2	2	2
1	2	2
1	1	2
3	1	1
1	2	
1	2	4
1	2	2
1	2	2
1	3	1
2	4	
2	2	
1	3	
1	2	

Betr Comp Cntl	Wait Per- iod	Inno vatv Meth
1	1	3
	1	
1	1	3
1	2	2
2	2	1
1	2	2
1	2	2
1	2	3
1	2	
1	1	2
2	2	2
2	1	1
1		
1	1	3
1	2	4
2		
2	4	1
2	1	3
1	2	3
1	1	2
1	1	
3	1	2
3	4	1
----	----	----
1.4	1.9	2.3

Averages for each column
(low values are most common;
high values are least common)

Comments Related to Repair, Design and Construction

The following comments are responses to questions no. 12, 13, 14 and 15.

Innovative tech. explan:	*see item 7 ("Deep enough backwalls to prevent spill thru, well compacted fill behind the abutments & good drainage.")
Other design explan:	Insure that the approach is properly constructed
Other design explan:	Caltrans has a design for approach slabs that are integral with the backwall to prevent any settlement from fill settlement or erosion.
Innovative tech. expl:	(The respondent has added an item "Proper drainage" and ranked it 2=important)
Other design explan:	If time allows preconsolidate the approach embankment & foundations
Innovative tech. expl:	Reinforced earth of the use of geofabrics.
Other repair explan:	Sometimes concrete pavement needs to be replaced, or have expansion joints saw cut in it.
Other design explan:	Use asphaltic approach pavements in areas likely to have problems. This allows for easier maintenance of the problem area.
Innovative tech. expl:	Flowfill and positive drainage at abutment areas.
Innovative tech. expl:	Preload Hilfiker wal and over burden (sic) used on recent major structure.
Other repair explan:	The respondent has checked, but not rated, leveling with ACC, mud jacking.
Innovative tech. expl:	None
Other repair explan:	Uretek-jack slab using high density polyurethane
Other repair explan:	Undersealing (5 psi pumping)
Other design explan:	Study problem as it relates to existing approach, type of bridge and abutment, and type of approach with type of previous maintenance.
Innovative tech. expl:	Drilled bentonite at locations of bridge approaches
Innovative tech. expl:	N.A.
Other repair explan:	* (comment to retrofit with approach slab) "We always use an approach slab."
Other design explan:	**(comment on "allow for more settlement under the bridge abutment") "98% of our abutments are on piling"
Innovative tech. expl:	Integral end bents & tying R.C. approach slab to end bent
Other repair explan:	Respondent has checked several methods, but not rated:
Other design explan:	Respondent has checked two above, but not rated:
Other design explan:	By response above, respondent has indicated that "specify better backfill" and "use more rigorous compaction specifications" should be done together.
Innovative tech. expl:	Pile supported approaches.
Innovative tech. expl:	Use of surcharges & wick drains to accelerate settlement is common practice.
Innovative tech. expl:	a. Occasionally an underdrain is placed behind the abutment.
Innovative tech. expl:	Improve natural soil properties/accelerate settlement by wick drains---
Innovative tech. expl:	Developing new details and procedures for backfilling at abutments to minimize bump
Other repair explan:	Level settled area with hot bituminous pavement.
Other design explan:	* [by four of above items] "It would be nice but a tough thing to do"
Innovative tech. expl:	Piles are used to prevent settlement
Other design explan:	* (by better cooperation... above) "good cooperation already exists"
Innovative tech. expl:	Thorough preconstruction investigation of existing soils
Other design explan:	* (by "use a properly designed approach slab") "See Attachment"--a detail sheet for Approach Slab is appended.
Innovative tech. expl:	Have used wick drains to speed settlement in rare situations.
Innovative tech. expl:	We are now tying (sic) approach slab to bridge deck and building a sill for other end to rest on. This helps bridge settlement gap. Also, install vert. drain to keep water out of fill material.
Innovative tech. expl:	Use select backfill behind the abutment.
Innovative tech. expl:	Wick drains have been used when existing subsurface material is expected to settle and problems may be encountered with the slow relief of pore pressure
Innovative tech. expl:	We design our approach slabs to extend over the wingwalls and place a grade beam (or piles) between the approach slab and paving slab.
Other design explan:	At the present time NCDOT is including a soil fabric reinforced system under the approach slab and behind the end bent or abutment in addition allows time for settlement to occur before end bent construction is specified in plans.
Innovative tech. expl:	Fabric to contain fill material and inhibit erosion
Innovative tech. expl:	We have used ground improvement techniques, compaction grouting to improve the soil under approach fills.
Innovative tech. expl:	The use of Select Borrow in abutment areas. Approach slab details that don't allow the drainage to get under slab.
Other repair explan:	Most problems only warrant work that can be performed quickly and with little disruption to traffic.
Innovative tech. expl:	1. Waiting period after abutment is backfilled prior to paving. We have also proposed an approach slab of reinforced concrete and AC concrete that can be more effectively repaved with shim AC pavement.
Other repair explan:	F Ash grout, URETEK foam (experimental)
Innovative tech. expl:	Flowable backfill, granular backfill, strong research program
Innovative tech. expl:	We are beginning to use Geot. settlement analyses to predict amount of settlement.
Other design explan:	Respondent has ranked the actions from 1 to 10. Data disregarded except for action ranked 1.
Innovative tech. expl:	Respondent has ranked the actions from 1 to 3. Data disregarded except for action ranked 1.
Other design explan:	Respondent has defined new response code 5=maybe. Respondent

	has pencilled in "2 or 5" for answer to "use a properly designed approach slab". and "5" for "design the bridge abutment and approach fill..."
Innovative tech. expl:	1) Reinforcing backfill with geogrids or other reingforcement (sic)
Innovative tech. expl:	Use 1) Controlled low strength material (flowable fill)
Innovative tech. expl:	We have used wick drains, temporary surcharges, and undercutting on various projects.
Innovative tech. expl:	Specify granular fill at the bridge end
Other repair explan:	Control grade elevations
Other design explan:	Grade Control
Innovative tech. expl:	On Bridge Replacement projects, flowable fill is being used to backfill against abutments
Other repair explan:	Foundation settlement is rarely the cause of serious problems.
Innovative tech. expl:	We are considering using shredded tires in lieu of granular backfill for backfill.
Other design explan:	* All structures, except simple span, are designed continuous. Allowing settlement under abutments would not be tolerable.
Innovative tech. expl:	Rarely used, but removal and replacement of unsuitable natural in-situ soils
Other design explan:	As stated earlier, in our area, it's an insignificant problem with usual bridges. The prevention is worse and more costly than the situation. Typical correction is a routine correction, same as other pavement depressions on a newly constr
Innovative tech. expl:	It's a routine and minim repair situation to build up with asphalt as the slow and slight settlement occurs.
Other repair explan:	Loss of fill through skeleton type abutments has been solved by driving short lengths of sheet piling through pavement behind abutment.
Other design explan:	Very few bridges are constructed on spread footings and permitted to settle with approach fill. When technique used, application was successful.
Innovative tech. expl:	Lightweight approach fills have been used. Also, designed preloads and surcharges have been used.
Innovative tech. expl:	See enclosed report pages 115-119
Other design explan:	* (by use a properly designed approach slab) "WSDOT has a policy to use approach slabs on a new construction.
Innovative tech. expl:	See Ron Cooks memo
Other design explan:	1) In some cases lengthening the approach slab would help
Innovative tech. expl:	Original ground should be surcharged prior to building abutments
Innovative tech. expl:	Fabric reinforced backfill with positive drainage to daylight, and a reinforced concrete approach slab supported on the abutment.

Comments Related to Organizational/Procedural Problems

The following comments are responses to question no. 15, about what can be done from a procedural or management perspective to minimize the bump.

Lack of coordination in design of the bridge-end of fill environment. This needs coordination between the bridge, geotechnical and roadway designer and must be customized for each case.

There are obstacles to collecting data on the problem. We have 8,000 test installations and very little usable or reliable information on these installations.

Geotechnical and Bridge personnel would better serve each other in the same organizational unit

Too big a hurry to finish the project and open it to traffic.

Maybe traffic

FHWA STIP Program

Ambitious construction schedules that do not allow time for settlement before paving.

Need more importance placed on construction inspection. This is restricted by staffing concerns.

Our Structures Design/Construction Divisioon focuses on the best structure design and does not interact with the highway designers.

Difficult to enforce high quality inspection practices

Lack of appreciation

Inspectors may not be properly trained or may not have support of upline managers.

Current integral abutment design leads to problem, but the design has also eliminated problems from the old design. Also, geotechnical engineers and structural engineers have differing viewpoints.

The lack of adequate time for embankment settlement to take its course before construction. The lack of proper maintenance of drainage elements.

Lack of assurance of the compaction of the fill and backfill material

Minor settlement of fills, over extended time usually presents only a minimum problem situation.

State recommends approach slabs on all bridges with exceptions--see attached internal memo.

Not enough trained inspectors with knowledge of geotechnical (soils).

Construction difficulties with potential for contributing to this problem are not well communicated back to design.

Comments Related to Research and Leading States

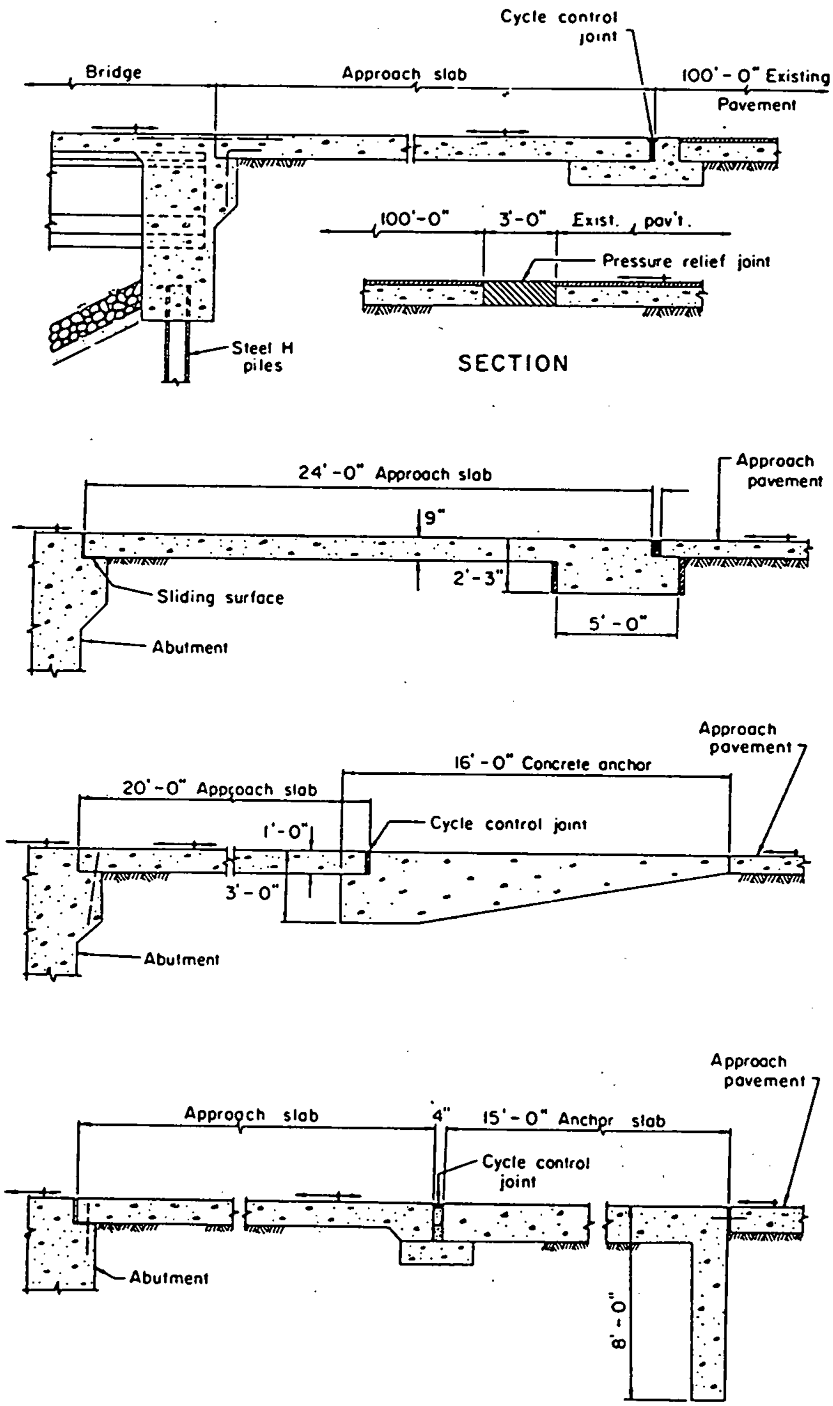
The following comments are responses to questions no 16, 17. and 18.

