NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **2**

BRIDGE APPROACH DESIGN AND CONSTRUCTION PRACTICES

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION
OF STATE HIGHWAY OFFICIALS IN COOPERATION
WITH THE BUREAU OF PUBLIC ROADS

SUBJECT CLASSIFICATION:
- PAVEMENT DESIGN
- BRIDGE DESIGN
- CONSTRUCTION
- MAINTENANCE, GENERAL
- FOUNDATIONS (SOILS)

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1969

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

NCHRP Project 20-5 FY '68

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway Officials has, through the mechanism of the National Cooperative Highway Research Program authorized the Highway Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices without in fact making specific recommendations as would be found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available concerning those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

Included with this document is a return card by which reader reaction is invited. The knowledge gained therefrom will be directed toward improvement of future issues in light of the express needs of the potential users. Further follow-up will be made to determine the usefulness of the syntheses in highway practice and to effect updating as appropriate.

FOREWORD

By Staff

Highway Research Board

Administrators, engineers and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information is often fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem is frequently not brought to bear on its solution, costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to resolve this situation, a continuing NCHRP project, carried out by the Highway Research Board as the research agency, has the objective of synthesizing and reporting on highway practices—a synthesis being defined as a composition or combination of separate parts or elements so as to form a whole. Reports from this endeavor constitute a new NCHRP series that collects and assembles the various forms of information into single, concise documents pertaining to specific highway problems or sets of closely related problems. This second report of this series, an impartial documentation of the leading practices currently in use across the nation for bridge approaches, will be of special interest to bridge design, soils, construction and maintenance engineers.

Pavement irregularities immediately adjacent to bridges have long plagued highway engineers, as well as the motorists. The "bump at the end of the bridge" is unpleasant for the traveling public, can be unsafe, can have detrimental effects on the vehicle, and has undesirable effects on the bridge and roadway. Because highway personnel responsible for the design, construction and maintenance of bridge approaches have a perpetual need for the best "how-to-do-it" information, the Highway Research Board has attempted in this project to set down those measures which have been found most successful in minimizing the "bump at the end of the bridge."

To develop this synthesis in a comprehensive manner and to insure inclusion of most significant knowledge, the Board analyzed all information—for example, current practices, plans, specifications, manuals, and research recommendations assembled from the knowledge of highway departments, toll road agencies, and other agencies responsible for highway and street design construction and maintenance. Furthermore, a thorough literature search of all pertinent publications was made, interviews were held with knowledgeable highway personnel, and a correspondence survey for pertinent information was conducted. A topic advisory panel of persons knowledgeable in the subject area was established to guide the researchers in organizing and evaluating the collected data, and for reviewing the final synthesis report.

As a follow-up, the Board will evaluate carefully the effectiveness of the synthesis after it has been in the hands of its users for a period of time. Meanwhile, the search for better methods is a continuing activity and should not be diminished. Hopefully, an early updating of this document will be made to reflect improvements that may be discovered through research or practice.

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ACKNOWLEDGMENTS

This synthesis was completed by the Highway Research Board under the supervision of Paul E. Irick, Assistant Director for Special Projects. The Principal Investigator responsible for the conduct of the synthesis was Thomas L. Copas, Special Projects Engineer.

Special appreciation is expressed to Henry E. Diers, Maintenance Engineer (retired), Illinois Department of Highways, who as special consultant to the Advisory Panel performed much of the field investigation and assisted in the preparation of the report.

Instrumental in the preparation of this synthesis were the members of the Advisory Panel, consisting of John E. Burke, Engineer of Research and Development, Illinois Division of Highways; J. N. Clary, Bridge Engineer, Virginia Department of Highways; and Clyde N. Laughter, Soils Engineer, Wisconsin Department of Transportation. The Advisory Panel was augmented by liaison representatives David S. Gedney, Soils Engineer, Office of Engineering and Operations; Vladimir F. Obrcian, Specialty Group Leader, Office of Research and Development; and John R. Sallberg, Highway Research Engineer, Office of Research and Development; all of the Bureau of Public Roads. J. W. Guinnee, Engineer of Soils, Geology and Foundations, and L. F. Spaine, Engineer of Design, both of the Highway Research Board, assisted the Special Projects staff and the Advisory Panel.

This synthesis could not have been completed without the assistance of the many state highway agencies and toll road authorities that provided information on the procedures they follow for designing, constructing and maintaining bridge approaches.

BRIDGE APPROACH DESIGN AND CONSTRUCTION PRACTICES

SUMMARY

Bridge Approach Problems

Most bridge approaches are reasonably smooth and require a minimum of maintenance. Nevertheless, the number of rough-riding approaches with heavy maintenance requirements is sufficient to convince highway agencies that a serious problem exists.

The importance of the problem of poor-riding bridge approaches is directly related to the type of system and the level of service that is demanded from a facility. The cost of additional site investigation, improved design, and more careful construction can be readily justified for the high-speed, high-volume type of system because of the hazards and costs involved in disrupting traffic by closures for maintenance, even for brief periods.

Problem Causes

There is general agreement that the rough-riding approach is the result of some movement or failure in another part of the roadway section. The embankment foundation is most often suspected to be the cause of settlement at bridge abutments. Most agencies are confident that their specified embankment construction methods are satisfactory. Yet, there are considerable differences among specifications as to what is adequate or satisfactory construction.

Several engineers, writing on the subject, have expressed strong views about the effect of abutment type on the total settlement of the approach. Most agencies agree that abutment backfill material, drainage, and construction methods are critical items in building and maintaining good bridge approaches. Subgrade treatment and special backfill construction have been helpful in areas that have expansive soils or freezing conditions.

Specifications

Most highway agencies are concerned with the enforcement of their current specifications. While this is essential to good approach construction, periodic reviews of existing specifications and appropriate revisions where necessary can be helpful in increasing the number of satisfactory approaches that are constructed. One agency's special provision for bridge end backfill appears in Appendix B. It is not suggested that this provision might be universal in application. Each agency should determine the best materials and methods, based on its own conditions.

Foundation Investigation

All agencies recognize the importance of an adequate investigation of the foundation site for bridge design and construction; however, there is reason to suspect that the investigations that are actually made are frequently less than adequate. It is

essential to investigate not only the embankment foundation material, but also the slope of the natural ground, the need for special drainage, and the material that is to be placed in the embankment.

Design Information

The soils engineer, using tentative grades, and the information obtained from the foundation site investigation, can provide advice on the depth of material that should be removed, special embankment foundation drainage, surcharge heights, waiting periods, construction rates, and the amount of post-construction settlement that can be anticipated.

Materials

Approach embankments are built of roadway excavation, select borrow, or special materials such as granular or lightweight aggregates. The need for special care in constructing the bridge approach embankment is widely recognized; many agencies have special requirements for both materials and construction in this area. Many agencies are taking additional precautions with rock fill embankments, requiring thin lifts of smaller stone size and the filling of voids near structures.

Construction

It appears that sufficient attention has not always been given to benching the natural ground to support the approach embankment. Benching of even slight slopes is desirable.

Other good practices that have been identified in approach embankment construction include: removal of unsuitable material and starting the embankment on solid material whenever possible; providing drainage for natural seepages; careful control of lift thickness, moisture, and compaction; prohibiting the use of frozen materials; directing surface water away from the abutment during construction; construction of extra-width embankments to permit dressing back to firm material; and reworking the top embankment layers after periods of rain or freezing temperatures.

Influence of Abutment Types

The type of abutment selected may have an effect on later settlement of approach pavements. Abutments with spread footings have been used successfully on compacted embankments, experiencing very little settlement. There is wide acceptance of the stub or shelf abutment that is supported on piles or drilled shaft supports. The problems associated with backfilling the closed or retaining wall abutment can be overcome with good construction using suitable backfill materials. The spill-through type of abutment is not desirable because of the difficulty of properly placing and compacting the embankment material. Special lightweight and bin-type abutments usually are designed for an unusual condition at a given location. It is important that adequate drainage be provided for all types of abutments.

Backfill

Settlement problems at bridge approaches often may be traced directly to the abutment backfill. Either the construction methods or the materials, or both, may be responsible. Other reasons offered to explain this weak zone in a vital area are the restricted work space and a fear of displacing the abutment alignment with the compaction effort. It is good practice to require that the completed superstructure be in place, or that satisfactory bracing be installed before compacting backfill behind wall- or column-supported abutments. Blocking behind girder beams to prevent closing of expansion devices may be desirable. The use of special backfill methods and materials may be necessary in dealing with expansive soils to provide a buffer between the swelling material and the abutment or approach slab, and to restrict the passage of moisture into or out of the embankment.

Abutment backfill practices that help to minimize either settlement or swell include the use of select materials; placement of relatively thin (4- to 6-in.) layers; strict control of moisture and density; installation of moisture barriers; and provisions for positive drainage.

Subgrade and Base

Failures that develop in any part of the pavement structure or the supporting materials present much greater problems when they occur at the bridge approach, because shoulder widths are not always adequate for either traffic or maintenance forces, making repair work difficult. A special effort to insure stability in the upper embankment and subgrade layers adjacent to the abutment is considered desirable. Treatment of the subgrade material to minimize the possibility of volume changes is essential when marginal or poor materials are used. The desirability of not using such materials in bridge approach construction has been pointed out by several agencies.

In areas where the base and subgrade may be subjected to extended freezing, materials should be specified that will lessen the possibility of frost heave. Because the elevation of the bridge abutment does not normally change with temperature, it is important that frost-susceptible base, subbase, and embankment materials be eliminated from use in the frost-penetration zone in approach construction.

Special Approach Slabs

The decision to use specially designed approach pavement is based on traffic volumes, construction costs, and an estimate of the problems that might occur if approach slabs are not used. Although stage construction may be used for adjusting approach pavement grades on low- to medium-volume facilities, most agencies now find stage construction is impracticable for key segments of high-volume systems.

Specially designed reinforced approach slabs are widely used for transition between the bridge and portland cement concrete pavement. Although several agencies specify the same transition slabs for bituminous concrete pavement, others do not follow this practice (apparently because they feel that the maintenance requirement may not substantially change with the use of a special approach slab).

Wide differences in length, thickness, reinforcement, transition, and support at the pavement end make it impractical to attempt to identify any particular design of approach slab as being more desirable than others. Pile bents, bolster beams, and aggregate sills have been used to support the pavement end of the approach slab. Some engineers question the need for this support, but others feel that it is desirable, especially when the approach slab is capable of carrying traffic without intermediate support. Ideally, the length of the span or spans should extend over the problem area. When this is not feasible it should at least provide a gradual ramp to the structure from a settling embankment.

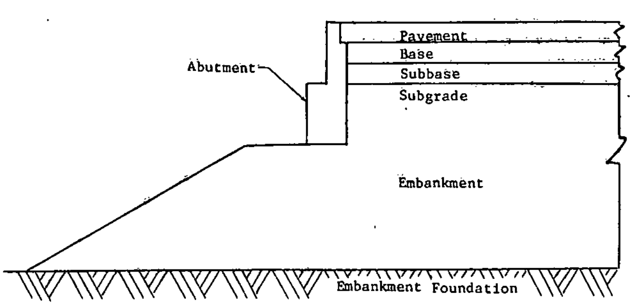
A limited amount of vertical movement of the roadway pavement is normal, and *is acceptable where structure approaches are not affected. Even small movement of the pavement caused by settlement, expansion, or abutment shifting can create bridge approach problems that defy solution. The threat of these problems is considered sufficient justification by most highway agencies for requiring a special effort at the bridge approach.*

CHAPTER ONE

INTRODUCTION

Surface irregularities in pavements immediately adjacent to bridges have long plagued both the traveling public and the highway maintenance organization. These bumps, dips, and rolls are unpleasant, unsafe, and sometimes destructive to vehicles and the bridge structure. One highway research engineer has put it this way:

> Differential settlement between an approaching highway pavement and the bridge deck not only presents a hazardous condition to rapidly flowing traffic, but creates a rough and uncomfortable ride as a vehicle passes onto and off a bridge. In addition these surface faults require costly maintenance which usually involves either mud-jacking (concrete approaches) or patching (concrete or bituminous concrete approaches) the approach pavement; where a heavy traffic flow exists, this maintenance operation may tend to impede the normal flow of traffic. Moreover, the settlement of bridge approaches adversely affects the durability of road and structure. With the increasing construction of modern, high-speed highways, the problem has become more evident—at least to an extent that highway engineers are looking for ways and means of eliminating or minimizing the effects of these undesirable surface faults at the ends of bridges.



Pavement Structure -- "The combination of subbase, base course, and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed." (AASHO)
Subgrade -- "The top surface of a roadbed upon which the pavement structure and shoulders are constructed." (AASHO)
-- "The prepared and compacted soil immediately below the pavement system and extending to such depth as will affect the structural design." (AASHO M-146)
Embankment -- "A structure of soil, soil-aggregate or broken rock between the embankment foundation and the subgrade." (AASHO)
Embankment Foundation -- "The material below the original ground surface whose physical characteristics affect the support of the embankment." (AASHO)

Figure 1. Typical section at abutment, and descriptive terms.

