# Drainage and Backfill Provisions for Approaches to Bridges

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Approaches to bridges are designed to provide a smooth and safe transition from the highway pavement to the bridge deck. Generally this transition area, regardless of pavement type, has provided poor riding quality. Despite widespread occurrence of bridge approach problems, only a few research studies have been performed on the subject, most of which have been limited to problems associated with specific bridge sites. The few comprehensive studies done in this area have not suggested a design or specification to rectify the problem. A state-of-the-art and state-of-practice study that covers published and unpublished work in the United States and overseas was conducted. It included a comprehensive literature review and survey of state highway agency design and construction practices currently in use at approaches to bridges. The literature indicated that most problems occurring at bridge approaches can be associated with differential settlement between the highway pavement and bridge deck, and poor design of both bridge and pavement components. On the basis of the literature review and survey of highway agencies, critical items in design and construction of bridge approaches are summarized and recommendations on drainage systems and approaches to embankments are made. Points regarding the control of water around abutments and under approach pavement are summarized. Recommendations on materials, compaction, and construction for approach embankments are made.

Pavement irregularities adjacent to bridges are unpleasant, unsafe, destructive to vehicles, and may cause excessive impact loading on the bridge. In addition, in high traffic volume areas, these surface faults require costly maintenance that usually involves mudjacking or patching the approach pavement. Maintenance operations are costly to the traveling public in time and money. Shutting down lanes to perform repairs causes long lines of backed up vehicles, which in turn may cause costly accidents.

Parts of the roadway that may contribute to a poor-riding bridge approach are the bridge deck and abutment, roadway pavement, base, subbase, subgrade, embankment, and embankment foundation. Poor riding qualities are usually caused by differential settlement between highway pavements and the bridge deck. The biggest contributors to such differential settlements are subsidence of the original ground below the fill and settlement within the fill mass. Other factors that may contribute to a vertical change in the constructed profile are the fill height, type of abutment, age, abutment skew, settlement period, and traffic count. Abutment backfill material, drainage, and construction methods are critical items in building and maintaining good bridge approaches. Difficulty in obtaining uniform compaction of the fill, especially near the abutment area, may also cause uneven settlement.

Despite the widespread occurrence of bridge approach defects, only a few research studies have been performed on the subject. Most of these studies have been limited to problems associated with specific bridge sites (*1–6*). Because of the complexity of the problem, these types of studies have often led to conflicting observations or conclusions. A NCHRP comprehensive study conducted in 1969 summarized the existing information on the design and construction of bridge approaches and provided a better insight into the problem (*7*). The study was revised and updated in the 1990 NCHRP Synthesis 159 (*8*) to cover the new construction techniques and materials developed since the 1969 report.

A comprehensive literature review on design and construction practices currently used at approaches to different types of bridges was conducted. On the basis of findings of the literature review, a questionnaire was prepared and sent to state highway agencies and 20 countries overseas to study current design and construction practices in bridge approaches. The literature search of pertinent publications (*9–14*) indicated that the critical items in the design and construction of bridge approaches are embankment foundation, embankment and backfill materials, drainage systems, and construction methods.

This paper compiles the different problems encountered at approaches to bridges, summarizes corrective measures used or suggested, and makes recommendations on drainage systems and approach embankments.

## EMBANKMENT FOUNDATION

Where compressible layers exist in the embankment foundation, proper design and construction techniques must be used to minimize postconstruction consolidation. Some of the construction measures used to stabilize foundation materials (*2,3,7,10*) are summarized in the following sections.

### Use of Surcharge

Densification and preconsolidation of weak and compressible soils (saturated soft clays, compressible silts, organic clays, and peats) by preloading are the most widely used methods to reduce the magnitude of settlement after construction. The effectiveness of preloading before construction of the approach pavement depends on the time available for consolidation under the surcharge load and the actual rate of settle-

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ment. Thus, it is important to construct the embankment and surcharge as early as possible to provide enough time for consolidation before removal of the surcharge load.

The increase in stresses produced by the surcharge loading must not cause shear failure within the foundation materials. Sometimes embankment and surcharge loading may need to be placed in increments, corresponding to the strength gain, to avoid an increase in shear stress between weak foundation sublayers.

The surcharge should be compacted to the embankment standards because, as settlement occurs, the lower part of the surcharge becomes the top layer for the embankment of the grade elevation. Usually the surcharge height varies from 1 to 3 m (3 to 10 ft) depending on the soil conditions at the site.

### Use of Drains

If the use of surcharge is not economical or the time required for surcharging is greater than the time available, vertical drains may be used to increase the rate of settlement. Vertical drains are effective in thick homogenous layers of clay where primary consolidation is the major part of the settlement (*5*). In peat and organic clays where settlement behavior is dominated by secondary consolidation, vertical drains are unnecessary.

Before the 1980s, sand drains—vertical columns of sand that provide a pathway for the excess water—were used successfully to accelerate the removal of water from foundation soil. In the early 1980s, prefabricated wick drains began to replace sand drains in the United States. The wick drains could be installed much more quickly and economically and provided more reliable drainage.