Research suggestions:	No recommendation
Leading states explan:	No knowledge
Leading states explan:	Hopefully your research will find the answer to this one
Performed research explan:	N/A
Research suggestions:	Determine impact loading imparted on the approach slabs when vehicle (sic) leave and enter the bridge deck.
Leading states explan:	Unknown
Performed research explan:	Respondent has included a two-page discussion of the problem. States that research is being performed by a Carl Stewart on a new approach slab design.
Performed research explan:	A research study entitled "Bridge approach settlement"
Research suggestions:	Use of geofabrics, EPS, flow fill
Leading states explan:	No idea. Northwestern states, Washington state
Performed research explan:	Literature research and data analysis of the problem. We may be carrying the study further to physical investigation in the future.
Research suggestions:	See above.
Leading states explan:	Don't know.
Performed research explan:	Survey type effort and reports by research
Leading states explan:	Unknown
Performed research explan:	SHRP
Research suggestions:	Better joint detail
Leading states explan:	Question is irrelavent (sic)
Performed research explan:	Presently are evaluating the Uretek process as mentioned in 12.)
Research suggestions:	Different type of joint designs
Performed research explan:	In House: Drilled bentonite into bridge approach, used double reinforced PCC paved approaches, used dowelled pavement forms, used geogrid
Research suggestions:	Compaction techniques for abutments and bridge approaches to reduce settlement, proper gradation of subbase materials, drainage systems, study of pavement/bridge joints, and affect (sic) of pavement notch and ties to abutment from approach
Leading states explan:	Iowa
Research suggestions:	1. A cushion material below the sleeper slab may reduce differential settlement due to impact loads.
Leading states explan:	Don't know
Performed research explan:	Qualified yes.--We formed small task force some year ago to study problem of settlement and drainage. Adopted preformed drainage system for abutment.
Research suggestions:	This is an inherent problem in bridge construction that has been investigated and written about for many years. A literature search will show that many things have been tried and few things have had wide success and still remained economic
Research suggestions:	Use of different materials in constructing approach embankments (styrofoam, shredded tires, etc;)--determine how heavy clay or other undesirable soil can be altered to perform adequately.
Leading states explan:	?
Research suggestions:	Proven insitu consolidation testing
Research suggestions:	Not sure
Leading states explan:	Don't know
Performed research explan:	Estimation of settlement for granular soils (on-going)
Research suggestions:	Construction control and case studies of completely known problems
Performed research explan:	See attached executive summary report--complete final report is available from NTIS Report No. FHWA/MD/89/13. [Respondent has transmitted copy of Maryland DOT State Highway Administration Research Report entitled "Structural and Soil Provi
Research suggestions:	Determine optimum compactive efforts to minimize settlement of the fill, while monitoring lateral soil pressures on the abutment.
Leading states explan:	Unknown, but possibly a state with poor/weak gravels and freeze-thaw cycles.
Research suggestions:	Research focused on evaluation of "solutions" implemented by various states and measurement of success or failure
Leading states explan:	Apparently most States have this problem
Performed research explan:	Sponsored NHI Course 13212, Soils & Foundations Workshop
Leading states explan:	Unknown
Research suggestions:	Methods to stablize the approach fill
Performed research explan:	See attached report.
Leading states explan:	Wyoming, Washington
Research suggestions:	Review of structural configuration
Leading states explan:	??
Leading states explan:	California has studied and proposed solutions to the problem, some of which Nevada has adopted as is or with some modifications.
Performed research explan:	However, we have a biannual program where construction and maintenance groups describe premature failures of recent construction. These problems are frequently brought to the attention of geotechnical people.
Research suggestions:	Do other states have innovative ideas? Share them. A simple method to differentiate embankment (internal) settlement versus foundation settlement.
Leading states explan:	I don't know.
Research suggestions:	Use better compaction effort near bridge
Performed research explan:	Flowable fill, Earth reinforced backfill, granular backfill, dynamic compaction
Research suggestions:	What/how does free water enter abutment area? How do we design drainage features to mitigate?
Leading states explan:	Texas
Performed research explan:	Research Division

Research suggestions:	Research different construction methods, practices & procedures.
Performed research explan:	1-Research Project at University of Okla. to development (sic) complete program to predict settlement complete.
Research suggestions:	Specific Geot. Site Studies.
Leading states explan:	?
Performed research explan:	1) Computer program to anticipate severity of settlement
Research suggestions:	Research into compaction methods and approach designs.
Performed research explan:	2 projects: An O.U. project by Dr. Zaman on the bump at the end of the bridge & an O.S.U. project by Dr. Shether [this name difficult to read] on the effects of different approach fills--Research is ongoing at this time by O.S.U.
Leading states explan:	Wyoming
Leading states explan:	Colorado
Research suggestions:	Research not needed
Research suggestions:	Unknown
Leading states explan:	Unknown
Performed research explan:	You have received reports from Vernon Bump.
Research suggestions:	Research on backfill designs that would accomodate movement from integral abutments.
Leading states explan:	Don't know.
Research suggestions:	Cost effective in-situ soil modifications
Leading states explan:	Don't know. See "Bridge Abt. & Approach Slab Settlement" Phase I, Tadros, Univ. of Nebraska Dec. 1989
Performed research explan:	Research by Dr. Clyde Lee, 1977
Research suggestions:	The main problem with approach slab settlement is not giving enough time to obtain the required settlement of the fill prior to constructint the bridge, inadequate compaction and keeping the drains functional by Maintenance personnel. Ther
Leading states explan:	probably California
Research suggestions:	?
Leading states explan:	Mild euphoria helps
Research suggestions:	None, there's enough subjective knowldege on the topic out there. Soil mechanics is not all that reliable to come to reasonable forecasts on project by project occurances to justify the cost of effort.
Leading states explan:	Is this really a problem for the usual situation?
Performed research explan:	Various types of approach slabs have been used.
Performed research explan:	Enclosed.
Performed research explan:	?
Research suggestions:	?
Leading states explan:	?
Performed research explan:	See Ron Cooks report of the 1992 Bridge Approach Study Team
Research suggestions:	Design development procedures that assure input from Soils Engineers regarding quality of embankment and backfill materials. Designs which allow embankments near the abutment to be compacted with larger equipment than small vibratory machinery
Leading states explan:	Possibly Minnesota and Iowa
Leading states explan:	No knowledge
Performed research explan:	RP#106-"Study of Bridge Approach Behavior and Recommendations on Current Practice" The research project is being executed by WVU, beginning 11/94; will include literature study and survey practice.
Performed research explan:	N/A
Research suggestions:	Soil settlement analysis
Performed research explan:	See copies of attached paper [attached is Edgar, Thomas V., Jay A. Puckett, William F. Sherman, and Jeffrey L. Groom, "Utilizing Geotextiles in Highway Bridge Approach Embankments", Geotextiles and Geomembranes 5(1987) 3-16.]
Research suggestions:	Achieving better compaction of granular material in fabric reinforced fills.

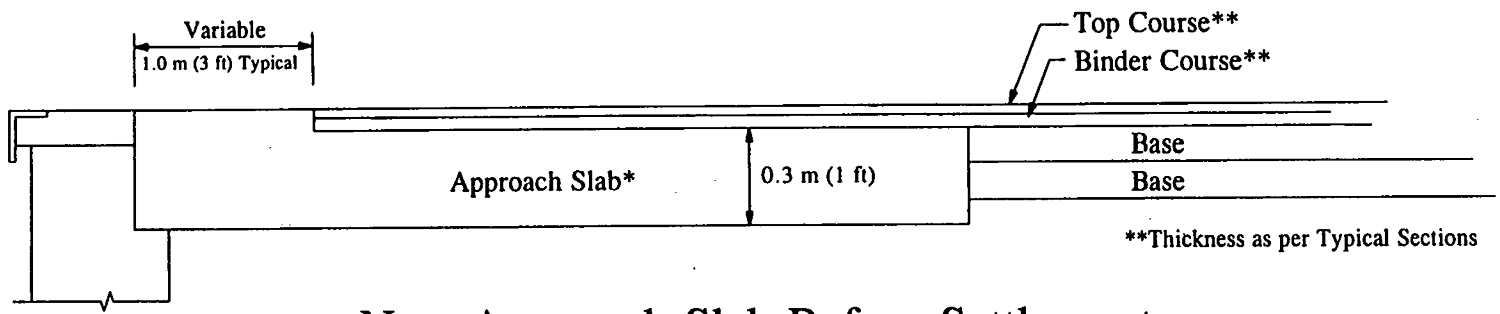
APPENDIX C

Example of Approach Slab Details



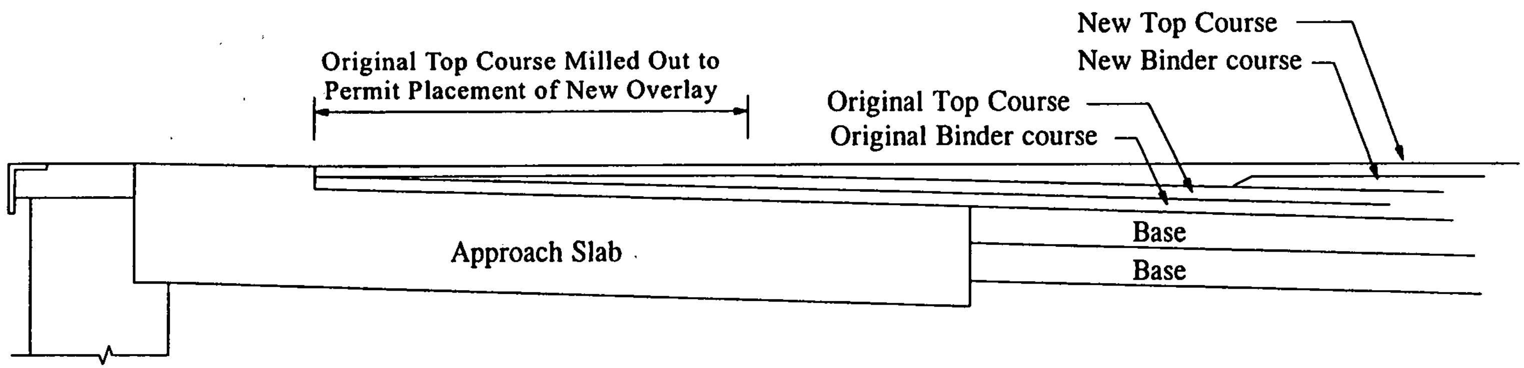
Burke, M.P., Bridge Approach Pavements, Integral Bridges, and Cycle Control Joints, in *Transportation Research Record 1113,* TRB, National Research Council, Washington, D.C., pp. 54-65.

Paved Approach Slab with Asphalt Roadway



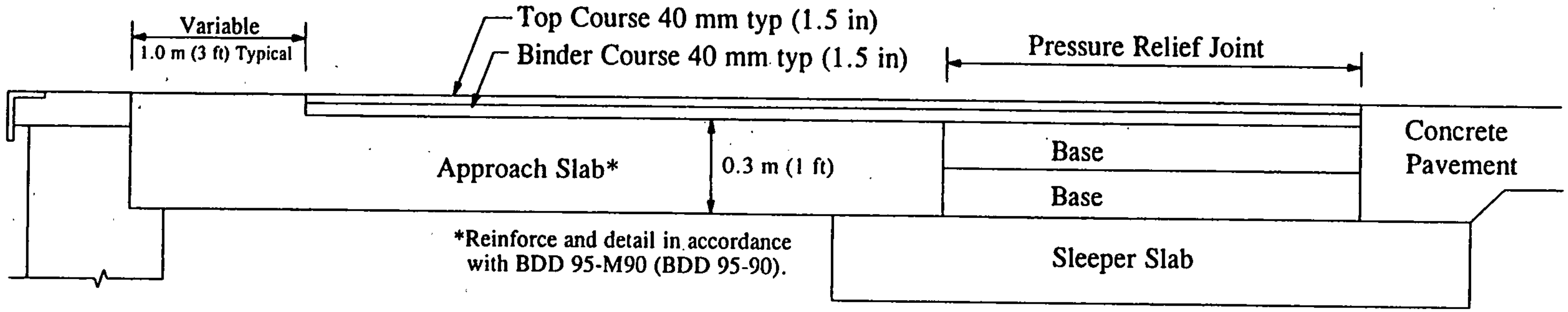
New Approach Slab Before Settlement

*Reinforce and detail in accordance with BDD 95-M90 (BDD 95-90).