PROBLEM INDICATORS

No general agreement exists on the specific physical boundaries of bridge approaches along the roadway. The effort to improve the bridge approach begins at the abutment and may extend to as much as 200 ft from the structure. The physical condition of the bridge approach pavement most often provides the only readily seen evidence of the approach condition, but the basic source of the problem usually lies elsewhere.

Parts of the roadway that may contribute to a poor-riding bridge approach include the bridge deck and abutment, roadway pavement, base, subbase, subgrade, embankment, and embankment foundation (Fig. 1). Other factors that may play an indirect role are the choice of materials, construction methods, and local climate.

The most prevalent indicator of an unsatisfactory bridge approach is the initial displacement of the pavement. It may move either up or down at the abutment or at the end of the approach slab. Although the problem appears to be characterized by settlement, upward movement is common in some areas and represents a very serious problem (Fig. 2).

Other common faults are dips or bumps near the abutment or approach slabs with flexible pavement. The dips may be leveled relatively easily, but bumps caused by swelling soils within the embankment or subgrade are not as easily corrected. Volume changes in the pavement material generally are minor, and the major roughness is usually created by movement of other parts of the abutment or embankment structure (Fig. 3).

Although not as prevalent as the other bumps, excessive camber or sag in the first span of the bridge must be considered as one of the causes of poor transitions from pavement to bridge structure. Another problem may be the increased impact on the structure caused by bumps at the end of the bridge. These problems, however, are considered to be structural and not within the scope of this project.

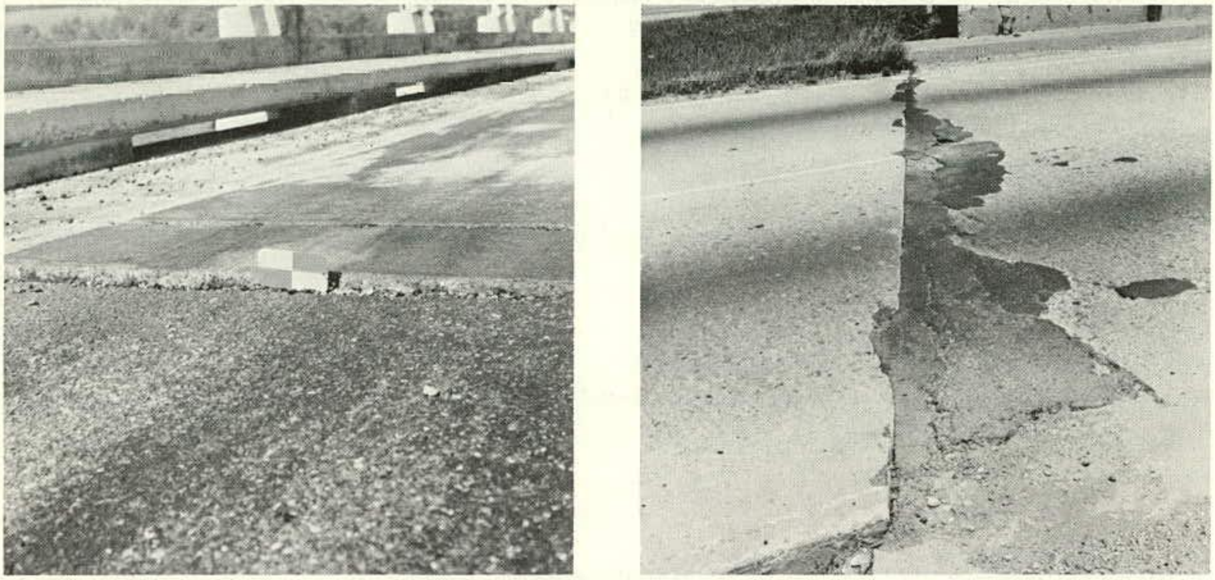


Figure 2. Examples of embankment settlement and swell at bridge approaches.

ENGINEERING RESPONSIBILITIES

Soils, design, construction, and maintenance engineers should consider themselves jointly responsible for efforts to eliminate rough bridge approaches. The designer, working with the information provided by the soils engineer, should consider each factor that might contribute toward rough approach pavement and should include preventive measures in the roadway plans. It is the construction engineer's responsibility to implement the designer's plans and carry out good construction procedure. When the design or construction effort fails to identify and to eliminate the causes contributing to poor bridge approaches, it is the maintenance organization which has the responsibility for making corrections or removing and replacing approach construction.

It is the maintenance engineer who eventually measures the adequacy of bridge approach design and construction. His efforts must include communication with design and construction engineers, as well as the physical repair of the bridge approach, if his problems are to be lessened. The importance of the communication effort should not be underestimated. For example, in one of the several agencies contacted during this project, the designer apparently was pleased with current design standards and specifications. The construction engineer believed the construction effort to be satisfactory. The maintenance engineer, on the other hand, reported that he was currently mudjacking approximately 60 percent of all concrete approach slabs.

Most agencies recognize the role of the soils engineer in helping to prevent unsatisfactory bridge approaches. Although the factors within his scope of interest that help cause poor-riding approaches have been identified for some time, they apparently are not always properly quantified and appear sometimes to be not adequately considered in plans, specifications, construction, and maintenance.

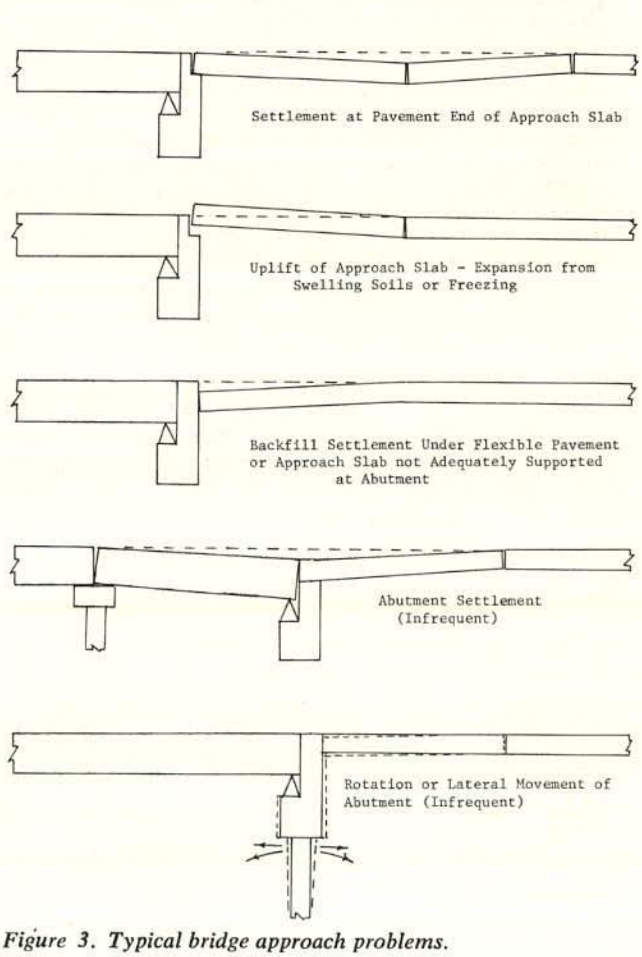


Figure 3. Typical bridge approach problems.

Carefully conducted site investigations, adequate soil testing, and properly prepared soil profiles and settlement estimates lead to recommendations for the control of abutment embankment heights, construction rates, surcharges, waiting periods, bridge lengths, and other useful information the soils engineer can provide to the roadway designer.

Most bridge approach problems can be minimized during the design and construction by adequate consideration of:

1. Foundation conditions.
2. The removal of unsuitable material.
3. The installation of special drains.
4. Embankment height, material, and construction methods.
5. Surcharges and/or waiting periods.
6. Subgrade, subbase, and base material.
7. Abutment type, support, drainage, and backfill.
8. Special approach slabs.

Although consideration of each of these points may produce an acceptable bridge approach, construction and maintenance costs should also affect the final design. A systems study that weighs preventive costs, driver benefits, and projected maintenance expenditures may enable the engineer to select the most feasible design.

Of the several components of the bridge approach structure, experience indicated that the one most likely to receive insufficient attention is the natural foundation soil. This material must support the embankment and the structure without appreciable movement if a satisfactory approach is to be obtained.

CHAPTER TWO

EMBANKMENT FOUNDATION

Post-construction consolidation of material within the embankment foundation is the main contributor to rough-riding bridge approaches. This fact has not been generally recognized. The increase in knowledge of soil behavior that has taken place in recent years offers opportunity for improved design that will keep this movement within reasonable limits. Maximum application should be made of this knowledge, consistent with economic considerations.

Foundation soil conditions that affect the rate of consolidation are the soil's structure, degree of preconsolidation, permeability, layer thickness, boundary conditions, and length of drainage paths. Loading conditions affecting rate of consolidation of the foundation soil include embankment height and width and the rate of embankment construction. The following construction measures have been used successfully to stabilize foundation materials:

1. Consolidation of natural material: (1) use of drains; (2) use of surcharge; (3) waiting periods.
2. Removal of unsatisfactory material.
3. Lightweight embankment materials.

All highway agencies require some type of site investigation at the abutment site prior to design of the structure. These investigations may be limited to rod soundings for rock, or may consist of more complete explorations that might include borings, standard penetration tests, cone penetration tests, flush-coupled penetrometer tests, and thin-walled "undisturbed" sampling along with laboratory testing of samples from the foundation material. The AASHO "Manual on Foundation Investigations" (1967) provides information about field and laboratory tests that may be performed when undertaking a foundation study. The objectives of the foundation site investigation are to determine the total amount of consolidation that can be anticipated in the embankment foundation and the time required for it to take place when subjected to loads imposed by embankment, surcharge, and abutment. The estimates of consolidation for a given time are used in selecting foundation and embankment design and construction methods that are to be employed.

When unsatisfactory material is encountered at or near the surface, common practice is to remove part or all of it and replace it with acceptable material. Most agencies contacted during the preparation of this report indicated that they consider the removal of from 5 to 10 ft of material to be feasible. A few indicated that they would remove up to 30 ft in the abutment area for major structures. Figure 4 shows the abutment portion of a foundation report that was prepared for a highway agency to describe the existing conditions at a bridge site. The recommendation for approach embankment construction at this site was as follows:

> The upper four to six feet of very soft compressible clayey soil should be stripped prior to fill construction at the approaches to the east bridge ends. Stripping should be carried out to full fill widths and to toes of front fill slopes at abutments. The stripping should extend from the front toe at the abutment fills to Stations "E" 1864+00

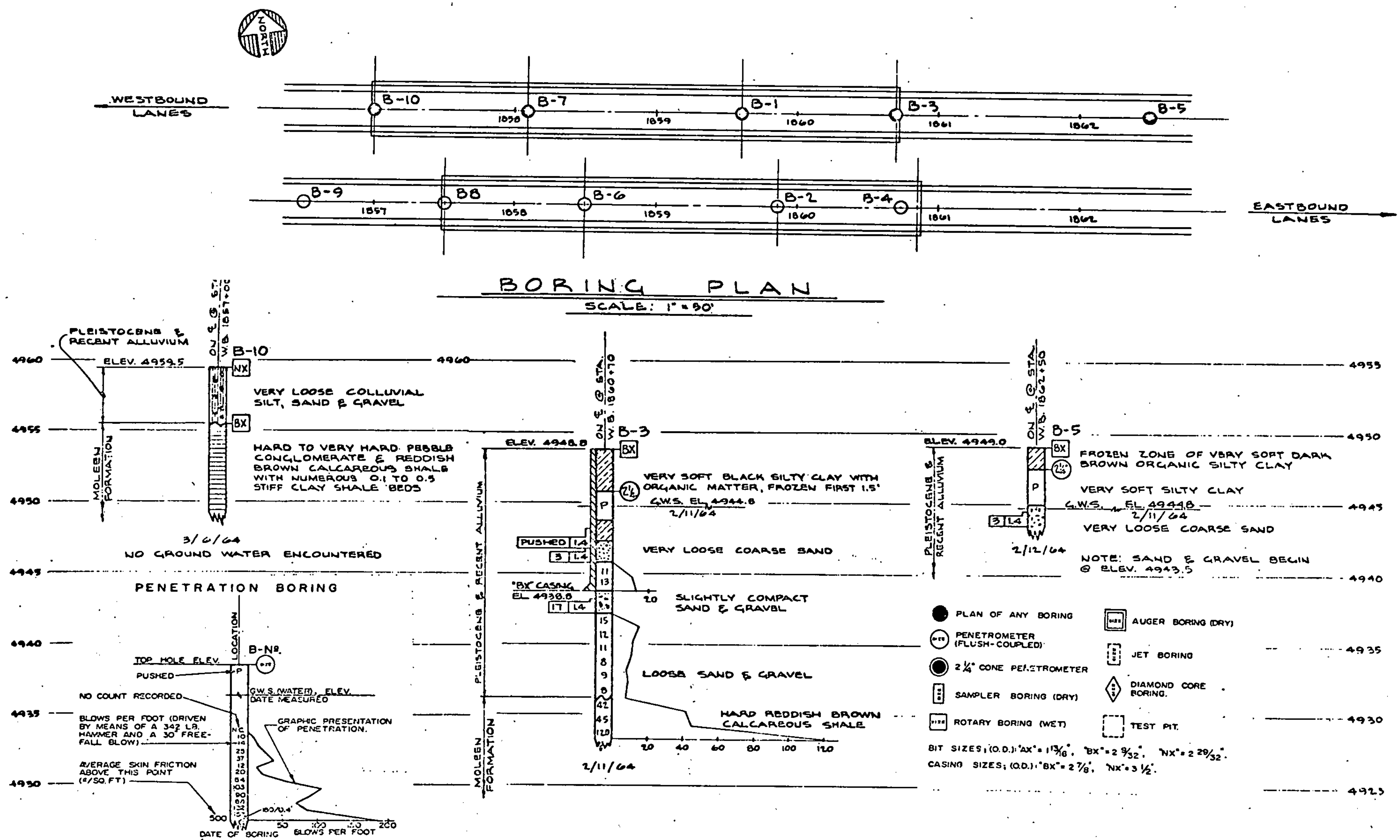


Figure 4. Bridge site boring plan and westbound soil profile (Nevada).

and "W" 1864+00 in order to prevent undesirable fill settlement and/or the possibility of actual embankment failure.