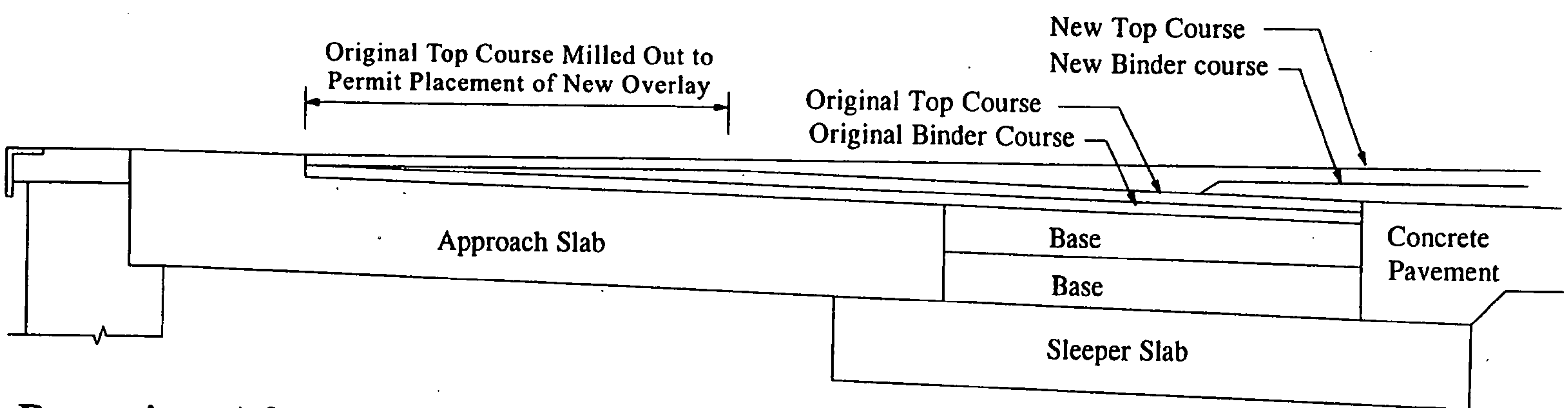


Repaving After Settlement

Paved Approach Slab with Concrete Roadway

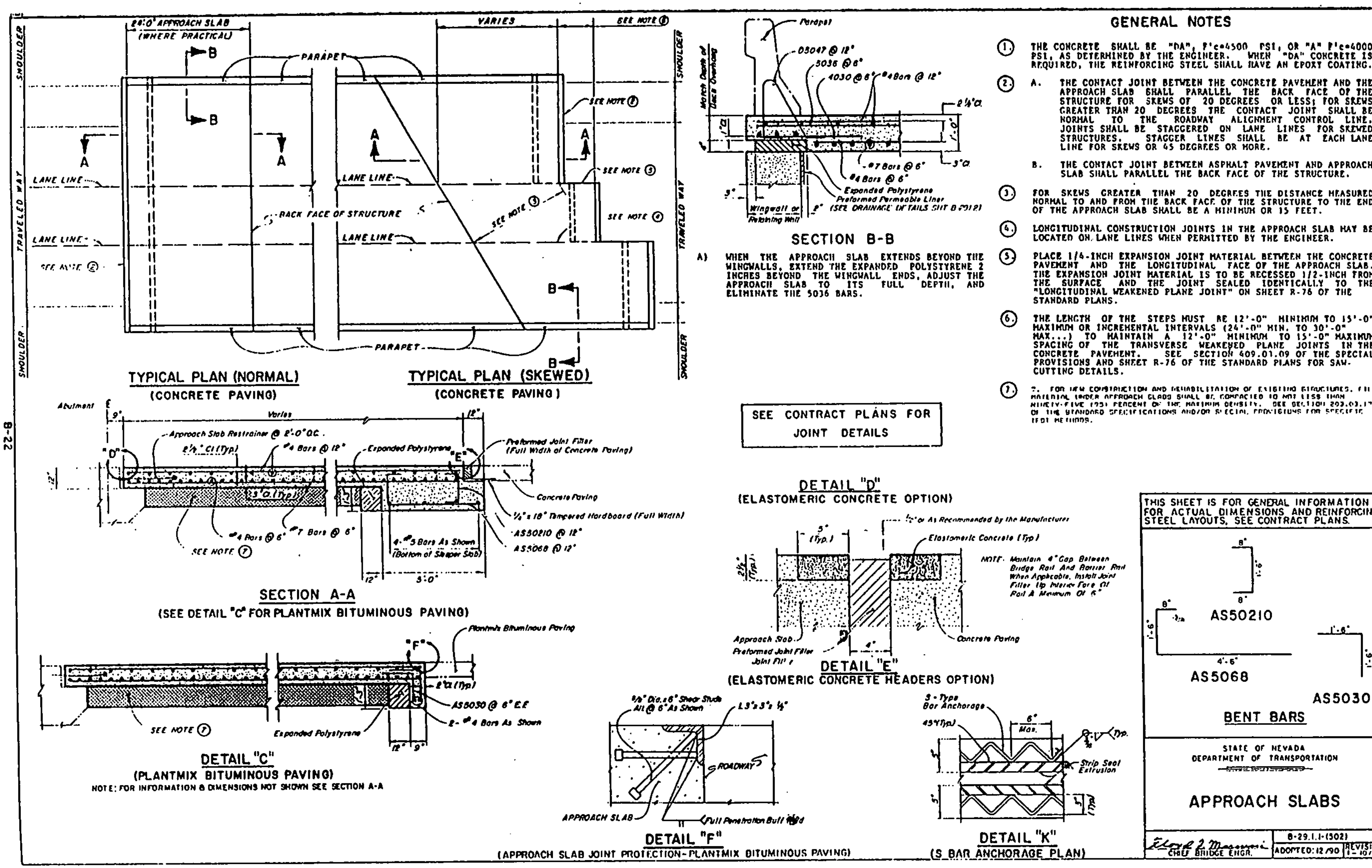


New Approach Slab Before Settlement

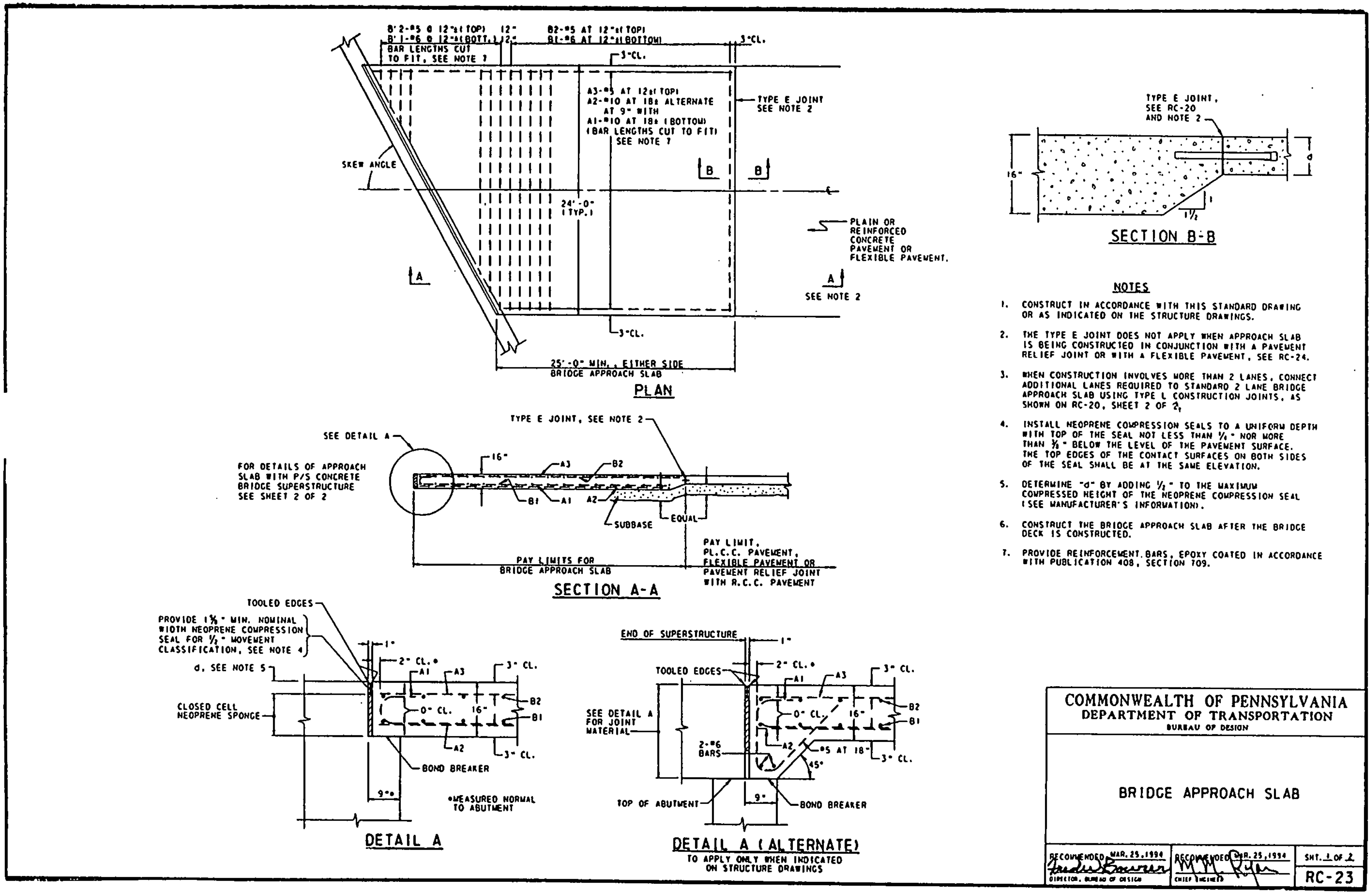


Repaving After Settlement

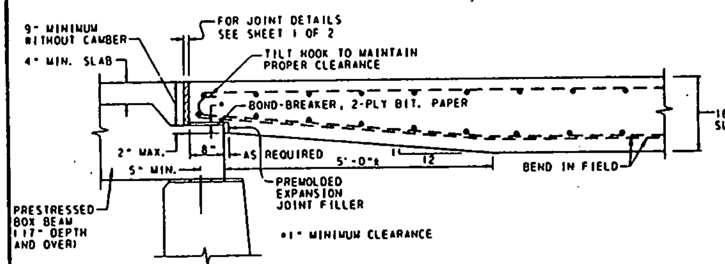
- **New York Department of Transportation, 1995, Approach Slab Details obtained from Robert Burnett, Soil Mechanics Bureau, Albany, New York.**



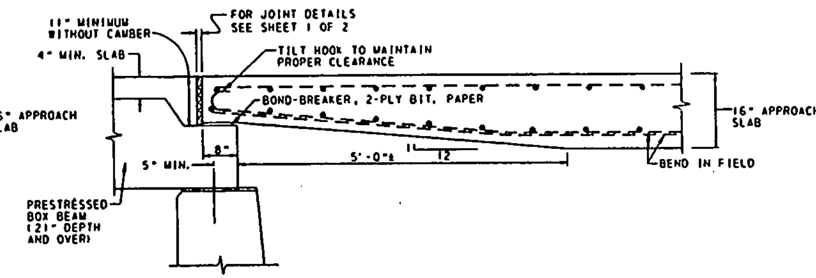
- **Nevada Department of Transportation, 1995, Attachment to Survey Response, Floyd Marcucci, Bridge Division, Carson City, Nevada.**



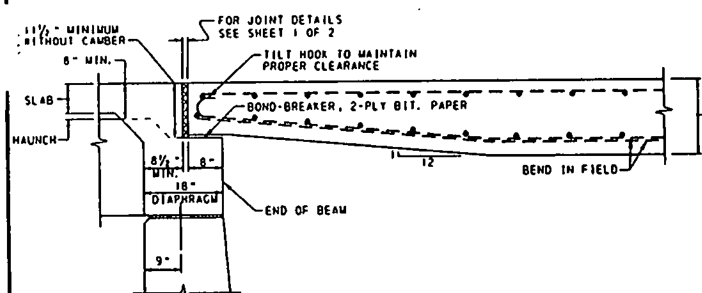
- **Commonwealth of Pennsylvania Department of Transportation, 1995, Attachment to Survey Response, H. C. Rogers, Bridge Division, Harrisburg, Pennsylvania.**



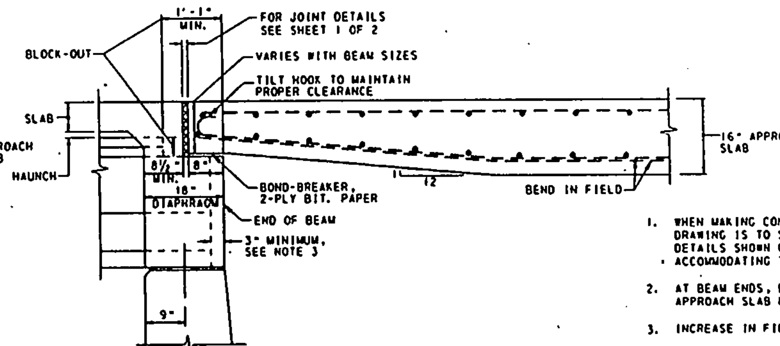
17" DEEP ADJACENT COMPOSITE BOX BEAMS WITH 9" DEEP APPROACH SLAB NOTCH



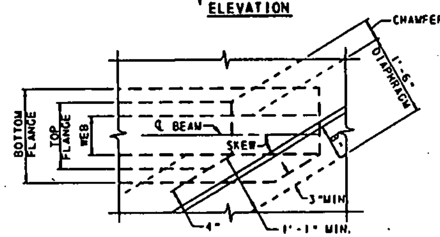
21" TO 48" DEEP ADJACENT COMPOSITE BOX BEAMS WITH 11" DEEP APPROACH SLAB NOTCH



SPREAD BOX BEAMS WITH APPROACH SLAB NOTCH 11½" OR DEEPER



ELEVATION



PLAN

I-BEAMS

NOTES

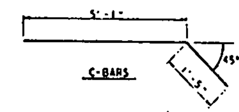
1. WHEN MAKING CONSTRUCTION CHANGES IN THE FIELD, THIS DRAWING IS TO SERVE AS A GUIDE FOR MODIFYING NOTCH DETAILS SHOWN ON P/S STANDARD DRAWINGS FOR ACCOMMODATING THE STANDARD 16" BRIDGE APPROACH SLAB.
2. AT BEAM ENDS, BURN OFF REINFORCEMENT PROTRUDING INTO APPROACH SLAB NOTCH.
3. INCREASE IN FIELD, PROVIDING OVERHANG, IF REQUIRED.
4. PROVIDE REINFORCEMENT BARS, EPOXY COATED, IN ACCORDANCE WITH PUBLICATION 408, SECTION 709.

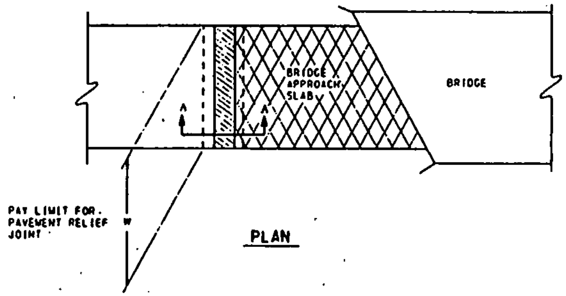
COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF DESIGN

BRIDGE APPROACH SLAB

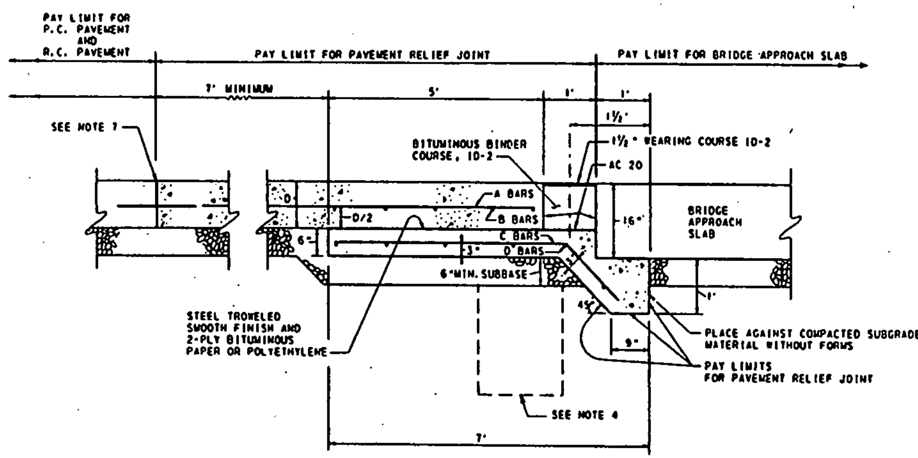
RECOMMENDED MAR. 25, 1994 [signature] DIRECTOR, BUREAU OF DESIGN	RECOMMENDED MAR. 25, 1994 [signature] CHIEF ENGINEER	SHT. 2 OF 2 RC-23

SCHEDULE OF REINFORCEMENT STEEL				
MARK	SIZE	SPACING C - C	LENGTH	NUMBER REQUIRED
A	#4	12"	10'-6"	W
B	#4	12"	W minus 4"	5
C	#4	6"	6'-6"	W x 2
D	#4	12"	W minus 4"	7





PLAN



SECTION A-A

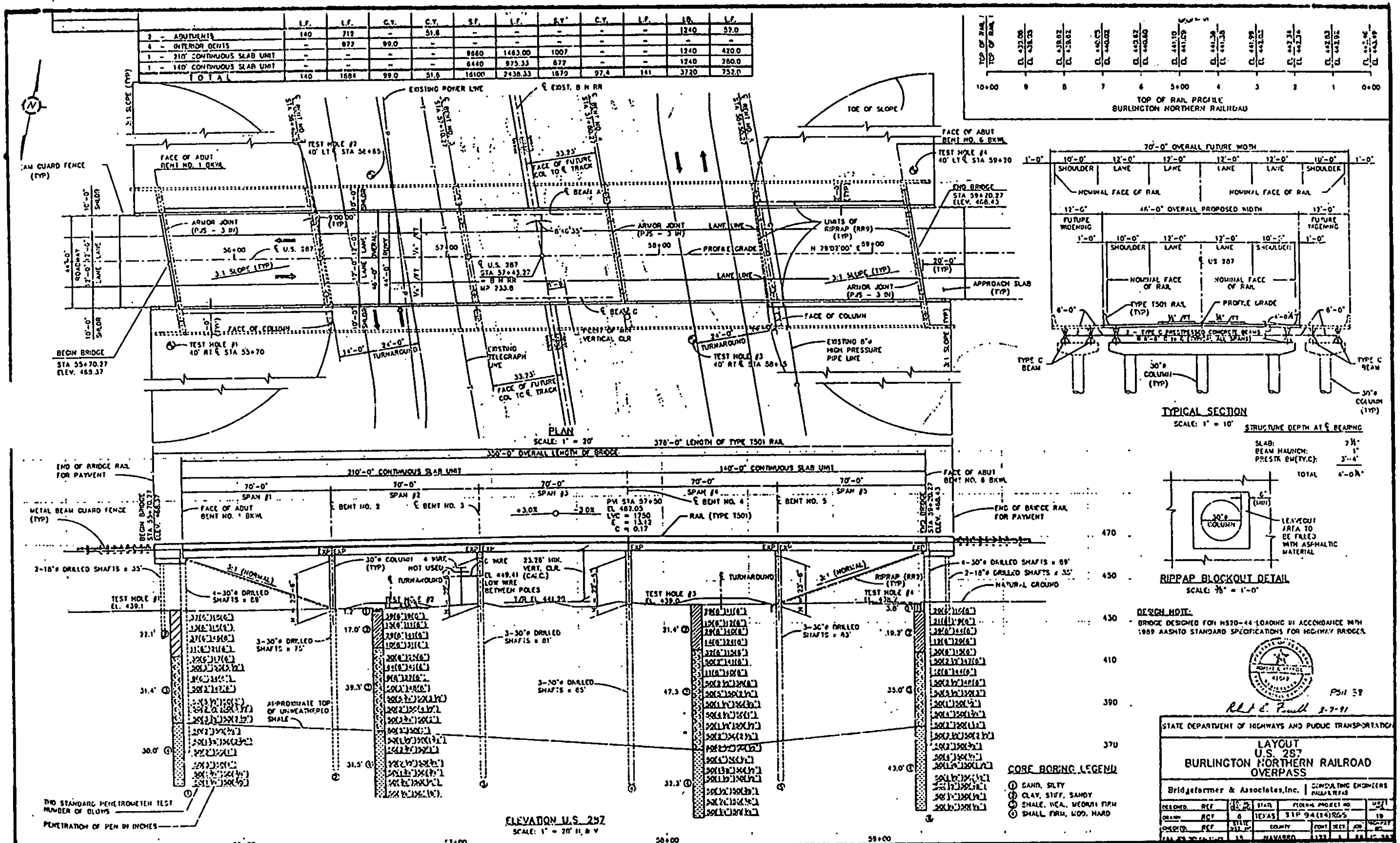
NOTES

1. PAVEMENT RELIEF JOINTS ARE APPLICABLE FOR ALL CEMENT CONCRETE PAVEMENTS.
2. CONCRETE IN SUBSLAB SHALL BE CLASS AA (AT CONTRACTORS OPTION, SUBSLAB CONCRETE MAY BE H.E.S.)
3. PORTIONS OF REINFORCING BARS WHICH ARE LOCATED OUTSIDE THE INDICATED PAY LINES SHALL BE INCLUDED IN BID PRICE FOR PAVEMENT RELIEF JOINT.
4. WHEN THE PAVEMENT GRADE CAUSES DRAINAGE TOWARDS THE BRIDGE, A SUBGRADE DRAIN (SEE RC-30) SHALL BE PLACED UNDER THE 6" PORTION OF THE SUBSLAB AND WILL BE MEASURED AND PAID FOR AS SPECIFIED IN SECTION 612, PUBLICATION 408.
5. WHERE BRIDGES ARE LOCATED LESS THAN 1,000 FT. APART, AS MEASURED FROM THE FACE OF THE NEAREST ABUTMENTS, NO RELIEF JOINT WILL BE USED BETWEEN THE BRIDGES.
6. WHERE BRIDGES ARE LOCATED BETWEEN 1,000 FT. AND 1,500 FT. APART, AND THE PAVEMENT STRUCTURE IS CEMENT CONCRETE, ONE RELIEF JOINT SHALL BE PLACED MIDWAY BETWEEN THE BRIDGES. IN THESE CASES, THE SUBSLAB SHALL BE A UNIFORM 6 IN. THICK AND 7 FT. WIDE.
7. FOR JOINT DETAILS ON NEW CONSTRUCTION, SEE RC-20. FOR JOINT DETAILS ON RECONSTRUCTION, SEE RC-26. IF THE DISTANCE TO THE NEAREST JOINT IS LESS THAN 10', REMOVE THE EXISTING PAVEMENT TO THE JOINT.

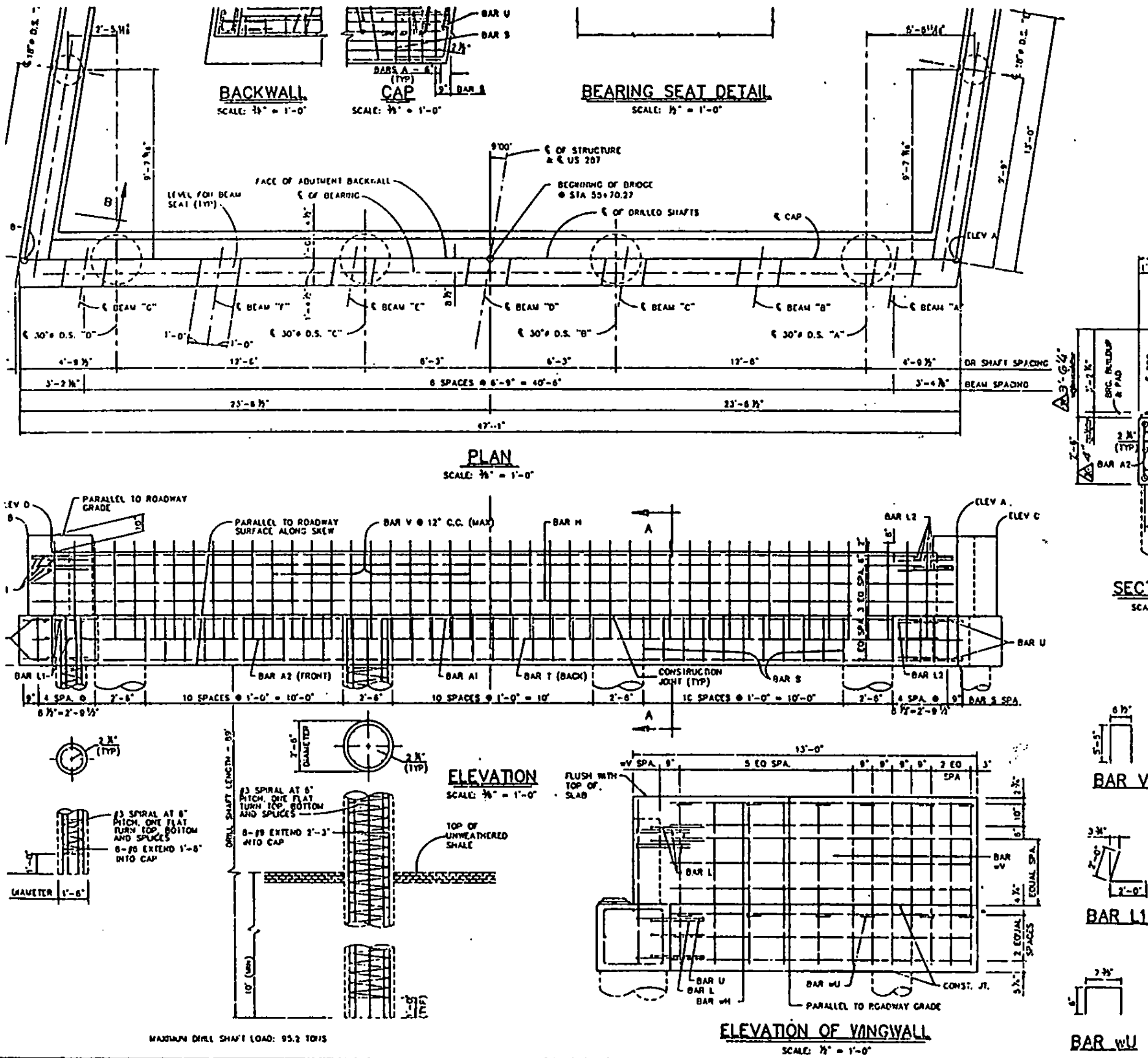
COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF DESIGN