Consideration should be given to stripping and recompacting the very loose to loose end-dumped rock fill that exists at the westerly abutment areas. Rocky fill, end-dumped at the time of Southern Pacific Railroad construction, occupies the area where approach fills to the west abutments will be constructed. This end-dumped fill extends from Station 1855+25 to ± 1857+00, and has a thickness which varies between fifteen and twenty feet.

When site investigations and laboratory tests indicate that an excessive length of time will be necessary to obtain an acceptable percentage of the anticipated consolidation of the embankment foundation, several courses of corrective action are available. In some instances the construction schedule can be adjusted to provide additional time for consolidation of foundation soils. Vertical sand drains or layers of free-draining material sometimes can be used to accelerate the removal of water from the foundation material, thus decreasing the time required for consolidation. Surcharges have been used successfully by several agencies to decrease the waiting period. Chemical or mechanical stabilization of the upper portion of the foundation material has been used for special conditions; however, most agencies indicated that removal of unsuitable material may be more effective. Chemical stabilization at considerable depths has been attempted, with questionable results. Mechanical stabilization may be accomplished by aeration and recompaction or by vibrating loosely packed granular material.

Surcharges have been used by both airport and highway agencies to accelerate foundation consolidation. The height and shape of the surcharge is usually based on information obtained from site investigation, laboratory tests, and the time available before pavement construction.

It is most important that the site investigation include recommendations for embankment heights and rate of placement to avoid the possibility of shear failure within the foundation material. Embankments may need to be placed by stages, enabling poor foundation soils to consolidate and increase in shear strength. The surcharges for abutment embankments should be specially designed for each case.

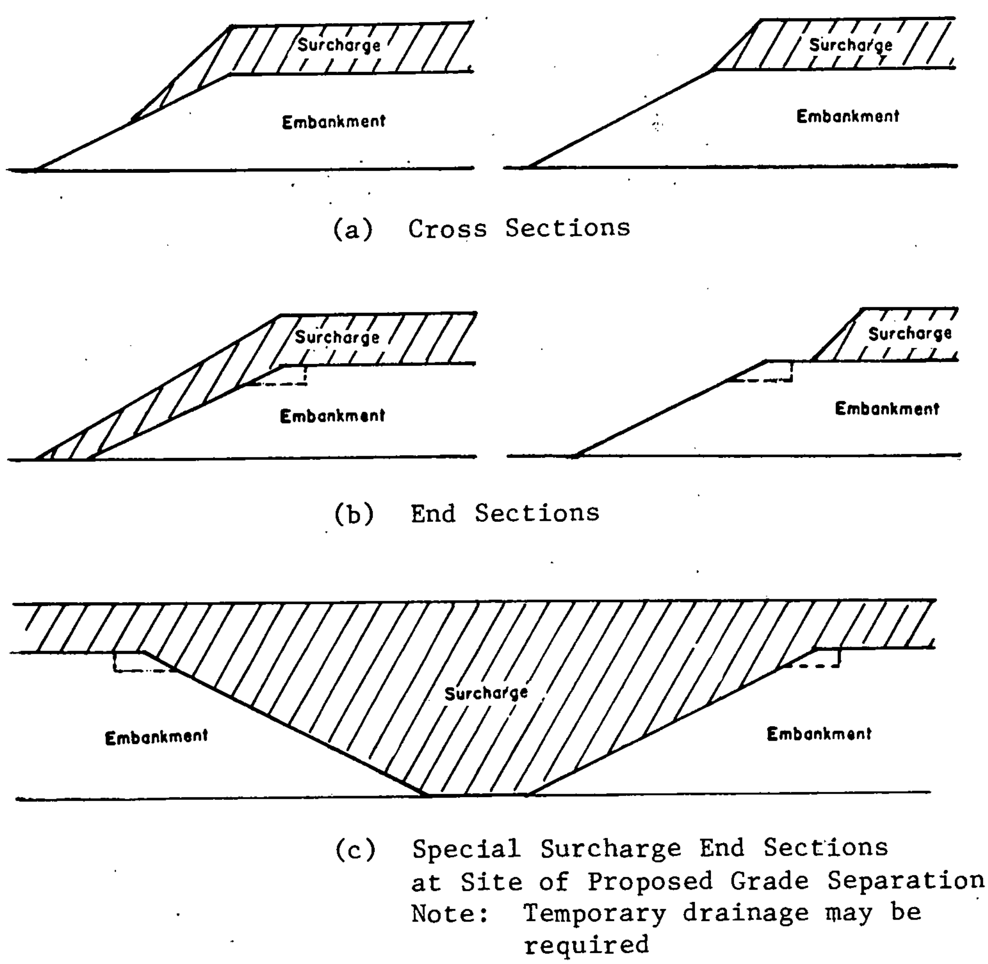


Figure 5. Typical surcharge sections.

Typical surcharge configurations are shown in Figure 5. At least one agency has commented on the advantages of continuing the embankment through a grade separation between abutments to preload the structure site (Fig. 5c). Wherever drainage conditions permit, this method provides increased foundation consolidation under both piers and abutments. An added bonus is the construction of excellent abutment embankments.

Some engineers make the mistake of not requiring that the surcharge be compacted, forgetting that as settlement occurs the lower part becomes the subgrade. In all cases, the surcharge should be compacted to embankment standards for a depth well in excess of the estimated settlement.

The removal of unsatisfactory material by both excavation and displacement is shown in Figure 6. The surcharge is moved forward as construction progresses.

Some agencies remove unsuitable foundation material up to 100 ft in back of the abutment. Others excavate only in the immediate vicinity of the abutment in an effort

Figure 6(a). Marsh displacement (45 ft deep) and embankment construction to surcharge grade (Michigan).

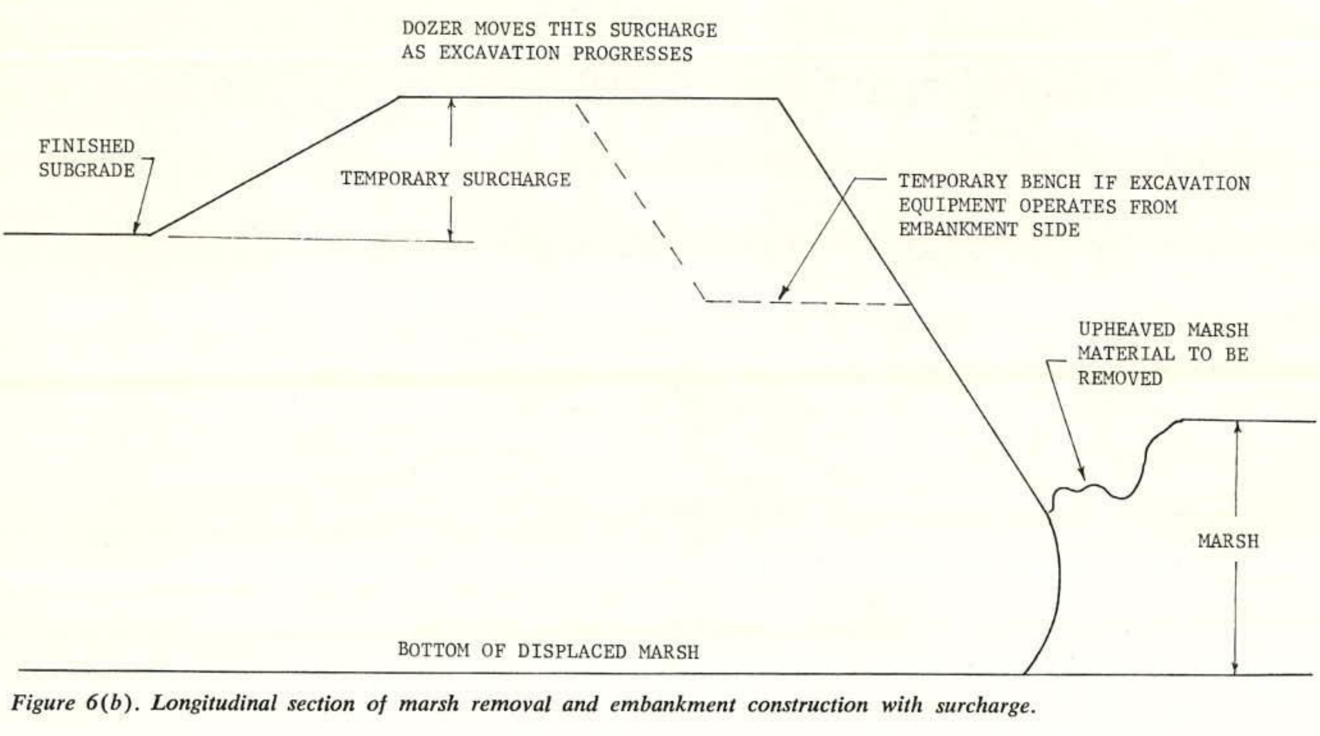


Figure 6(b). Longitudinal section of marsh removal and embankment construction with surcharge.

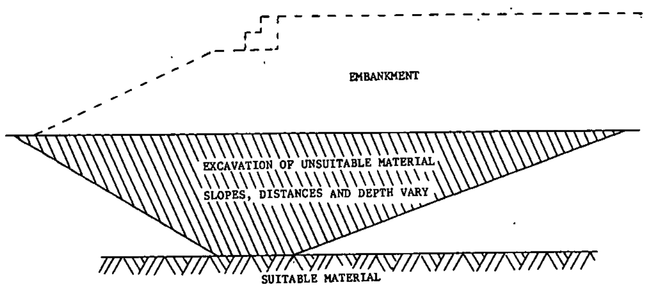


Figure 7. Typical section, excavation of unsuitable material at abutment.

to provide a smooth transition from pavement to the bridge. A typical section is shown in Figure 7.

An elapse of time between embankment construction and paving operations has been found helpful by several agencies. Three to six months are normal for some construction; longer waiting periods are necessary for other conditions. Long waiting periods extending into the next construction season are normal for major structures.

Sand drains have been used successfully by some agencies to accelerate the removal of water from the foundation soil. The size and spacing of individual drains are designed for specific cases. Figure 8 shows a typical sand drain installation.

Accurate predictions of total settlement within foundation material, with or without correctional treatments, are difficult because of variations in both material and construction methods. It is the joint responsibility of soils, design, and construction engineers to review the problem and to arrive at workable solutions for each situation. One agency's views of settlement problems at bridge abutments are given in Appendix C.

Inasmuch as post-construction settlement produces most of the roughness at bridge approaches, several agencies have found it advantageous to measure foundation settlement throughout the construction period. Although it is not always possible to accurately predict the time required for total settlement to take place, measured settlement and knowledge of the shape of the theoretical settlement curve can be helpful during construction. This is indicated in the relation between theoretical and measured settlements shown in Figure 9. The installation of embankment and foundation movement indicators is shown in Figure 10. Unless actual settlement is measured during construction, it is most difficult to determine when total settlement has been obtained.