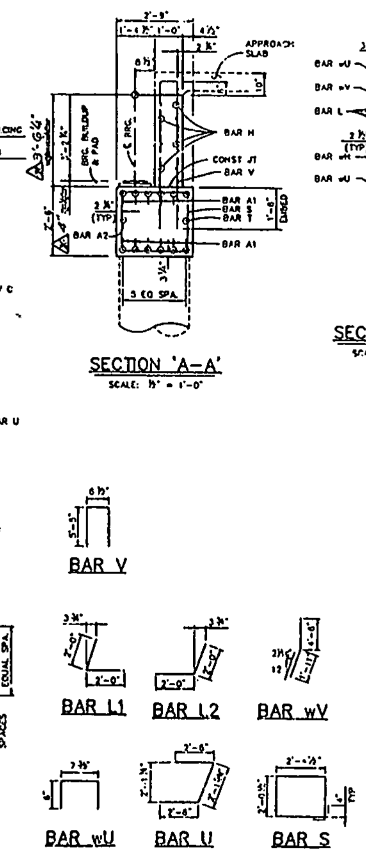
PAVEMENT RELIEF JOINT

RECOMMENDED MAR. 25, 1994 — DIRECTOR, BUREAU OF DESIGN	RECOMMENDED MAR. 25, 1994 — CHIEF ENGINEER	SHT. 1 OF 1 — RC-24



- **Texas Department of Transportation, 1995, Approach Slab Details obtained from Charles Terry, Bridge Division, Austin, Texas.**





TOP OF DRILL SHAFT ELEVATIONS

DRILL SHAFT	A	B	C	D	E	F
ELEVATION	461.12	461.38	461.31	461.16	460.95	461.00

CONTROL ELEVATIONS

CONTROL POINT	A	B	C	D
ELEVATION	487.87	487.92	487.78	487.83

A1	12	#8	48'-1"	1,478
A2	1	#11	48'-1"	245
H	8	#5	48'-4"	387
wH	32	#6	12'-9"	613
L1	9	#6	4'-0"	54
L2	9	#6	4'-0"	54
S	43	#4	9'-8"	273
T	1	#5	48'-1"	48
U	4	#6	7'-2"	43
wU	24	#4	1'-7"	25
V	45	#5	11'-5"	536
wV	52	#5	6'-5"	348

REINF. STEEL *	LB.	4,102
CL "C" CONC (ABUT)	C.Y.	25.6
DRILL SHAFT (18" ø)	L.F.	70
DRILL SHAFT (30" ø)	L.F.	358

* FOR CONTRACTORS INFORMATION ONLY. NON-PAY ITEM

Indicates Changes Sealed By Van M. McElroy

NOTES:

ALL CONCRETE EXCEPT DRILLED SHAFT CONCRETE SHALL BE CLASS "C".

THE PRICE BID FOR DRILL SHAFT SHALL INCLUDE THE REINFORCING EXTENDING FROM THE SHAFT INTO THE CAP.

FOUND SHAFTS AT DEPTH SHOWN OR LOWER IF NECESSARY TO PENETRATE UNWEATHERED SHALE DIMENSION SHOWN.

SPIRAL STEEL SHALL HAVE ONE EXTRA TURN TOP, BOTTOM, AND AT SPLICES.

ALL REINFORCING STEEL SHALL BE ASTM A-615 GRADE 60

2-7-91

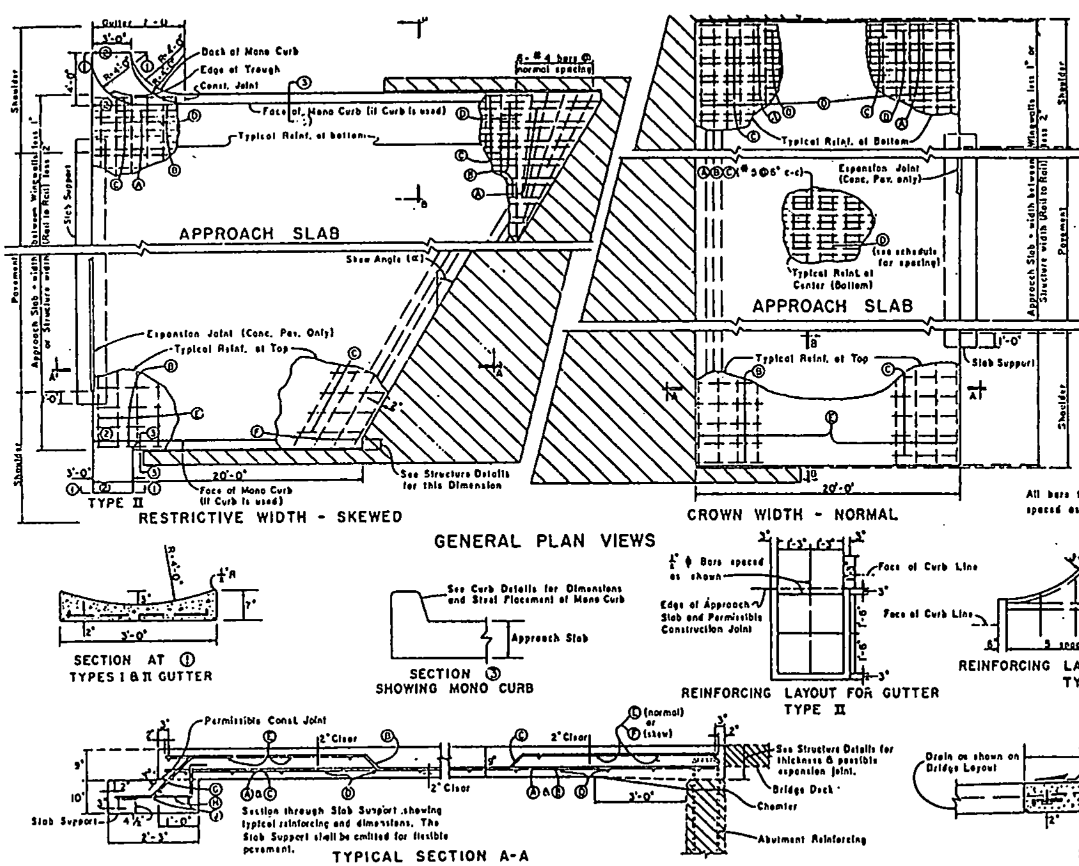
STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

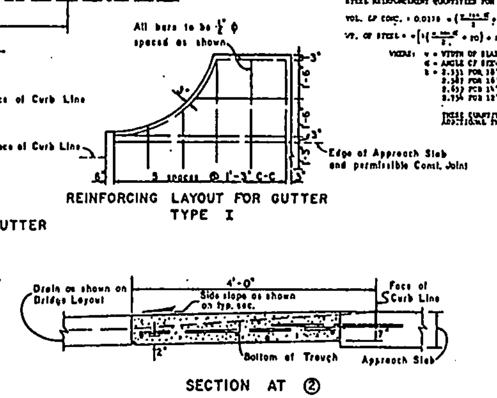
ABUTMENT NO. 1

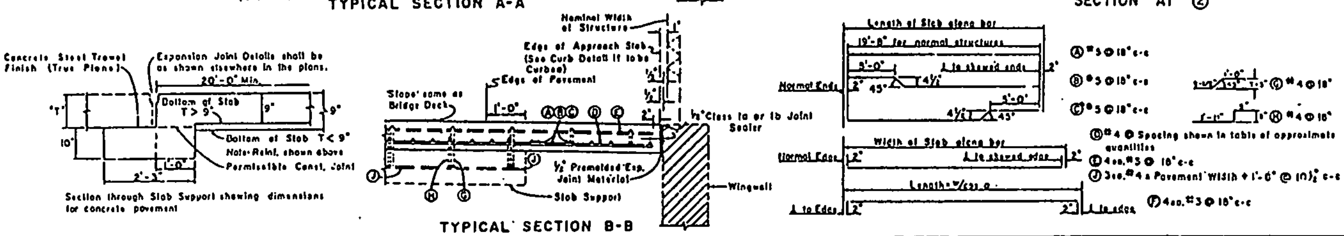
DETAILS

Bridgefarmer & Associates, Inc. | CONSULTING ENGINEERS DALLAS, TEXAS

DESIGNED REF		STATE	FEDERAL PROJECT NO.				SHEET NO.
DRAWN SUD	6	TEXAS	STP 94(14)R55				20
CHECKED REF	STATE DIST. NO.	COUNTY		CONT.	SECT.	JOB	HIGHWAY NO.
	18	NAVARRO		122	4	26	US 287







GENERAL NOTES

1. THE APPROACH SLAB SHALL HAVE THE SAME TRANSVERSE CROWN THROUGHOUT ITS LENGTH AS THE STRUCTURE WHICH IT ADJOINS.
2. THE APPROACH SLAB SHALL BE FINISHED AS REQUIRED FOR THE STRUCTURE OR AS DIRECTED BY THE ENGINEER.
3. IF A CURB IS USED ON THE STRUCTURE, A CURB WITH HEIGHT AND INSIDE FACE MATCHING THE STRUCTURE CURB SHALL BE USED ON THE APPROACH SLAB. THE CURB SHOULD TAPER TO A TWO INCH HEIGHT AND TERMINATE AT THE END OF THE SLAB OR AT THE DRAINAGE GUTTER, IF A DRAINAGE GUTTER IS USED.
4. TYPE I GUTTERS SHOULD BE USED IN LIEU OF TYPE II GUTTER WHEN SPACE PERMITS.
5. REINFORCING STEEL SHALL CONFORM TO ASTM DESIGNATION: A-615, GRADE 60. SPLICES SHALL BE A MINIMUM OF 30 TIMES THE NOMINAL DIAMETER OF THE BAR.
6. THE CHAIRS USED TO SUPPORT THE BAR MAT SHALL BE OF SUFFICIENT STRUCTURAL QUALITY AND NUMBER TO HOLD THE MAT WITHIN THE PLACEMENT HEIGHT TOLERANCES, AND SHALL BE OF A TYPE APPROVED BY THE ENGINEER.
7. DETAILS AND QUANTITIES FOR CURB ARE TO BE AS SHOWN ELSEWHERE IN PLANS.
8. SAWED OR FORMED JOINTS 1½" DEEP SHALL BE CONSTRUCTED AT SAME TIMES. JOINTS SHALL BE SEALED AS SPECIFIED IN THE CURRENT JOINT SEAL STANDARD, METHOD A OR B.

WIDTH OF APPROACH SLAB (FT)	SPACING OF BOTTOM TRANS. STEEL D (IN)	APPROXIMATE QUANTITIES FOR ONE APPROACH SLAB *									
		NORMAL		15° SKEW		30° SKEW		45° SKEW		60° SKEW	
		CONC. (CY)	STEEL (LB)	CONC. (CY)	STEEL (LB)	CONC. (CY)	STEEL (LB)	CONC. (CY)	STEEL (LB)	CONC. (CY)	STEEL (LB)
25'	18	13.9	1343	16.0	1765	18.9	1603	22.6	2151	29.9	2753
30	18	16.7	1609	20.0	1916	23.9	2223	29.2	2764	38.3	3547
35	18	17.6	1716	21.6	2063	26.0	2472	32.0	3032	42.6	4409
40	16	22.2	2190	28.2	2757	33.1	3354	44.5	4104	60.8	5435
45	14	24.5	2472	31.1	3164	40.0	3749	51.6	5074	71.1	6497
52	12	28.9	3021	39.0	4021	50.6	5181	66.5	6776	94.0	9348

* FOR SLAB WIDTHS AND BRIDGE SKEWS OTHER THAN THOSE SHOWN, USE THE FOLLOWING FORMULAS FOR ESTIMATING:

STEEL REINFORCEMENT QUANTITIES FOR CONTRACTOR'S INFORMATION ONLY.

VOL. OF CONC. = 0.0370 w ([illegible] + 20) CUBIC YARDS

WT. OF STEEL = w [k ([illegible] + 20) + 1.334 (1 + sec α)] POUNDS

WHERE: w = WIDTH OF SLAB
α = ANGLE OF SKEW
k = 2.333 FOR 18" ± 4 ± SPACING OF D BARS (SLABS 35 FEET WIDE OR LESS)
2.583 FOR 16" ± 4 ± SPACING OF D BARS (SLABS 36 - 40' WIDE)
2.653 FOR 14" ± 4 ± SPACING OF D BARS (SLABS 41 - 45' WIDE)
2.734 FOR 12" ± 4 ± SPACING OF D BARS (SLABS 46 - 52' WIDE)

THESE QUANTITIES DO NOT INCLUDE SLAB SUPPORT, CURB, GUTTERS OR ADDITIONAL THICKNESS ADJACENT TO BRIDGE END.

ESTIMATED QUANTITIES FOR ONE 24 FOOT WIDE SLAB SUPPORT					
Pavement Thickness (In.)	6	7	8	9	10
Concrete Cu. Yd.	1.41	1.43	1.51	1.58	1.66
Steel (Lbs.)	99	101	103	104	105

ESTIMATED QUANTITIES FOR ONE GUTTER			
TYPE I		TYPE II	
Concrete CY	Reinf. Steel (Lbs.)	Concrete CY	Reinf. Steel (Lbs.)
0.44	24.73	0.70	17.35

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

BRIDGE APPROACH SLAB
FOR USE WITH ASPHALT AND CONCRETE PAVEMENTS NORMAL OR SKEW
BAS - 75

STATE: TEXAS | FEDERAL PROJECT NO.: STP 94(14)?G? | SHEET NO.: 29
COUNTY: NAVARRO

A-16

APPENDIX D

Example of Compaction Specifications

Texas Department of Transportation, 1995, Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges, Austin, Texas

ITEM 132

EMBANKMENT

132.1. Description. This Item shall govern for the placement and compaction of all materials necessary for the construction of roadway embankments, levees and dykes or any designated section of the roadway where additional material is required.

132.2. Material. Materials may be furnished from required excavation in the areas shown in the plans or from off right of way sources obtained by the Contractor and meeting the requirements herein. All embankment shall conform to one of the following types as shown on the plans, except that material which is in a retaining-wall-backfill area shall meet the requirements for backfill material of the pertinent retaining-wall item:

Type A. This material shall consist of suitable granular material, free from vegetation or other objectionable matter, and reasonably free from lumps of earth. This material shall be suitable for forming a stable embankment and, when tested in accordance with Test Methods Tex-104-E, Tex-105-E, Tex-106-E and Tex-107-E, Part II shall meet the following requirements:

The liquid limit shall not exceed 45
The plasticity index shall not exceed. 15
The bar linear shrinkage shall not be less than 2

Type B. This material shall consist of suitable earth material such as rock, loam, clay, or other such materials as approved by the Engineer that will form a stable embankment.

Type C. This material shall be suitable and shall conform to the specification requirements shown on the plans.

Type D. This material shall be that obtained from required excavation areas shown on the plans and will be used in embankment.

132.3. Construction Methods.

(1) General. When off right of way sources are involved, the Contractor's attention is directed to Item 7, "Legal Relations and Responsibilities to the Public". Prior to placing any embankment, all work in accordance with Item 100, "Preparing Right of Way", shall have been completed on the areas over which the embankment is to be placed. Stump holes or other small excavations in the limits of the embankments shall be backfilled with suitable material and thoroughly tamped by approved methods before commencing embankment construction. The surface of the ground, including disk-loosened ground or any surface roughened by small washes or otherwise, shall be restored to approximately its original slope by blading or other methods. Where shown on the plans or required by the Engineer, the ground surface thus prepared shall be compacted by sprinkling and rolling.

The Engineer shall be notified sufficiently in advance of opening any material source to allow performance of any required testing.

Unless otherwise shown on the plans, the surfaces of unpaved areas (except rock) which are to receive embankment shall be loosened by scarifying to a depth of at least 150 millimeters. Hillsides shall be cut into steps before embankment materials are placed. Placement of embankment materials shall begin at the low side of hillsides and slopes. Materials which have been loosened shall be recompacted simultaneously with the new embankment materials placed upon it. The total depth of loosened and new materials shall not exceed the permissible depth of the layer to be compacted, as specified in Subarticle 132.3.(3).(a) and (b).

Trees, stumps, roots, vegetation or other unsuitable materials shall not be placed in embankment.

Unless otherwise shown on the plans, all embankment shall be constructed in layers approximately parallel to the finished grade of the roadbed.

Embankments shall be constructed to the grade and sections shown on the plans or as established by the Engineer. Each section of the embankment shall correspond to the detailed section or slopes established by the Engineer. After completion of the roadway, it shall be continuously maintained to its finished section and grade until the project is accepted.

(2) Constructing Embankments.

(a) Earth Embankments. Earth embankments shall be defined as those composed principally of material other than rock, and shall be constructed of acceptable material from approved sources.

Unless otherwise specified, earth embankments shall be constructed in successive layers for the full width of the individual roadway cross section and in such lengths as are best suited to the sprinkling and compacting methods utilized.

Layers of embankment may be formed by utilizing equipment and methods which will evenly distribute the material.

A minor quantity of rock or broken concrete encountered in the construction of this project may be incorporated in the lower layers of the embankment if acceptable to the Engineer. Or, it may be placed in the deeper fills, in accordance with the requirements for the construction of rock embankments, provided such placement of rock is not immediately adjacent to structures or in areas where bridge foundations are to be constructed. Also, rock or broken concrete may be placed in the portions of embankments outside the limits of the completed roadbed width where the size of the rock or broken concrete prohibits its incorporation in the normal embankment layers. All exposed reinforced steel shall be cut and removed from the broken concrete.

Each layer of embankment shall be uniform as to material, density and moisture content before beginning compaction. Where layers of unlike materials abut each other, each layer shall be featheredged for at least 30 meters, or the material shall be so mixed as to prevent abrupt changes in the soil. No material placed in the embankment by dumping in a pile or windrow shall be incorporated in a layer in that position, but all such piles or windrows shall be moved by blading or similar methods. Clods or lumps of material shall be broken and the embankment material mixed by blading, harrowing, disking or similar methods until a uniform material of uniform density is achieved in each layer.

Sprinkling required to achieve the moisture content necessary for compaction shall meet the material requirements of Item 204, "Sprinkling". It shall be the responsibility of the Contractor to secure a uniform moisture content throughout the layer by such methods as may be necessary. In order to facilitate uniform wetting of the embankment material, the Contractor may apply water at the material source if the sequence and

methods used do not cause an undue waste of water. Such procedures shall be subject to the approval of the Engineer.

(b) Rock Embankments. Rock embankments shall be defined as those composed principally of rock, and shall be constructed of acceptable material.

Unless otherwise specified, rock embankments normally shall be constructed in successive layers for the full width of the individual roadway cross section and of 450 millimeters or less in depth. When, in the opinion of the Engineer, the rock sizes necessitate a greater depth of layer, the layer depth may be increased as necessary, but in no case shall the depth of layer exceed 0.75 meter. Each layer shall be constructed in such a manner that the interstices between the larger stones are filled with smaller stones and spalls which have been created by this operation as well as from the placement of succeeding layers of material.

The maximum dimension of any rock used in embankment shall be less than the depth of the embankment layer, and in no case shall any rock over 0.6 meter in its greatest dimension be placed in the embankment unless otherwise approved by the Engineer. Unless otherwise shown on the plans, the upper or final layer of the embankment shall be composed of material so graded that the density and uniformity of the surface layer may be secured by the "Ordinary Compaction" or "Density Control" method. Exposed oversize material shall be reduced by sledging or other methods as approved by the Engineer.

When "Ordinary Compaction" is specified, each embankment layer shall be rolled and sprinkled when and to the extent directed by the Engineer. When "Density Control" is specified, each layer shall be compacted to the required density as outlined for "Earth Embankments", except that in those layers where rock will make density testing difficult, when shown on the plans, the Engineer may require the layer to be proof rolled to insure proper compaction.

(c) Embankment Adjacent to Culverts and Bridges. Embankments adjacent to culverts and bridges shall be compacted in the manner prescribed under Item 400, "Excavation and Backfill for Structures", or other appropriate bid items.

As a general practice, embankment material placed adjacent to any portion of any structure and in the first two layers above the top of any culvert or similar structure shall be free of any appreciable amount of gravel or stone particles more than 100 millimeters in greatest dimension and of such gradation as to permit thorough compaction. When, in the opinion of the Engineer, such material is not readily available, the use of rock or gravel mixed with earth will be permitted, in which case no particle larger than 300 millimeters in greatest dimension and 150 millimeters in least dimension may be used. The percentage of fines shall be sufficient to fill all voids and insure a uniform and thoroughly compacted mass of proper density.

(3) **Compaction Methods.** Compaction of embankments shall be by "Ordinary Compaction" or "Density Control" as shown on the plans.

(a) **Ordinary Compaction.** When "Ordinary Compaction" is shown on the plans, the following provisions shall govern:

Each layer shall not exceed 200 millimeters of loose depth, unless otherwise directed by the Engineer. Each layer shall be compacted in accordance with the provisions governing the Item or Items of "Rolling". Unless otherwise specified on the plans, the rolling equipment shall be as approved by the Engineer. Compaction shall continue until there is no evidence of further compaction. Prior to and in conjunction with the rolling operation, each layer shall be brought to the moisture content directed by the Engineer, and shall be kept leveled with suitable equipment to insure uniform compaction over the entire layer. Should the subgrade, for any reason or cause, lose the required stability or finish, it shall be recompacted and refinished at the Contractor's expense.

(b) **Density Control.** When "Density Control" is shown on the plans, the following provisions shall apply:

Each layer shall be compacted to the required density by any method, type and size of equipment which will give the required compaction. The depth of layers, prior to compaction, shall depend upon the type of sprinkling, mixing and compacting equipment used. However, maximum depth (400 millimeters loose and 300 millimeters compacted) shall not be exceeded unless approved by the Engineer. Prior to and in conjunction with the rolling operation, each layer shall be brought to the moisture content necessary to obtain the required density and shall be kept leveled with suitable equipment to insure uniform compaction over the entire layer.

Each layer shall be sprinkled as required and compacted to the extent necessary to provide the density specified below, unless otherwise shown on the plans.

Description	Density, Percent	Moisture
Non-swelling soils with plasticity index less than 20	Not less than 98	
Swelling soils with plasticity index of 20 to 35	Not less than 98 nor more than 102	Not less than optimum
Swelling soils with plasticity index over 35	Not less than 95 nor more than 100	Not less than optimum

The density determination will be made in accordance with Test Method Tex-114-E. Field density determination will be made in accordance with Test Method Tex-115-E.

After each layer of earth embankment is complete, tests as necessary may be made by the Engineer. When the material fails to meet the density requirements or should the material lose the required stability, density, moisture or finish before the next course is placed or the project is accepted, the layer shall be reworked as necessary to obtain the specified compaction, and the compaction method shall be altered on subsequent work to obtain specified density. Such procedure shall be subject to the approval of the Engineer.

Excessive loss of moisture shall be construed to exist when the subgrade soil moisture content is four (4) percent less than the optimum.

The Contractor may be required to remove a small area of the layer in order to facilitate the taking of density tests. Replacement and compaction of the removed material in the small area shall be at the Contractor's expense.

When shown on the plans and when directed by the Engineer, the Contractor shall proof roll in accordance with Item 216, "Rolling (Proof)". Soft spots shall be corrected as directed by the Engineer.

132.4. **Tolerances.** The tolerances shall be as follows:

(1) **Grade Tolerances.**

(a) **Stage Construction.** Any deviation in excess of 30 millimeters in cross section and 30 millimeters in five (5) meters measured longitudinally shall be corrected by loosening, adding or removing the material, reshaping and recompacting by sprinkling and rolling.