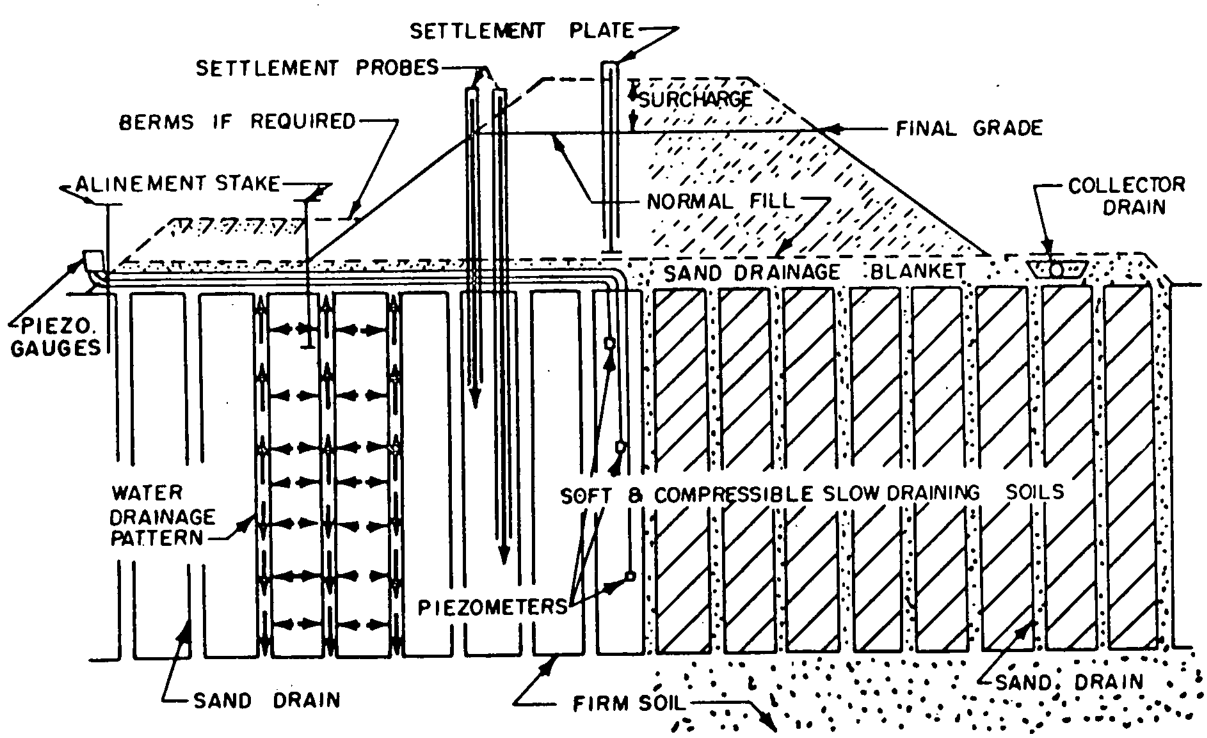


Figure 8. Design information for sand drain installation.

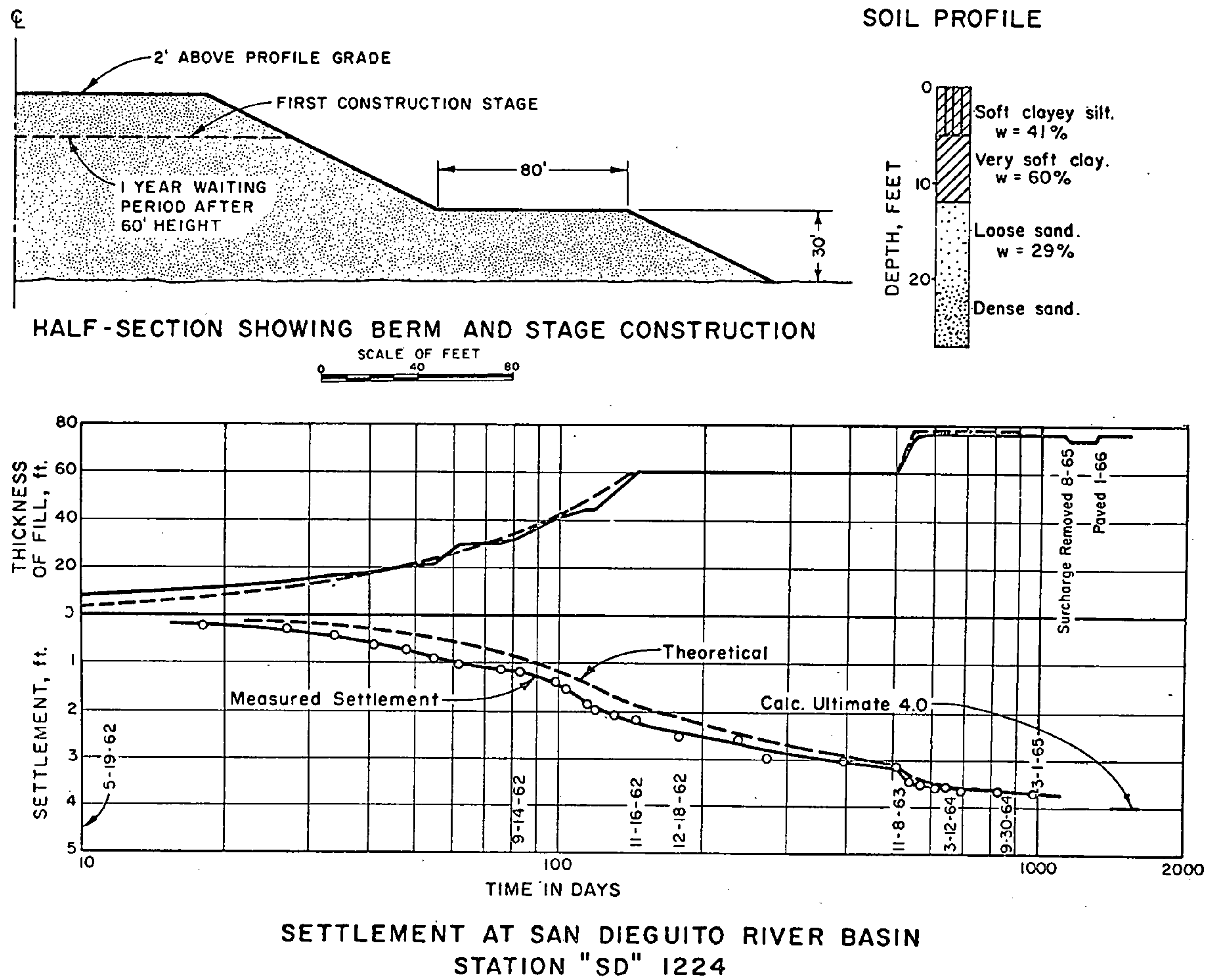


Figure 9. Theoretical and measured settlement at a California embankment using stage construction with berm and surcharge.

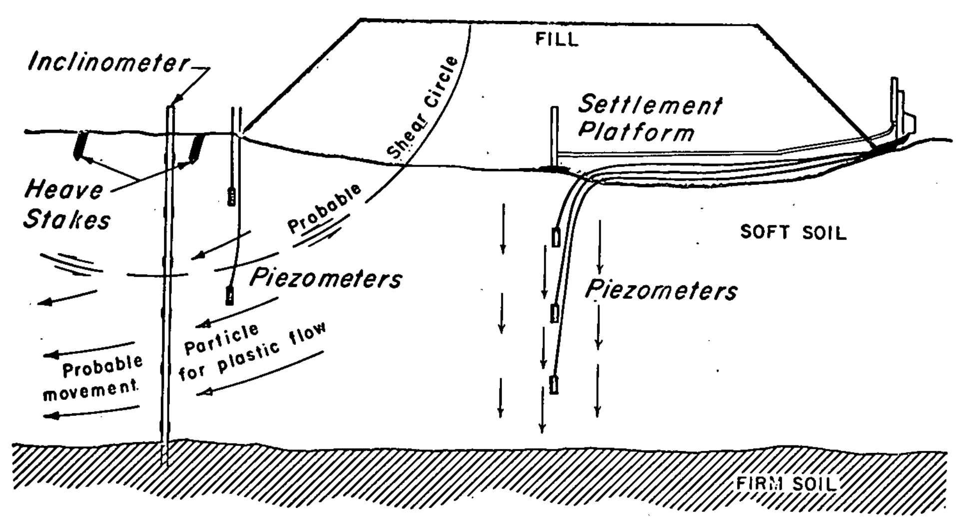


Figure 10. Installation of devices used to measure embankment and foundation soil movement.

CHAPTER THREE

EMBANKMENT, SUBBASE AND BASE

The settlement occurring within the roadway embankment is generally assumed to be relatively small in comparison with the settlement that takes place in the foundation material. This assumption is probably valid when good materials and good construction methods are employed; however, these conditions do not always exist.

Problems with subbase and base at bridge approaches are not widespread and are generally attributed to local conditions such as frost action, high moisture content, excessive volume change, and inadequate construction specifications.

The AASHO definitions are used herein to identify the base, subbase, subgrade, and embankment. Figure 11 shows these construction layers.

The importance of maintaining a satisfactory moisture content and obtaining the specified density in embankment construction at bridge approaches is clearly recognized by both design and construction engineers. Inspectors assigned to embankment construction at bridge approaches should be carefully trained and made to realize that specification enforcement here is at least as important as, and perhaps more important than for normal roadway embankments. The amount of earthwork involved in the construction of bridge approaches, though small, is critical and should never be considered incidental to other features of construction.

EMBANKMENT

Volume changes within the approach embankment may result from rearrangement of soil particles, loss of moisture (shrinkage), or increase in moisture (swelling). Settlement occurs when the embankment voids are reduced, moisture is forced out by increased loading, or the embankment shrinks upon drying. Although most roughness at bridge approaches is traceable to settlement, roughness caused by upward movement is also encountered in practice. Swelling within the embankment may be caused by the wetting of overcompacted soil or the wetting of naturally expansive materials that were compacted at too low a moisture content.

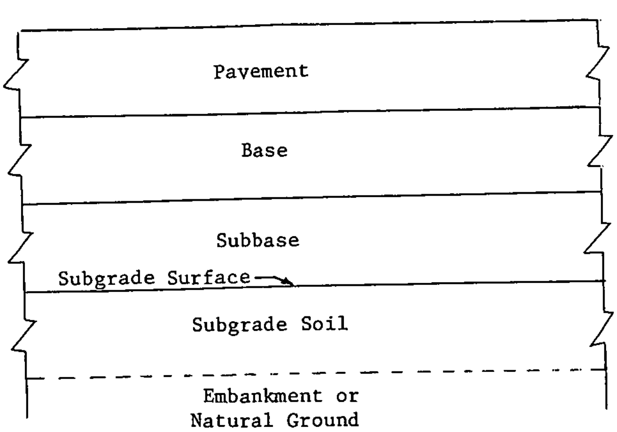


Figure 11. Typical pavement structure, subgrade, and embankment.

Although soil engineers can determine whether a material can be expected to shrink or swell under specific conditions and can estimate reactions within the embankment for a range of field conditions that might be encountered, it is not always practical to accommodate all of the possible conditions in the design. Variations in the soil moisture content or the extent of the compactive effort can affect the final behavior of the embankment material, but with competent inspection and adequate control measures these volume changes can be minimized so that they will contribute very little to the bridge approach problem.

Several highway agencies report difficulty both during and after construction in maintaining constant moisture content in the upper layers of expansive soil embankments. Long periods of low rainfall followed by seasons of heavy rainfall complicate this problem on roadways built on expansive embankments and subgrades. Efforts to obtain the optimum embankment moisture conditions during construction include flooding of the top layers, or construction at relatively high moisture content with low compaction effort. Membranes or other moisture barriers have been used to maintain constant moisture conditions. Even though the methods used to lessen this swelling may not be economically practical for the entire roadway, they are frequently justified in maintaining uniform moisture in the subgrade and upper embankment layers at structure approaches.

Problems also have been encountered with bridge approach embankments constructed of rock excavation. It appears that either soil or base material placed over the open rock embankment can sift down into the voids, causing settlement. In some instances, the settlement may be gradual adjustment of the rock fill or further breakage of rock materials under load. One site was visited where a rock approach embankment resting on a solid rock foundation had settled approximately 1 in. Corrective measures successfully employed to minimize this type of settlement include restrictions on the top size of stone permitted in the top of embankment within 100 ft of the abutment, control of lift thickness, and the use of spalls to fill voids.

Lightweight materials (fly ash, expanded shale, cinders) have been used with apparent success in England and the United States for abutment embankment construction to lessen the load on the foundation materials. However, the availability of these materials and the relative costs are factors that affect their use.

Most embankments for bridge approaches are constructed of the materials that are readily available from roadway excavation or a convenient borrow site. These materials, when placed at the designated moisture content and adequately compacted, will usually perform satisfactorily. However, several agencies provide extra assurance of good performance by specifying select materials and increased density for bridge approach embankments. Typical sections are shown in Figure 12.

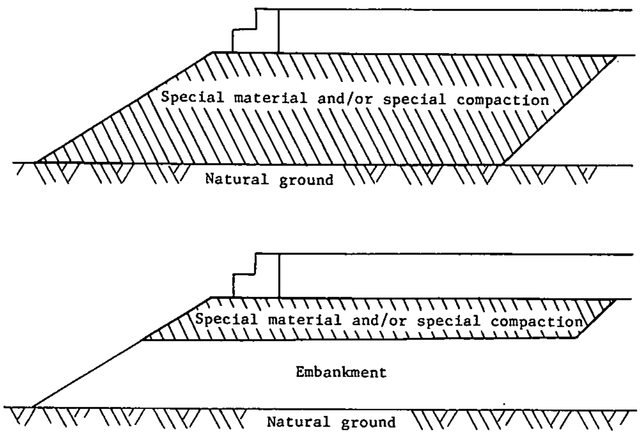


Figure 12. Typical abutment sections using special materials and/or construction methods.

Two important factors that affect the construction of good bridge approach embankments are the selection of suitable materials and the use of good construction methods. Although these requirements appear to be reasonable, they apparently are not always given sufficient recognition in plans and specifications and by the construction forces.

One item that may be overlooked in approach embankment construction is the benching of sloping ground. Because even small movements of the embankment create problems at the bridge approach and abutment, it is good practice to bench even slight slopes to provide a horizontal foundation (Fig. 13).