(b) **Turnkey Construction.** Any deviation in excess of 15 millimeters in cross section and 15 millimeters in five (5) meters measured longitudinally shall be corrected by loosening, adding or removing the material, reshaping and recompacting by sprinkling and rolling.

(2) **Gradation Tolerances.** The Engineer may accept the material, providing not more than one (1) out of the most recent five (5) gradation tests performed are outside the specified limit on any individual sieve by more than five (5) percent.

(3) **Density Tolerances.** The Engineer may accept the work providing not more than one (1) out of the most recent five (5) density tests performed is outside the specified density, provided the failing test is no more than 50 kilograms per cubic meter outside the specified density.

(4) **Plasticity Tolerances.** The Engineer may accept the material providing not more than one (1) out of the most recent five (5) plasticity index samples tested are outside the specified limit by no more than two (2) points.

132.5. **Measurement.** This Item will be measured as follows:

(1) **General.**

Retaining-wall-backfill areas which are also in embankment areas will be measured for payment as embankment except as shown on the plans; such material shall meet the requirements for backfill material of the pertinent retaining-wall item(s). Limits of measurement for embankment in retaining-wall areas will be as shown on Standard Detail Sheet "Earthwork Measurement at Retaining Walls" (EMRW) in the plans.

Shrinkage or swellage factors will not be considered in determining the calculated quantities.

(2) **Class 1.** Embankment will be measured in its original, natural position, and the volume computed in cubic meters by the method of average end area.

(3) **Class 2.** Embankment will be measured by the cubic meter in vehicles as delivered on the road.

(4) **Class 3.** Embankment will be measured by the cubic meter in its final position as the volume of embankment computed in place between (1) the original ground surfaces or the surface upon which the embankment is to be constructed, and (2) the lines, grades and slopes of the accepted embankment, using the average end area method.

Class 3 is a plans quantity measurement Item and the quantity to be paid for will be that quantity shown in the proposal and on the "Estimate and Quantity" sheet of the contract plans, except as may be modified by Article 9.8. If no adjustment of quantities is required, additional measurements or calculations will not be required.

132.6. **Payment.** The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Embankment", of the compaction method, type and class specified. This price shall be full compensation for furnishing embankment; for hauling; for placing, compacting, finishing and reworking; and for all labor, royalty, tools, equipment and incidentals necessary to complete the work.

When proof rolling is shown on the plans and directed by the Engineer, it will be paid for in accordance with Item 216, "Rolling (Proof)".

When "Ordinary Compaction" is shown on the plans, all sprinkling and rolling, except proof rolling, will not be paid for directly, but will be considered subsidiary to this Item, unless otherwise shown on the plans.

When "Density Control" is shown on the plans, all sprinkling and rolling, except proof rolling, will not be paid for directly, but will be considered subsidiary to this Item.

When subgrade is constructed under this project, correction of soft spots in the subgrade will be at the Contractor's expense. When subgrade is not constructed under this project, correction of soft spots in the subgrade will be in accordance with Article 4.3.

ITEM 134

BACKFILLING PAVEMENT EDGES

134.1. **Description.** This Item shall govern for backfilling pavement edges in conformity with widths and typical sections shown on the plans. This Item also includes the application of an emulsified asphalt and/or fertilizer with the backfill material, when specified on the plans.

134.2. **Material.**

(1) **General.** Unless otherwise indicated on the plans, the top 100 millimeters of the backfill material shall be capable of sustaining vegetation. When less than 100 millimeters of backfill is required, the material supplied shall be capable of sustaining vegetative growth.

(2) **Backfill Material.** Backfill material shall be one of the following types:

Type A. Backfill material shall be provided from a source outside the right of way and be in accordance with the requirements shown on the plans.

Type B. Backfill material shall be secured from within the existing right of way as shown on the plans or as directed by the Engineer.

Type C. Backfill material shall be mulch sodding provided from an approved source in accordance with Subarticle 162.3(8).

(3) **Emulsified Asphalt.** The emulsified asphalt shall be of the type specified on the plans and shall meet the requirements of Item 300, "Asphalts, Oils and Emulsions".

(4) **Fertilizer.** Fertilizer, of the type shown on the plans, shall meet the requirements of Item 166, "Fertilizer".

(5) **Water.** Water required for proper compaction, the promotion of plant growth, and/or emulsion dilution shall conform to Item 204, "Sprinkling".

134.3. **Construction Methods.** Unless otherwise permitted by the Engineer, when backfill material is required to be hauled to or within the project site, the backfill material shall be hauled to the approximate required location prior to placement of the pavement finish surface course. After the pavement finish surface course has been placed, the backfill material shall be spread, compacted, and shaped in accordance with the typical sections.

(1) **Types A and B Backfill.** After the surface course has been placed, the necessary backfill material shall be brought to the approved moisture content, bladed, and compacted as directed by the Engineer. The material shall be shaped to the lines and grades as shown on the plans. After the backfill has been compacted, the roadway sideslopes shall be bladed to a smooth surface conforming to the details indicated on the typical sections or as directed by the Engineer.

(2) **Type C Backfill.** Mulch sodding backfill material shall be placed in a uniform windrow and kept moist as directed by the Engineer.

After the surface course has been placed, the necessary backfill material shall be bladed and compacted in accordance with Subarticle 162.3(8) or as directed by the Engineer. After the backfill has been compacted, the pavement side slopes shall be bladed to a smooth surface conforming to the details indicated on the typical sections or as directed by the Engineer.

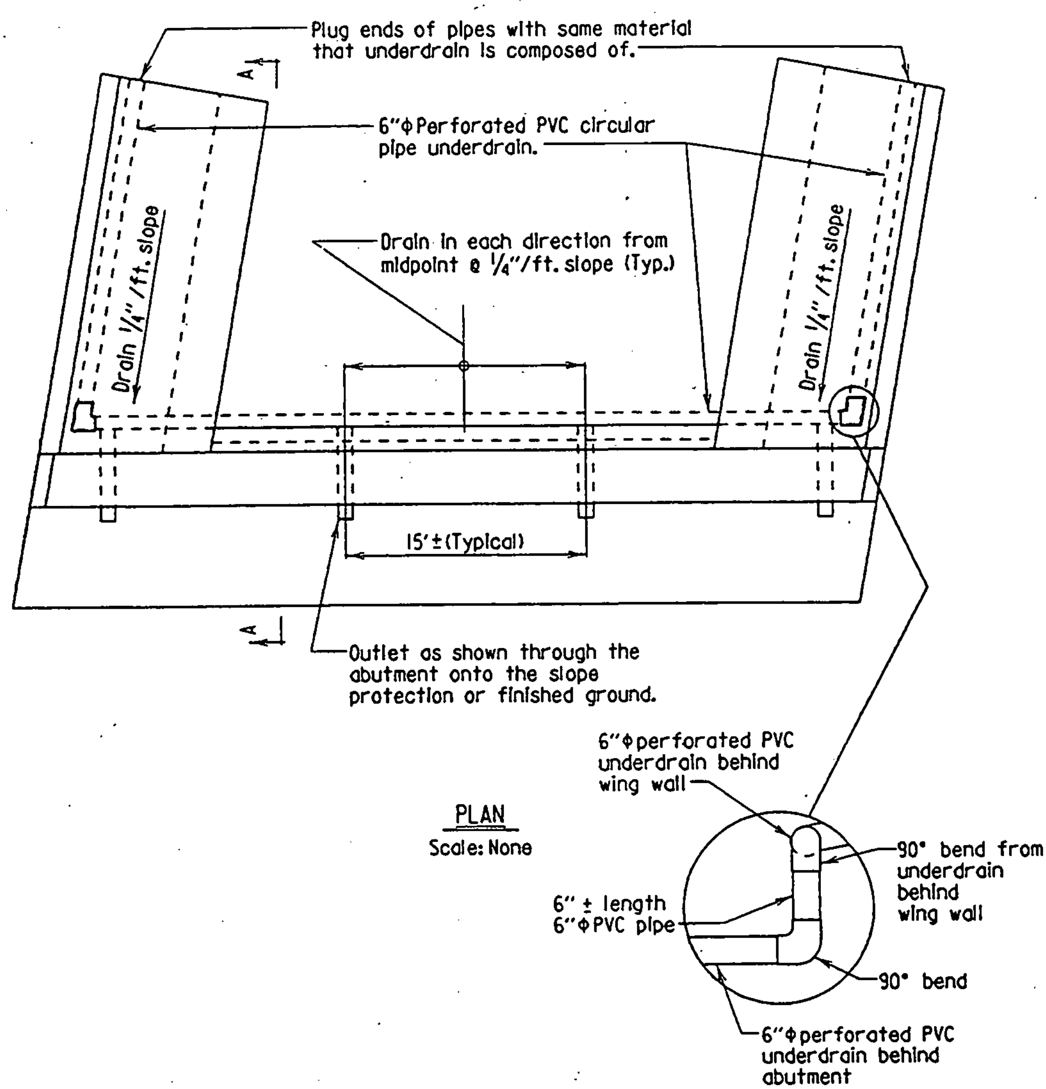
(3) **Emulsified Asphalt.** Emulsified asphalt mixture, when shown on the plans, shall be applied following final finishing of the backfill material until the specified amount of mixture has been applied. The rate of application, after dilution, shall be as specified on the plans.

(4) **Fertilizer.** Fertilizer, when shown on the plans, shall be distributed uniformly at the rate specified over the backfilled area following final finishing. After the application of fertilizer, the backfill areas shall be thoroughly moistened to a depth of 100 millimeters or to the maximum depth of the backfill whichever is less.

APPENDIX E

Example of Bridge Approach Drainage Details

Maryland Department of Transportation, 1995, Attachment to Survey Questionnaire, Charles Byus, Bridge Division, Brooklandville, Maryland



Notes:
1. To be used for all abutments, regardless of the direction of the approach roadway grades.
2. Minimum slope of Pipe Underdrain Outlets is 1/4"/ft.
3. For Section A-A see Sheet No. 2, 3 or 4
4. The drainage system behind each wing wall can be connected to the drainage system behind the abutment using 2 - 90° bends and a short length of pipe. This will necessitate the drainage system behind the wing wall be slightly higher.
5. For wing walls over 25 ft. long, the drainage system behind them may be independent of the drainage system behind the abutment. They can be outletted directly through the wing wall.

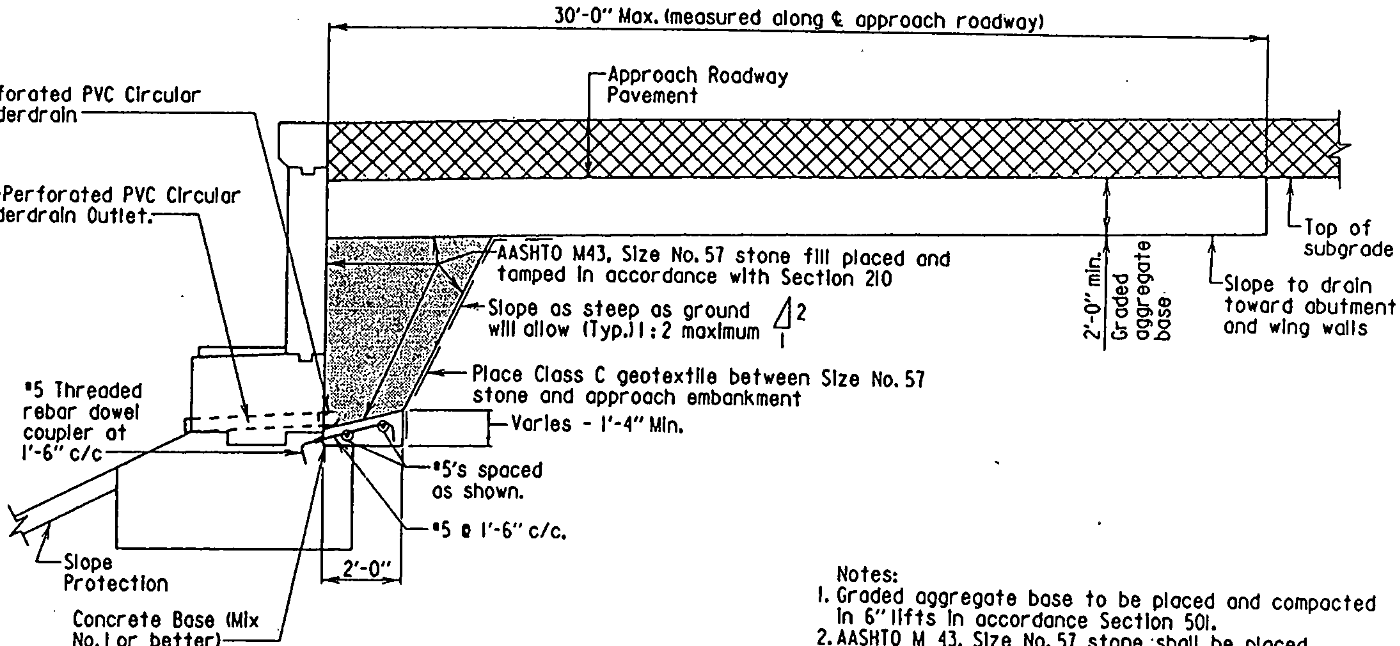
APPROVAL	
DEPUTY CHIEF ENGR. BRIDGE DEVEL.	
DATE: 3/4/80	
REVISIONS	
SHA	FHWA
9-1-82	6-8-90
6-24-87	6-8-90
2-19-92	
2-28-95	