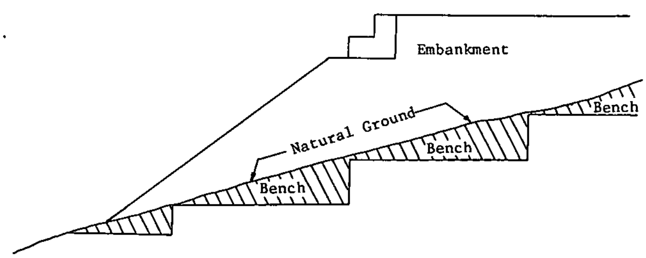


Figure 13. Abutment end section with natural ground benched.

On sidehill fills, provisions for drainage under the embankment may be required. Wet-weather seepages should be collected and drained with special outlets to prevent the embankment from acting as a dam and the possible saturation of the embankment.

When a retaining wall or bin-type abutment is used, compaction of the approach embankment requires special care near the structure. Even if the area is accessible, not all engineers agree to using conventional compaction equipment near the wall. Small mechanical and vibration devices are available that will perform the compaction task satisfactorily without endangering the vertical alignment of the structure. Most agencies recognize this problem and instruct the inspector to be especially diligent while this work is in progress.

It is generally agreed that neither moisture nor density control is possible when frozen materials are incorporated in embankments. Construction during cold weather should be prohibited without exception whenever silts, clays, or sand are used for abutment embankments. One soils engineer states that he believes many of the embankment settlement problems in the northern United States to stem from permitting the construction of soil embankments during cold weather. The enforcement of this restriction is the responsibility of the inspector; however, he should not delay work when the temperature is well above freezing and the frozen crust can be stripped aside to give access to unfrozen material.

Special construction requirements for abutment embankments include placement of special earth cores, surcharges, extra width sections, and the use of select materials. Whenever it appears that the abutment embankment must be constructed largely of rock material, it is not uncommon to specify that an earth core be provided to permit adequate pile penetration. The design requirement often will be similar to the section in Figure 14. Because this section is difficult to construct, most contractors will elect to extend the earth core to the face of the embankment.

One agency is known to build the abutment embankment

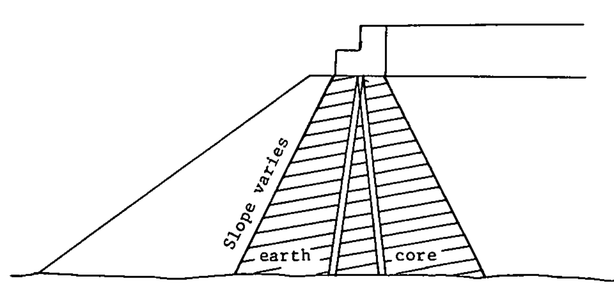


Figure 14. Special earth core to permit pile penetration.

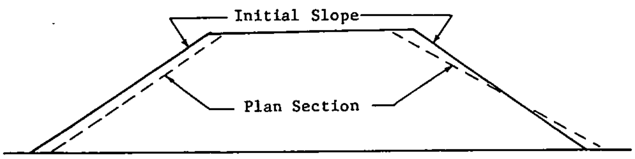


Figure 15. Embankment initially constructed extra wide to facilitate good compaction. Final dressing brings slopes to plan section.

on a 1.5:1 slope and finish it to a 2:1 slope (Fig. 15). This probably insures better compaction than is otherwise achieved at the edge of the embankment—an area that often fails to get the desired compaction.

Occasionally, a choice is available between the use of one long structure and two shorter structures connected by a short embankment section. In this case, the problems associated with bridge approaches (especially when the distance between structures is short) should be evaluated during design.

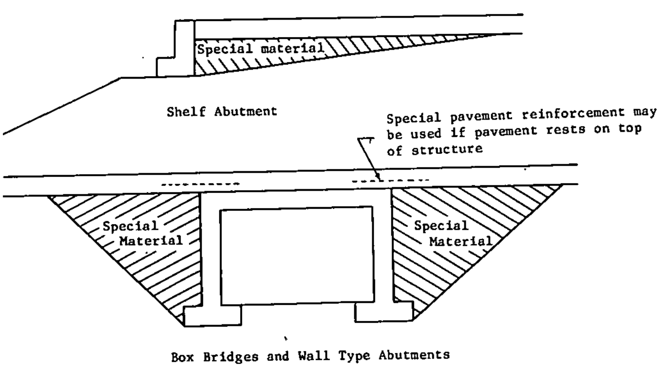


Figure 16. Special backfill section to minimize damage from expansion resulting from freezing or swelling soils.

Although embankment sections are usually considered in discussions of bridge approach problems, cut sections are occasionally encountered. A report on approach slab settlement by the Illinois Divison of Highways indicates that each of two approaches located in cut sections experienced as much settlement as those on embankment, if not more. This would appear to justify consideration of the improvement of the support capability in the cut as well as in embankment sections.

SUBBASE AND BASE

It is necessary in many areas to consider the subbase and base when attempting to identify and correct the causes of surface irregularities at bridge approaches. Settlement occurring in these layers is usually small, but the stability of each layer is dependent on the behavior of the other layers.

Freezing of moisture-laden subbase and base materials creates a bridge approach problem that is particularly burdensome to northern highway agencies. This expansion may raise the pavement an inch or more above the bridge deck, producing a condition similar to that of expansive soils. The general practice for minimizing this problem is to use free-draining bases on top of frost-free select materials where deep freezing is anticipated. The use of special materials for approach construction over expansive soils or in cold climates is shown in Figure 16.

The use of treated base material under the approach slab has been proposed by at least one maintenance engineer to provide increased support for the slab. Several agencies are considering the use of cement-treated material for base construction near abutments.

CHAPTER FOUR

ABUTMENT TYPE AND CONSTRUCTION

Highway engineers generally agree that the bridge abutment is sometimes a factor in causing irregular approach surfaces. However, discussions with several knowledgeable engineers indicate that perhaps no more than 5 to 10 percent of the problems associated with bridge approaches may be attributed to the abutment. Known serious problems have been limited to cases involving settlement of abutments on pile groups, excessive settlement of abutments on spread footings, and the rotation of abutments on pile supports.

ABUTMENT TYPES

Closed

The closed abutment is generally used where there is a need to limit the total bridge length (Fig. 17). An objectionable feature of this abutment is the difficulty associated with placing and compacting material against the retaining wall and between the wing walls. It is possible that this type of abutment may be shoved out of vertical alignment if heavy equipment is permitted to work near the

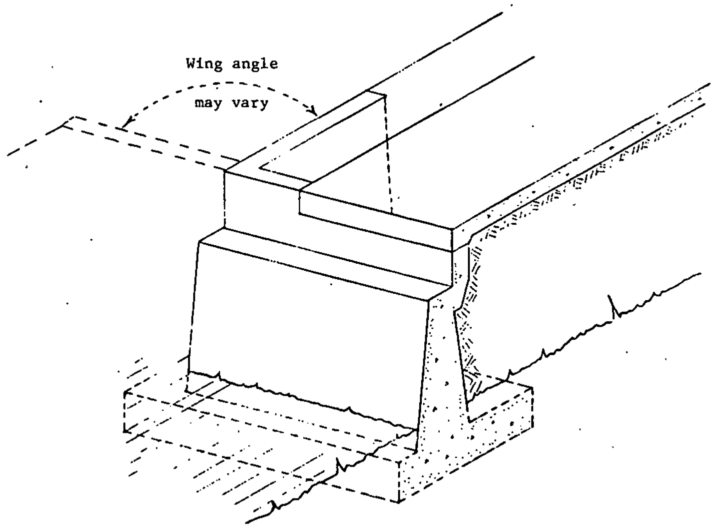


Figure 17. Typical closed abutment.

walls. Even small movements of the abutment are objectionable. The placement of the embankment after abutment construction may cause foundation settlement. Efforts to overcome the disadvantages of using this type of abutment have included prohibiting backfill until the first bridge span is in place and placing as much of the adjacent embankment as practical before starting the abutment construction (Fig. 18).

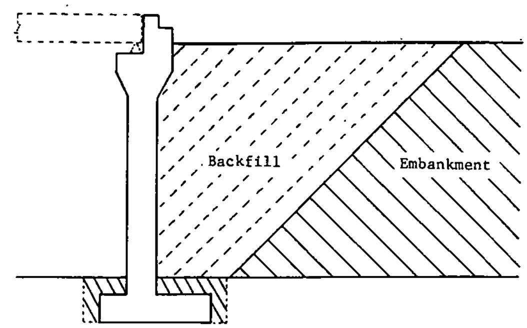


Figure 18. Embankment constructed before abutment. Backfill placed after first span is completed.

Stub or Shelf

The stub or shelf abutment is constructed after the embankment has been brought essentially to final grade (Fig. 19). It may be supported on spread footings, piles, or drilled shafts. Many consider that this abutment offers the best means of avoiding most of the problems that cause rough approach pavements. It eliminates the difficulties of obtaining adequate compaction adjacent to the relatively high walls of closed abutments. In addition, depending on the type of support used, the differential settlements of abutment and embankment under the approach pavement can be minimized.

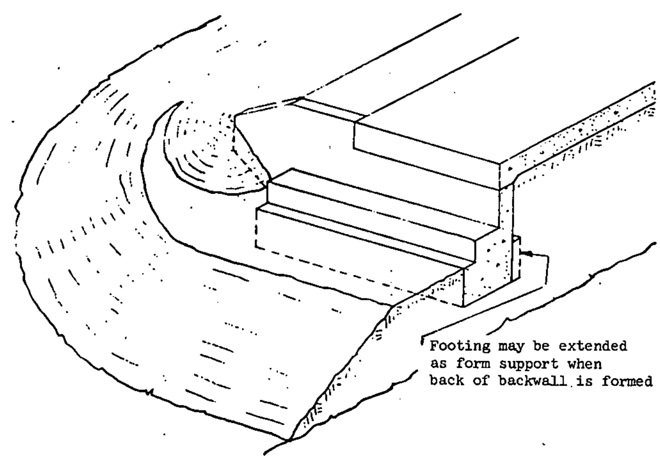


Figure 19. Typical stub or shelf abutment.

Spill-Through or Open

There is now a general feeling that the spill-through abutment may be the cause of some poor approach conditions (Fig. 20). This type is situated on columns or stems that extend upward from the natural ground, making it nearly impossible to properly compact the embankment material that must be placed around the columns and under the abutment cap. Spill-through construction is an invitation to early settlement and erosion. Many agencies that once used this type of construction have abandoned it in favor of the stub or shelf type supported on piles that are driven through the compacted embankment.

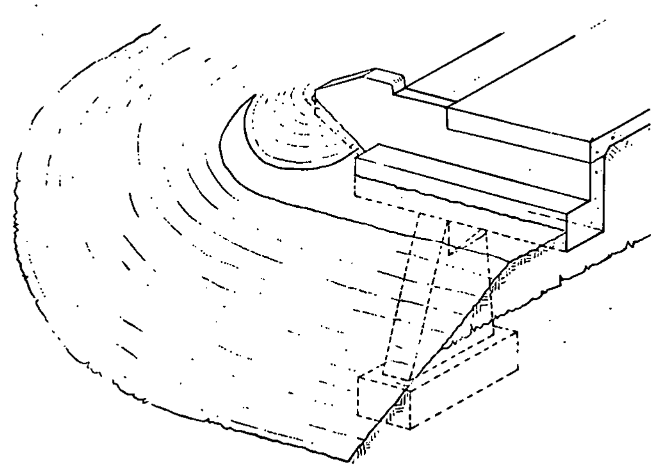


Figure 20. Typical pedestal or spill-through abutment.

TYPE OF SUPPORT

Regardless of the abutment type used, there are only two principal methods of providing foundation support; spread footing, and pile or drilled shaft. The type of support selected for the abutment may have a relationship to the bridge approach problem. For example, some agencies elect to use abutments with spread footings on compacted embankments to eliminate differential settlement between abutment and approach pavement.

Pile or Drilled Shaft

When pile or drilled shaft support is used, their movement may be involved to some extent in approach pavement or abutment settlement. This movement may be the result of foundation support failure, friction drag caused by settlement of embankment or foundation material, lateral movement of the embankment, pavement growth, or expansive soils behind the abutment.

A complete foundation site investigation is a first prerequisite to successful prevention of pile movement. Other practices include predrilling holes through the embankment, waiting for embankment settlement, surcharging embankment, and using batter piles. Predrilling through the embankment may not be effective unless the hole is larger than the pile and non-cohesive material is used for filling around the pile. It has also been reported that foundation settlement causing some lateral movements may take place for several years. This would appear to indicate that a waiting period may not be feasible and that a surcharge prior to abutment construction should be required.

Some agencies, fearing that preventive measures may not always be successful, cast jacking slots in beams. This permits the bridge to be adjusted if settlement of the abutment does occur.

Spread Footings

Improved procedures in site investigations and analysis and better control of embankment construction have helped to promote the use of spread footings for abutment support. This minimizes the tendency for differential settlement that exists for pile-supported structures. It is important that construction be timed to permit the foundation material to consolidate before the spread footings are constructed. The bridge structure should also be designed to accept small amounts of settlement, should they occur. Drainage for abutments on spread footing can be very critical. Most agencies elect to use a special granular material for this type of foundation (see Attachment 1 of Appendix C) to offset the possibility of settlement or erosion.