FHWA APPROVAL
DATE: 6-20-80

STATE OF MARYLAND
DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION
OFFICE OF BRIDGE DEVELOPMENT

DRAINAGE SYSTEM AND BACKFILL FOR ABUTMENTS

STANDARD NO. BR-SB(0.01)-80-101 SHEET 1 OF 4



SECTION A-A
Scale: None

Notes:

1. Graded aggregate base to be placed and compacted in 6" lifts in accordance Section 501.
2. AASHTO M 43, Size No. 57 stone shall be placed as shown behind the abutment and to the same geometrics behind the abutment wingwalls when they parallel the highway.
3. The Contractor must provide a well compacted surface to place the geotextile and stone fill against. In fill areas it will be necessary to overfill a sufficient distance so that a well compacted surface will be produced when the overfill is removed. The removed material will be paid for as Class 2 Excavation. The maximum pay limits for the stone will be the 2 ft. base and the slope as steep as ground will allow with the 1:2 maximum slope.
4. The cost of the stone and geotextile will be incidental to the pertinent structure concrete item.

FHWA APPROVAL
DATE:

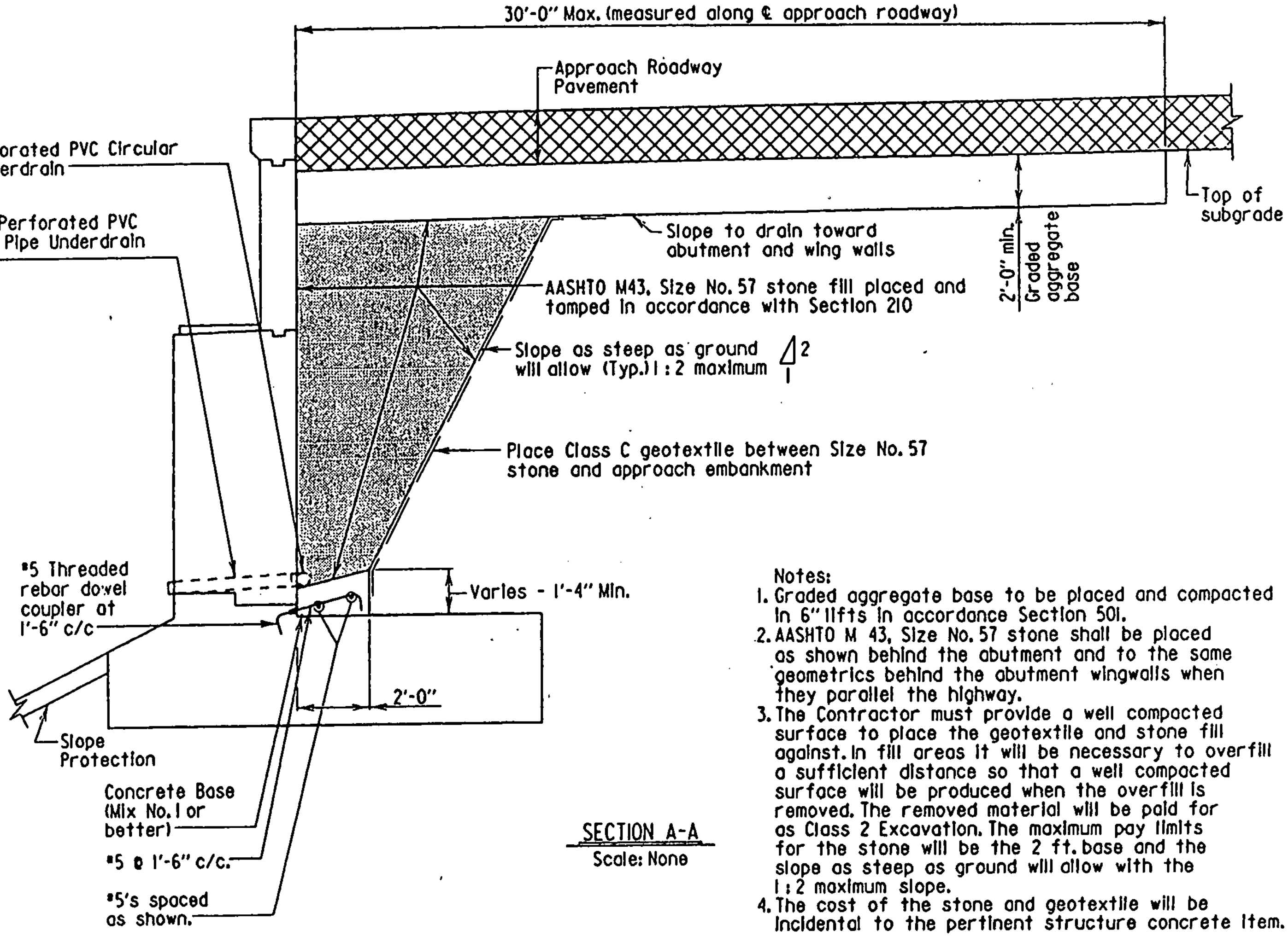
APPROVAL
DEPUTY CHIEF ENGR. BRIDGE DEVEL.
DATE
REVISIONS
SHA FHWA

STATE OF MARYLAND
DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION
OFFICE OF BRIDGE DEVELOPMENT

DRAINAGE SYSTEM AND BACKFILL FOR ABUTMENTS (PEDESTAL)

STANDARD NO. BR-SB(0.01)-80-101 SHEET 2 OF 4

SUBSTRUCTURE ABUT



SECTION A-A
Scale: None

Notes:

1. Graded aggregate base to be placed and compacted in 6" lifts in accordance Section 501.
2. AASHTO M 43, Size No. 57 stone shall be placed as shown behind the abutment and to the same geometrics behind the abutment wingwalls when they parallel the highway.
3. The Contractor must provide a well compacted surface to place the geotextile and stone fill against. In fill areas it will be necessary to overfill a sufficient distance so that a well compacted surface will be produced when the overfill is removed. The removed material will be paid for as Class 2 Excavation. The maximum pay limits for the stone will be the 2 ft. base and the slope as steep as ground will allow with the 1 : 2 maximum slope.
4. The cost of the stone and geotextile will be incidental to the pertinent structure concrete item.

FHWA APPROVAL
DATE:

APPROVAL
DEPUTY
CHIEF ENGR. BRIDGE DEVEL.
DATE:

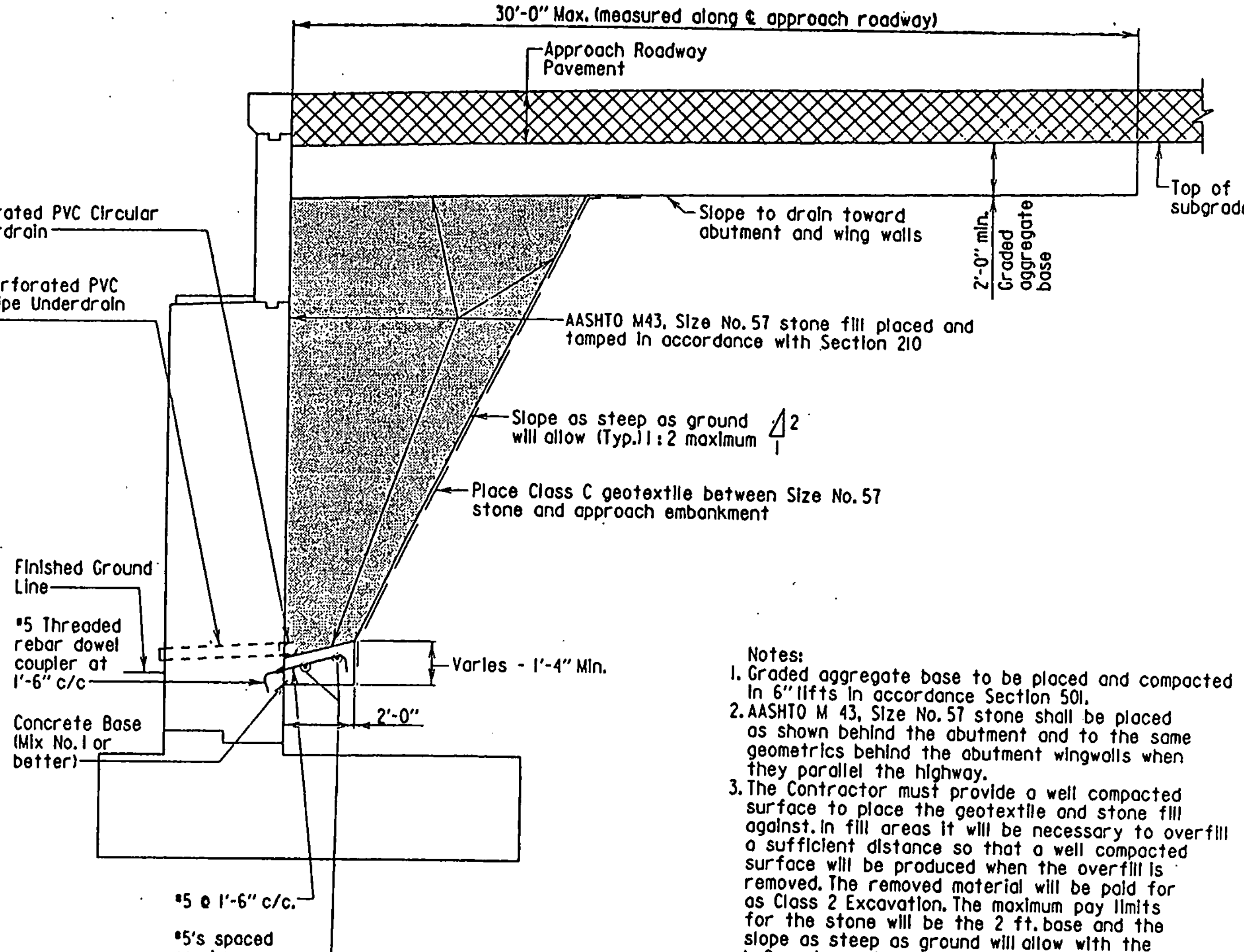
REVISIONS
SHA | FHWA

STATE OF MARYLAND
DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION
OFFICE OF BRIDGE DEVELOPMENT

DRAINAGE SYSTEM AND BACKFILL
FOR ABUTMENTS (SEMI-CANTILEVER)

STANDARD NO. BR-SB(0.01)-80-101
SHEET 3 OF 4

SUBSTRUCTURE ABUT



SECTION A-A

Scale: None

Notes:

1. Graded aggregate base to be placed and compacted in 6" lifts in accordance Section 501.
2. AASHTO M 43, Size No. 57 stone shall be placed as shown behind the abutment and to the same geometrics behind the abutment wingwalls when they parallel the highway.
3. The Contractor must provide a well compacted surface to place the geotextile and stone fill against. In fill areas it will be necessary to overfill a sufficient distance so that a well compacted surface will be produced when the overfill is removed. The removed material will be paid for as Class 2 Excavation. The maximum pay limits for the stone will be the 2 ft. base and the slope as steep as ground will allow with the 1:2 maximum slope.
4. The cost of the stone and geotextile will be incidental to the pertinent structure concrete item.

FHWA APPROVAL

DATE:

APPROVAL

DEPUTY CHIEF ENGR. BRIDGE DEVEL.

DATE:

REVISIONS

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STATE OF MARYLAND
DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION
OFFICE OF BRIDGE DEVELOPMENT

DRAINAGE SYSTEM AND BACKFILL FOR ABUTMENTS (FULL CANTILEVER)

STANDARD NO. BR-SB(0.01)-80-101

SHEET 4 OF 4

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 400 committees, task forces, and panels composed of more than 4,000 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

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The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encouraging education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is interim president of the National Academy of Engineering.

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