ABUTMENT BACKFILL

The attention that is given to the selection of abutment backfill materials and construction control procedures in plans, special provisions, and specifications indicates the concern of highway agencies for this vital part of the bridge approach construction. The use of unsuitable backfill material, combined with poor placement and compaction procedures, has been a serious cause of settlement at bridge approaches.

Many agencies specify specially graded granular materials for abutment backfill. Several typical gradations are shown in Figure 21. The specifications may also include a requirement for a special compaction effort, such as 95 to 100 percent of AASHO T-99 or T-180 densities.

Most highway agencies need to be concerned with settlement at bridge approaches, but those agencies located in areas of expansive soils also are concerned with upward movement or swell. In these areas special backfill material is used sometimes as a buffer to protect the approach pavement and the bridge abutment from the forces created by soil expansion. This backfill often will be an open-graded granular material that is placed without compaction under specially designed approach slabs. Where granular material is not economically available, backfill

SECTION 1009
POROUS BACKFILL MATERIAL

1009.1 Class B Drains. Porous backfill material adjacent to and for a height of 2 feet above the top of the perforated pipe shall be gravel, crushed stone, or other material of approved quality, and shall meet the gradation requirements specified in Sec 1005.1.4.1, 1005.1.4.4, or 1005.1.5. The remainder of the porous backfill material shall conform to the requirements of Sec 1009.2.

1009.2 Class A and Class C Drains. Porous backfill material used in constructing pipe or French underdrains shall be of approved quality. It may be sand meeting the gradation requirements of Sec 1005.2, or may be a mixture of washed sand and gravel meeting the following gradation requirements:

	Percent
Passing 1½-inch sieve	100
Passing ½-inch sieve	55-90
Passing No. 10 sieve	20-50
Passing No. 20 sieve	15-35
Passing No. 100 sieve	0-10
Passing No. 200 sieve	0- 3

Porous backfill material shall, at all times during loading, hauling, and placing, contain sufficient moisture to prevent segregation.

1005.1.4.1 .....

Gradation A	*Percent*
Passing 2-inch sieve	100
Passing 1½-inch sieve	95-100
Passing ¾-inch sieve	35- 70
Passing ⅜-inch sieve	10- 30
Passing No. 4 sieve	0- 5

Figure 21. Specification for granular backfill (Missouri Standard Specifications, 1968).

soil placed at lower density and higher moisture content may help to alleviate swelling. Where granular backfill material is not available, special treatment with small percentages of lime may be used to minimize volume changes.

DRAINAGE

Along with the paved ditches, gutters, and other surface drains, special provisions for the removal of surface water that leaks into the area behind the abutment are an essential part of good abutment design practice.

The method used to drain water from behind the abutment will vary with the abutment type, backfill material, and method used to collect and carry the water. Aggregates (both loose and contained in wire baskets or sacks) have been used to pass water from behind abutments and wing walls. Depending on the gradation of the backfill and drainage material, a filter blanket may be required to maintain adequate drainage. Several types of under-drain pipe are also used to collect and carry water away from the abutment. Various schemes are shown in Figure 22.

Design measures may also include provisions for controlling moisture levels within the approach embankment. Plastic sheets and bituminous membranes and other materials have been used to form moisture barriers above expansive soils.

SPECIAL DESIGNS

As part of the effort to reduce loads on the embankment foundation, special abutments or transition structures are occasionally designed. One such structure is the cellular or hollow type that is designed to lessen foundation loads by eliminating approach embankment. This structure may be considered a part of the bridge; however, it actually is a transition section between bridge and normal embankment. Another expedient is to cantilever the end spans, which removes all bridge loads from the abutment and transfers them to the first pier. Adequate support for the structure is of more concern with this design than approach rideability.

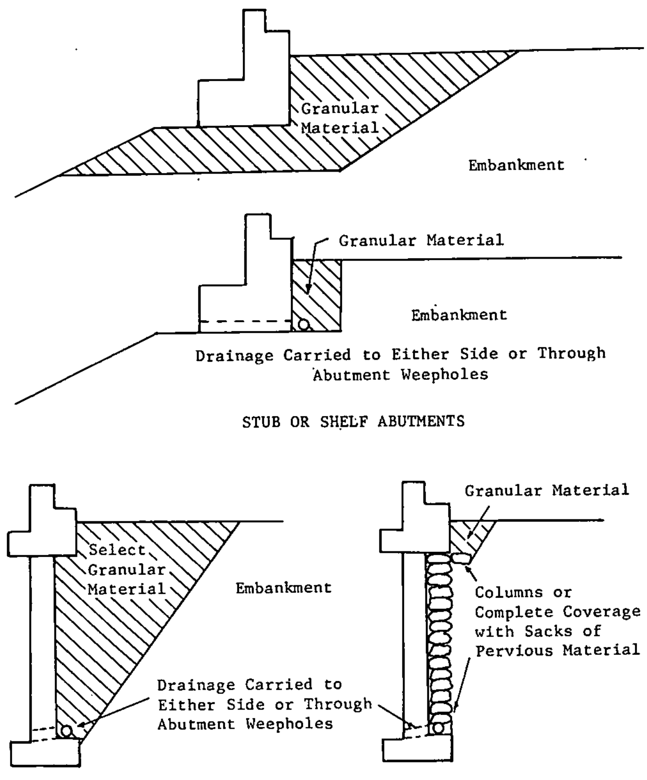


Figure 22. Typical methods used to provide abutment drainage.

CHAPTER FIVE

RIGID APPROACH PAVEMENT

Many agencies consider reinforced portland cement concrete approach slabs the most satisfactory means for controlling surface irregularities caused by settlement at bridge approaches. It should be mentioned that this is not unanimous. Several agencies are wavering in their use of specially designed reinforced concrete approach slabs to connect bituminous pavements to bridge structures. However, an obvious advantage of having heavily reinforced approach slabs is their ability to bridge minor undermining caused by flash floods.

GEOMETRY

Approach slabs are designed in a wide range of lengths, widths, depths, and shapes. Uniform-thickness, tapered, and haunched sections are common, but the apparent trend is toward the use of the uniform-thickness slab (Fig. 23). Lengths of individual slabs most frequently used are generally from 20 to 30 ft, but range from 10.5 ft minimum to 55 ft maximum. The slab width usually matches the roadway or bridge width. Several maintenance engi-

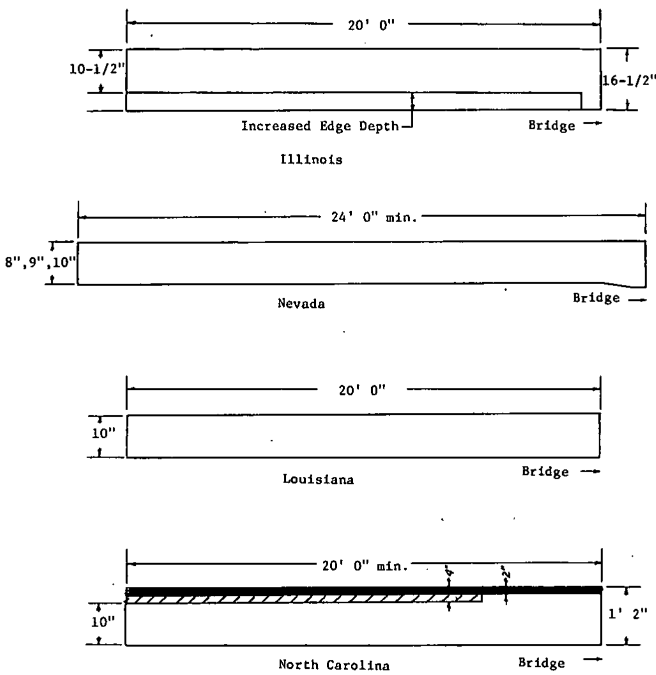


Figure 23. Commonly used bridge approach slabs.

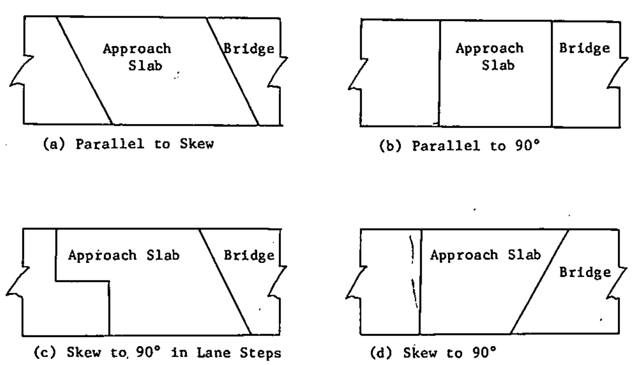


Figure 24. Plan view of possible approach slab configurations.

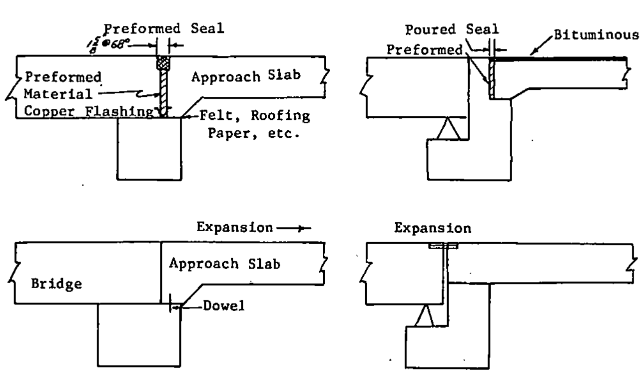


Figure 25. Joints used between bridge structures and approach slabs.

neers indicated a preference for single-lane approach slabs that can be removed or adjusted by slab-jacking without the need to divert traffic from the adjacent lanes.

The treatment of approach pavements at skewed structures is shown in Figure 24. Several agencies design the approach slab to match the bridge skew, while others eliminate the skew on the pavement end of the slab. There is a general feeling that the slightly skewed joint should provide a somewhat smoother riding transition.

REINFORCEMENT

The amount and distribution of steel reinforcement that is used in approach slabs varies with the anticipated loads and the amount of support assumed for the subbase or base material. Design is generally based on one of two bearing assumptions: (1) the slab is a bridge span without intermediate support; or (2) the slab is supported at intermediate points.

APPROACH PAVEMENT JOINTS AT THE ABUTMENT

Most agencies use approach pavements that are supported at the abutment on a seat. Materials used between the slab and the abutment to permit movement include building paper, asphalt cement, and roofing felt. At least one agency has used a dowelled connection to prevent independent movement of the approach slab or abutment. The joint treatment between the approach slab and the abutment should perform the following functions with a minimum of maintenance:

1. Transfer traffic loads from approach slab to abutment.
2. Prevent surface water from entering.
3. Permit expansion as necessary to prevent abutment damage.

Several types of joints that are reported to have been used successfully between the approach pavement and the abutment are shown in Figure 25.

APPROACH SLAB-PAVEMENT TRANSITION

In many cases, the use of special approach slabs to prevent approach irregularities has shifted the bump to the pavement end of the approach slab. This shifting cannot be considered a solution to the problem—this joint is equally as important as the one at the abutment. There are major differences in the attention given to the joint between the pavement and approach slab. A few agencies use only a butt joint supported by the base material, while others provide additional support with bolster beams, paving blocks, or even pile bents, as shown in Figure 26.

To minimize the bump at the pavement end of the approach span, a few agencies have elected to provide additional approach spans. In many cases, this will bridge a major part of the problem area where settlement is most likely to occur.

The step type of transition has been used by some agencies for connecting bituminous pavement to approach slabs

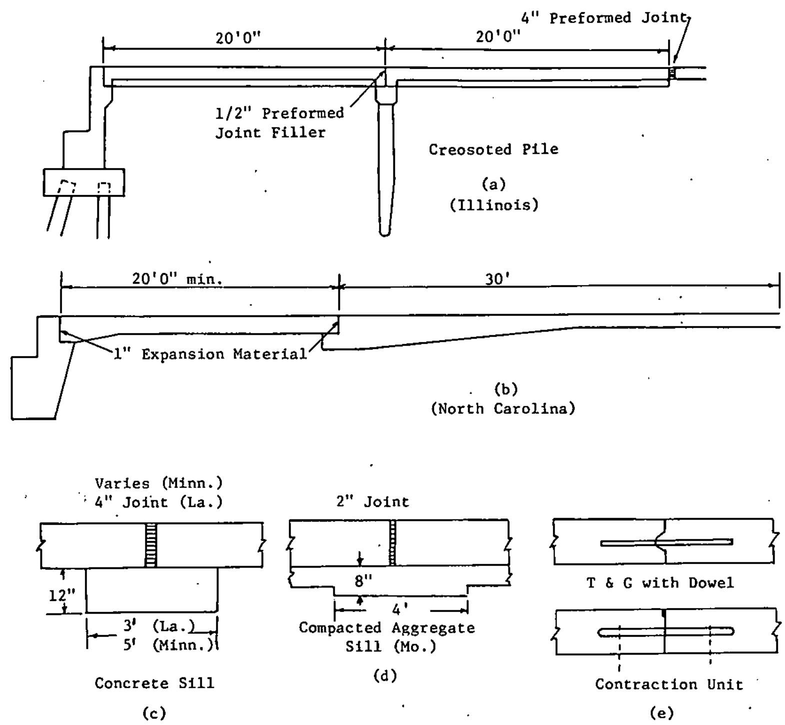


Figure 26. Joints used between roadway pavement and approach slabs.

(Fig. 23, North Carolina). This transition apparently has worked satisfactorily. The use of short (10 to 20 ft) sections of bituminous pavement between concrete pavement and approach slabs may cause both construction and maintenance problems. It is difficult to obtain the desirable density in these small sections of pavement initially and it is even more difficult for maintenance forces to level the bumps and depressions that often occur. Although this type of joint may protect the structure from damage by pavement growth, the rough ride and maintenance requirement may offset this benefit. Several agencies indicated an interest in using longer sections of bituminous construction between concrete pavement and the bridge approach to facilitate maintenance if uneven settlement were to take place. These sections may be replaced with concrete pavement after several years when final settlement has taken place.

The importance of sealing all pavement joints at the bridge approach is demonstrated in the plans of most agencies. Both preformed and poured materials are used to prevent the entrance of water at abutment and pavement joints. A few agencies use rubber waterstop devices and copper flashing to prevent water from entering. Special drains are sometimes provided under the joints to help remove any surface water that does enter.

SLAB-JACKING PROVISIONS

Slab-jacking or mudjacking of approach slabs as a preventive or corrective measure is usually necessary at some time during the life of the structure or pavement. This is normally accomplished through holes in the pavement; however, the possibility of horizontal jacking has been demonstrated by at least one agency.

Several agencies provide for the slab-jacking operation by precasting holes in the approach pavement; others contend that they can drill the holes as needed without difficulty. Many feel that precast holes are preferable when heavy reinforcement is used in the approach slab.

CHAPTER SIX

MAINTENANCE

It is the maintenance organization in most highway agencies that is most aware of the problems associated with rough bridge approaches. They are concerned with the detection and correction of minor deficiencies before they become problems, and with the repair of major failures. The problem is complicated even further by the need to justify budget allocations for equipment, materials, and personnel well in advance of the actual need. In many cases, special training in traffic control as well as in work methods may be required.

Approach repair work is made more difficult because of the necessity for controlling traffic. On many urban facilities, it is not practicable to perform even minor maintenance on bridge approaches because of heavy volumes of traffic.

The practices of highway agencies vary in identifying and repairing the bumps on the pavement at the bridge end. Some make repairs as a part of a scheduled preventive maintenance task, while others have used impact measuring devices to identify the approaches demanding immediate attention.

The advantages of preventive maintenance on bridge approaches were mentioned by one agency. Whenever the work crew had to raise or repair one approach slab, it was the policy to pump any grout that might be required under the other approach slabs on either that structure or companion structures. Another agency uses the same approach to correct the joints between bituminous pavement and the approach slab or bridge deck.

BITUMINOUS APPROACHES

Settlement creates the need for repairs at most bituminous approaches; however, problems with swelling soils, although not as widespread, often are more difficult to correct. The principal difference is the placement of the leveling material. Settlement is usually corrected by leveling the pavement; however, when swelling has lifted the pavement, the leveling is placed on the first span of the bridge (Fig. 27).

"Timeliness" is the key to maintaining bridge approaches constructed of or connecting to bituminous pavement. There is general agreement that repairs should be made on rough bituminous approach pavements before they become major problems. This is not always possible (due to traffic volumes, maintenance work load, funding, or other factors), and lack of repair results in more serious problems that may require machine-placed overlays, removal of base and/or pavement, or the use of heater-planer machines. The ability of the heater-planer to correct pavement shoving at bridge ends appears promising to several agencies, particularly where only small amounts of material have been transposed, as shown in Figure 28.

CONCRETE APPROACH SLABS

Practices employed to correct settlement of approach slabs include bituminous or epoxy resin overlays, slab-jacking, and in extreme cases removal and replacement. However, there is a reluctance to place materials of contrasting colors over concrete approach slabs. This is undoubtedly because this practice is viewed unfavorably by the public, who see it as a need for early maintenance. To many, this is almost as obvious and objectionable as the bump itself.

Practically all agencies rely to some degree on slab-jacking to raise approach slabs and pavements to their original grade. Both holes in the pavement and horizontal pipes under the pavement are used to pump the slurry or grout mixture under the pavement. Some agencies express fear of blowouts through joints or along the pavement edge, but others are more concerned with the problems associated with traffic control during the packing operation.

It is possible to obtain some relief from raised approach

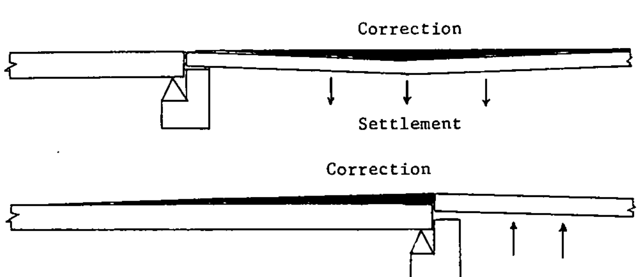


Figure 27. Use of bituminous leveling to correct settlement or swelling.

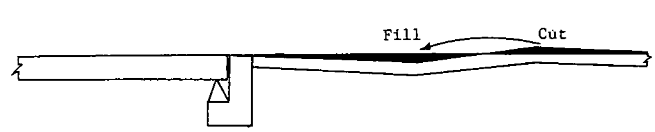


Figure 28. Smoothing rough bituminous bridge approaches with a heater-planer.

slabs by leveling on the structure with bituminous materials. In many cases it is necessary to remove the slab and the swelling material causing the problem. Because this is usually a soils problem, it is considered good maintenance practice to discuss this type of problem with the soils engineer before replacing the approach construction.

The expense and problems associated with the replacement of approach spans that had been pushed up by swelling embankment soils prompted one district maintenance engineer to suggest that they be replaced with a special bituminous section, as shown in Figure 29. As the pavement is forced upward, it could be cut to grade with a heater-planer without adversely affecting the section. This section is somewhat similar to approaches where settlement had been repaired for a number of years.

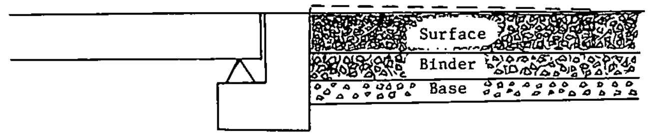


Figure 29. Extra-depth bituminous surface suggested where swelling is a problem. This thick surface can be smoothed as needed with a heater-planer.

CHAPTER SEVEN

RESEARCH

Although only a limited amount of active research is specifically concerned with bridge approach problems, investigations and studies are under way that may provide additional information for the highway engineers that are designing and constructing this part of the roadway. The list of current or recently completed research in Table 1 was selected from the HRIS *Highway Research in Progress* index.

RESEARCH NEEDS

Opinion appears to be divided on whether additional research will contribute significant advances in the control of roughness at bridge approaches. Many engineers believe that the prinicipal causes of bridge approach failures have been identified, that adequate solutions are known, and that careful application of this information will prevent most problems. Others point to the disproportionate amount of maintenance effort and funds being expended in correcting bridge approach failures as evidence that more needs to be known.

These failures could indicate a need for better site investigation, careful design, improved construction inspection, and more timely maintenance for bridge approaches. All too often the identification of the contributing causes of poor approaches is not possible because of the nonavailability of design, construction, and maintenance data. The desired information, if available, may be scattered in different departments or in separate locations in the archives. The practice followed by several agencies—of using a bridge book to record all essential bridge information—is recommended. The bridge record book should also contain information about the bridge approach. This would include: site investigation, special foundation treatment or construction, embankment design and construction, drainage provisions, subgrade construction along with post-construction field measurements, and the work required to maintain smooth approaches.

Soils engineers are capable of estimating the amount of settlement that might be expected. However, in many locations there is no effort to confirm these predictions. Additional study of foundation, embankment, and approach slab behavior, using data such as might be obtained from the proposed bridge record book, could provide information that would help improve the validity of future design.

There are other bridge approach problem areas not discussed in this synthesis that may warrant investigation. Some engineers have expressed concern about the impact loads which are magnified by rough bridge approaches. Others are equally as concerned with the problems associated with rigid pavement growth that may produce damaging forces at the bridge abutment. Considerable differences of opinion exist with regard to the best joint design for preventing roughness and transferring loads while barring the passage of moisture to the subgrade or backfill. It is, at present, difficult to identify any prevalent practices that have proven successful in minimizing these problems.

Further soils research, particularly that which is concerned with the behavior of soils under load, will undoubtedly contribute to improvements that can be made in bridge approach design and construction processes. However, this study did not identify any specific area where research relating directly to the bridge approach problem might be profitable.

TABLE 1

RESEARCH IN PROGRESS [a]

RESEARCH PROJECT TITLE	RESEARCH AGENCY	HRIP NO.[b]
Control of Pavement Movements Adjacent to Structures	Mississippi University	25 001071
Measurement of Earth Pressure, Deformation and Strain in the Concrete in a Bridge Abutment	Federal Institute Road Research (Germany)	27 061537
Earth Pressure Against Vertical Front Walls in Long Frame Bridges	Swedish Geotechnical Institute	27 062594
Examine Long-Range Settlements at Structural Approaches and Procedures for Overcoming Post-Construction Bump	California Division of Highways	33 080448
Settlement of Rock Fills	Georgia Institute of Technology	62 001168
Movements Within Large Fills	California Division of Highways	62 001184
Settlement of Bridge Approaches and Embankments	Kentucky Department of Highways	62 007062
Comprehensive Settlement Study of the Interstate Fill Across the James River Valley, Proj. I 90-7(6), Davison County	South Dakota Department of Highways	62 012883
Movement and Stability of Cuts and Fills	Massachusetts Institute of Technology	62 019756
Behavior of Soil Deposits as Determined from Case Histories	University of Illinois	62 040406
Volume Changes in Subgrade Soils	Alberta Coop. Highway Research Program (Canada)	62 050183
Moisture and Density Changes in Subgrades	Alberta Coop. Highway Research Program (Canada)	62 050198
Prediction of Settlements and Pore Pressures Beneath a Highway Embankment Near Sydenham, Ontario	Queens University, Kingston (Canada)	62 050249
Movement of Bridge Abutments and Approaches on Soft Foundation Soils	Sydney University (Australia)	62 060214
Settlement Behind Bridge Abutments	Road Research Laboratory (England)	62 060280
Settlement of Structures on Over-Consolidated Clays	Imperial College Sci. & Technol. (England)	62 060441
Vertical Sand Drains Under Earth Dams and Embankments	Manchester University (England)	62 060446
Settlement and Frost Heave in High Embankments Constructed in Winter	National Road Research Institute (Sweden)	62 062566
Methods to Minimize Settlement of Embankments Constructed During the Winter	Swedish Assoc. General Contractors	62 062657
Measuring the Settlement of Highway Structures	Bridges & Highways Center & Reg. Labs. (France)	62 063074
Study of Long-Term Deformation of Compacted Cohesive Soil Embankments	Purdue University	62 085143
Simulation of Settlements of Supports of Full-Scale Continuous Concrete Bridges	Auburn University	62 089832
An Investigation of the Use of Lime Stabilization in Construction of Bridge Cones	Illinois Division of Highways	62 201686
Experimental Sand Drain Fill at Napa River	California Division of Highways	63 001165
Settlement Study	Louisiana Department of Highways	63 006258
Downdrag on Foundation Piles	National Science Foundation	63 017344
Improvement of a Soft Foundation With Vertical Sand Drains	Public Works Res. Inst., CM (Japan)	63 061016
Stability of Slopes With Seepage	Kumamoto University (Japan)	63 061254
Rebound of Material in Highway Cuts	California Division of Highways	64 080463

[a] As of June 1969. [b] Acquisition number assigned by the Highway Research Information Service of the Highway Research Board; HRIP = publication entitled *Highway Research in Progress* (current issue).

APPENDIX A

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APPENDIX B

SPECIAL PROVISION FOR BRIDGE END BACKFILL

STATE OF SOUTH DAKOTA
DEPARTMENT OF HIGHWAYS

SPECIAL PROVISION
FOR
BRIDGE END BACKFILL

DATED: APRIL 3, 1968

I. DESCRIPTION

This work shall consist of backfilling bridge abutments and sills with select granular backfill as shown on the plans and specified herein.

II. MATERIALS

A. Select Granular Backfill: This material shall be free from dirt, vegetable matter or other foreign substance. This material shall meet the following requirements.

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

The fraction passing the No. 40 sieve shall have a liquid limit not to exceed twenty-five (25) and a plasticity index not greater than six (6) as determined by AASHO Test Methods. Abrasion loss per AASHO T-96 shall not exceed forty-five (45) percent.

III. CONSTRUCTION REQUIREMENTS

The provisions of Section 150 of the Standard Specifications pertaining to the backfilling of sills and abutments are superseded by this Special Provision.

Prior to placement of select granular backfill, the area to be backfilled shall be shaped to the lines and grades shown on the plans and all loose or unstable subgrade material shall be stabilized and compacted as directed by the Engineer.

An underdrain system shall be installed prior to placement of the select granular backfill as shown on the plans.

Select granular backfill shall be placed in layers of a thickness and by methods which satisfactorily demonstrates to the Engineer that uniform and required compaction has been achieved. To obtain this result it is anticipated that the lift thicknesses can vary from three (3) to six (6) inches (provided the moisture content therein is substantially uniform and near optimum) and compaction can be best achieved by use of pan-type vibrating equipment. The select granular backfill shall be compacted to a density of at least ninety-seven (97) percent of AASHO T-99.

IV. METHOD OF MEASUREMENT

No measurement for payment will be made of quantities included in the work of Bridge End Backfill.

V. BASIS OF PAYMENT

This work will be paid for at the contract lump sum price for the item "Bridge End Backfill."

Payment for this item will be full compensation for necessary shaping and compaction of the area to be backfilled and for furnishing an underdrain system, water and satisfactory select granular backfill complete in place.

APPENDIX C

SETTLEMENT PROBLEMS AT BRIDGE ABUTMENTS

M E M O R A N D U M

August 3, 1967

TO: Principal Civil Engineer
Bureau of Final Plan Review

FROM: Director, Bureau of Soil Mechanics
New York Department of Transportation

SUBJECT: Settlement Problems at Bridge Abutments

In accordance with your request, we have assembled the following information that may be useful to you for your forthcoming HRB Committee meeting. Since 1963 the Bureau of Soil Mechanics has furnished to the Bridge Subdivision Foundation Investigation Reports for all bridges. The purpose of this program is to insure that there is adequate subsurface investigation, soil testing, and necessary analyses to adequately evaluate the foundation conditions for each structure. The sources of settlement at bridge approaches can be divided into two broad categories. First there is consolidation of the underlying soil caused by the weight of the approach embankments, abutments and pier loads. In order to understand this settlement, it is important to realize that soil is composed of a mixture of soil particles and voids filled with air or water. When loads are applied to this soil system, the soil structure compresses to a smaller volume. The magnitude of this compression is a function of the density and strength of the soil structure and the magnitude of the applied load. In relatively impervious soil containing clay, the settlement does not occur immediately since the soil structure cannot compress until the soil water can flow from underneath the embankment. This time lag in compression is one cause of differential settlement between a pile-supported structure and the adjacent embankment.

The second cause of settlement adjacent to a bridge is consolidation of the embankment material placed during construction. If the material is properly compacted, then there should be no subsequent settlement under superimposed loads. However, factors such as vibration, water movement, and climatic effects may cause some consolidation of this material.

I. Methods Used to Eliminate or Decrease Differential Settlement at Bridge Abutments in New York State.

The majority of bridges are founded on soils consisting of compact glacial till which does not offer any settlement problem and on soils consisting of water-laid mixtures of sand, silt and gravel which present minor settlement problems. For these particular problems, the expected settlement is in the order of 0 to 6 inches, and occurs very rapidly. In order to eliminate abutment settlements, the embankments are constructed to the footing elevation or higher with a waiting period before abutment construction to allow the foundation soil to consolidate.

It is important to realize that often the principal cause of settlement in a bridge abutment is not the weight of the abutment but the weight of the embankment material in the general area. For example, a 20 ft. approach embankment superimposes a weight of about 2000 tons on the ground and the abutment has a load of about 500 tons. For a 40 ft. high embankment, the fill will weigh 4000 tons as compared with 500 tons contributed by the abutment. Therefore, it is obvious that if most of the grading is done within the abutment area followed by a waiting period to eliminate settlement, then the future loads from the abutment, bridge structure, and live load are of a minor magnitude. The settlement from the abutment load is usually less than 2 inches. This is tolerable and no differential settlement occurs since abutment and fill settle together.

Attached is drawing No. SM 1664A entitled, "Preloading Conditions for Stabilization of Foundation Soil at Bridge Abutments." These are the principal treatments used. The selected treatment depends upon the soil conditions and the height of the approach embankment. Structure settlement and differential settlement between the fill and structure can be eliminated by the use of one of these preloading methods for the majority of bridge projects.

In areas of more critical foundation soil conditions, we not only have to think of the settlement approach embankment but also of the stability of the embankment against shear failures of the underlying soil. Shear failures involve a rapid displacement of the foundation soil and a subsequent sinking of the embankment. Failures of this type will destroy an abutment even if it is supported on piles. The principal methods of treatment for this problem used in New York State are described as follows:

(a) Excavation of the Critical Soil

This treatment is often used in swamp areas for peat and muck deposits. The excavation is backfilled with a suitable granular material which will compress rapidly as the embankment is constructed.

(b) Lightweight Fill

Settlement and stability problems may be decreased if the weight of the embankment is reduced. In certain areas of New York State, expanded shale aggregate is available and is used for approach embankments to structures. The weight of this material in place is 65 to 75 pcf as compared to 120 to 140 pcf for ordinary fill material. The cost of this material is approximately $6.00 per cu. yd. in place plus transportation. Water-cooled blast furnace slag can also be used where available. This material weighs about 80 to 90 pcf in place.

(c) Sand Drain Treatment

Occasionally sand drain treatment is used to increase the rate of consolidation of a foundation soil and at the same time to increase the shear strength of this soil to prevent a foundation failure. Usually this treatment is used for embankment construction in critical soil areas. However, there is one project in New York State presently under construction in the Buffalo area where sand drain treatment has been used at bridge approach abutments principally to eliminate differential settlement. On this project high vertical abutments are designed crossing city streets and it is impossible to preload the area before constructing the abutment and backfilling. A waiting period is provided between the time of backfilling behind the abutments and the time of paving in order that one foot of settlement of the approach fills can be accomplished prior to paving instead of having the settlement extend over a period of 2 to 5 years after construction.

(d) Shear Key Treatment

Occasionally the geometrics of structures on stream crossings involves relatively low approach embankments with a relatively high effective fill height between the final grade and the bottom of the stream channel. Where soft soils occur, there is a danger of a shear failure of the embankment into the stream. In these cases we have used a shear key under the abutment to provide stability for the embankment and prevent movement of the abutment toward the stream. The shear key involves excavation of the low strength soil and replacement with suitable granular backfill.

(e) Pile Drag

Another important problem which deserves attention is the case of pile-supported abutments and high embankments on compressible soils. When the embankment settlement cannot be eliminated by one of the above methods of treatment and there is long-term settlement of the embankment adjacent to the abutment, the problem of pile drag comes into the picture. This often causes the abutment to tip backward resulting in some concern about the support of the structure on the abutment seats. Downward movement of the fill and underlying soil caused frictional forces to develop on the rear row of piles for the granular materials and cohesive forces to develop on the piles for plastic materials. The magnitude of these forces can be quite high especially where high embankments are concerned. We have found no practical methods of predicting the magnitude of the forces for design. The only practical solution that has been used is to place more piles in the rear row to help offset this tendency.

II. Embankment Consolidation

The second principal cause of differential settlement is due to subsequent consolidation of the embankment fill. The following restrictions have been incorporated into the specifications to reduce this problem in the abutment area.

(a) Item 2 material shall be placed in 8" layer and compacted to a minimum density of 95% AASHO T-99. The maximum size of stone allowed is 6 inches.

(b) The 10 ft. of fill directly under abutments supported on spread footings shall be Item 2VJB. This material is sound, hard, durable stone, gravel, sand, blast furnace slag or other acceptable granular material with a top-size of 4 inches, having 0 to 70% passing the No. 40 sieve, and 0 to 15% passing the No. 200 sieve. The purpose of this selected granular material is as follows:

(1) More efficient and more uniform compaction may be obtained using this granular material as compared with Item 2.

(2) This material is not susceptible to erosion or piping by water movement, or will it be effected by wetting and drying.

(c) Rock Fill Embankment

An unusual problem occurred on the design of the Interstate Route 503 in Dutchess County in a mountainous area. Approach embankments for several structures required fills 60 to 80 ft. high. A large amount of rock excavation was available. It was necessary to design a fill using the available material that would not undergo consolidation. Sound rock with a maximum size of 12 inches was placed in layers not exceeding 12 inches in thickness. Compaction of each layer was accomplished by four passes of a vibratory roller having a static weight of not less than 20,000 lbs. This method was used to build high embankments with a uniform density and adequate density. The end slopes were steepened from the standard 1 vertical to 2 horizontal to 1 on 1-3/4. This allowed the length of structure to be decreased.

Director, Bureau of Soil Mechanics

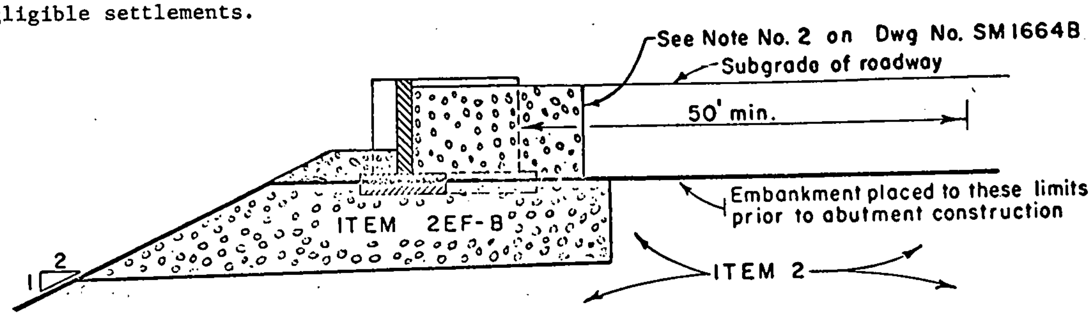
By: Associate Soils Engineer

Attachment: Drawing No. SM 1664A

PRE-LOADING CONDITIONS
FOR STABILIZATION
OF FOUNDATION SOIL
AT BRIDGE ABUTMENTS N.Y.

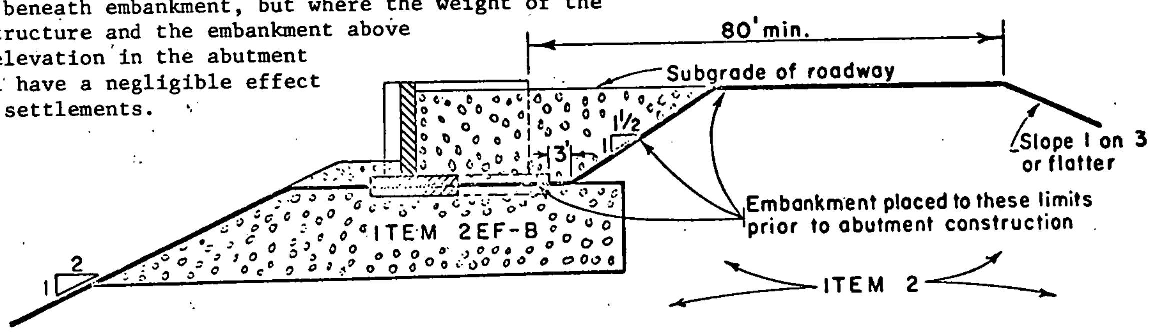
CONDITION 1

Used where no waiting periods are required since the foundation soil is very compact and negligible settlements can be expected, or where weight of embankment above footing elevation and structure load will cause negligible settlements.



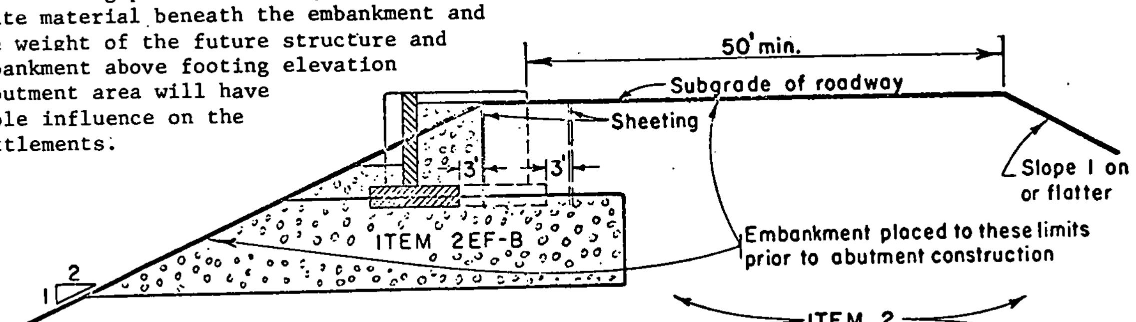
CONDITION 2

Used where waiting periods are required to pre-consolidate material beneath embankment, but where the weight of the future structure and the embankment above footing elevation in the abutment area will have a negligible effect on total settlements.



CONDITION 3

Used where waiting periods are required to pre-consolidate material beneath the embankment and where the weight of the future structure and final embankment above footing elevation in the abutment area will have appreciable influence on the total settlements.



A modification of Condition (3) is the use of a surcharge above subgrade elevation to decrease the waiting period.

Note that the treatment cost for Condition (2) is approximately $2000 less than for Condition (3).

The following notes are included in the Contract Plans

Used where waiting period have been specified

1. The embankment constructed to the required grade shall be allowed to stand a minimum of ___ days or for a period of time as determined by the Deputy Chief Engineer (Design) prior to any substructure construction.

Used where no waiting periods have been specified

2. The embankment shall be allowed to stand for a period of time satisfactory to the Deputy Chief Engineer (Design) prior to any substructure construction.

For further information refer to the Bridge Subdivision design sheet entitled "Placement Limits of Item 2EF-B For Abutments Founded on Spread Footings."

From Drawing No. SM 1664A

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Highway Research Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

Rep. No.	*Title*
—*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80
1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20
5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p. $3.20
7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80
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