Prefabricated wick drains consist of a formed polymeric core surrounded by a geotextile filter fabric. They are installed vertically to depths of 45 m (150 ft) with modern wick installation rigs that use vibration and hydraulic crown to achieve high installation rates. A horizontal sand filter-blanket must be constructed beneath the embankment (above the vertical drains) to carry the excess water away. Today prefabricated drains completely replace sand drains.

### Waiting Periods

If the analysis shows that excessive time is required to obtain an acceptable percentage of consolidation of the embankment foundation, additional time may be necessary for consolidation before construction of the approach pavements. The design and construction methods used in bridge approaches have a great influence on the rate of consolidation. For instance, the embankment and surcharge should be constructed before the construction of the abutment to provide more time for stabilization of the embankment foundation. However, in some cases in which embankments are on a highly compressible foundation, it is necessary to extend this period.

### Removal of Unsatisfactory Material

When a soft compressible material is encountered in the embankment foundation, the rate of consolidation and the foundations ability to carry the loads may be questionable. A common practice is to remove a part or all the unsatisfactory material and replace it with rock or suitable well-compacted material. This method may not be practical or economical if the analysis shows that more than 3 or 5 m (10 or 15 ft) of the foundation depth must be removed (*10*).

Existing structures or rivers, or both, near the site may sometimes limit the dimensions of the foundation soil that can be removed. However, partial removal or stripping of the upper layers of very soft compressible soils will reduce the secondary consolidation of the soil (*7*).

### Use of Lightweight Embankment Material

In cases in which the foundation's ability to carry the embankment load is limited, reduction in the approach-fill weight near the abutment may be necessary to reduce the settlement and movement of the underlying soft soils to an acceptable level. Lightweight fill, such as furnace slag, expanded shale, coal waste refuse, lightweight concrete, sawdust, bark, polystyrene foam, or other materials having small unit weights, may be used (*6*). The type of material used depends on its availability, cost, time required for construction, environmental concern, and existing conditions of the foundations. To avoid or minimize the acidity and corrosive effects, such materials should be encapsulated in geomembrane liners.

### Dynamic Compaction

Dynamic compaction is another method applied in bridge approaches with loose, clean, coarse-grained deposits. In this method soil compaction is achieved by the repeated dropping of a heavy weight on the ground surface. Typically, weights ranging from 5.5 to 27.5 Mg (6 to 30 tons) are dropped from heights of 9 to 23 m (30 to 75 ft) at each point on a predetermined grid pattern (*8*).

The effective depth of dynamic compaction depends on the impact energy, soil type, and degree of saturation. Common effective depth is 12 m (40 ft), but higher effective depth can be achieved by increasing the impact load.

## APPROACH EMBANKMENTS

Problems associated with embankments of bridge approaches are generally attributed to volume changes of the soil within the approach embankment. Highway designers usually permit the use of locally available soils in design of the highway embankment to reduce project costs. Substantial amounts of settlement of such materials may not affect the performance of the highway. Highway structures, on the other hand, are designed for little or no settlement to maintain specified highway clearances and ensure integrity of structural members. The approach embankment must therefore provide a smooth transition between roadway and structure and requires special materials and placement criteria to prevent internal consolidation.

Volume changes within the approach embankment may result from the rearrangement of soil particles, loss of moisture (shrinkage), increase in moisture (swelling), or ice and frost action. Although roughness at bridge approaches is generally due to settlement of the embankment, in practice, roughness caused by swelling is also encountered. In cold climates, the uplift force could also be caused by the growth of ice lenses between the soil particles when frozen materials are incorporated in embankments.

Two parameters that affect the embankment performance are (a) suitability of various soil types as bridge approach embankment material and (b) proper compaction specification to be followed for a given soil type.

## Material

Where embankments are composed in part or entirely of compressible materials, embankment settlement may contribute significantly to approach pavement settlement.

Primary consolidation of the soil involves a gradual escape of water from voids of the loaded soil. The time for settlement is controlled by the soil properties (compressibility, permeability, stress history, and void ratio) and by the geometry of the soil mass. For embankments consisting of granular soils, which have small void ratios and large permeabilities, this compression occurs rapidly within a few months and is completed before construction of approach pavement. However, where silty sand and silt exist, completion of primary compression requires 1 to 3 years. Where clay exists, several years may be required for complete consolidation. Hence, settlement of the approach pavement may be significantly affected where embankments are composed of soft clay.

Most approach embankments are constructed of materials readily available from roadway excavation or a convenient borrow site. However, there is a need to place restrictions on the type of fill material used behind bridge abutments. The survey of state highway agencies in this study (*15*) showed that at least 15 states specify select materials for bridge approach embankment. A typical suggested approach embankment cross section for a bridge on spread footing (*16*) is shown in Figure 1. FHWA (*16*) specifies select material to conform to the following requirements:

1. Gradation:

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

2. Soundness: the material shall be substantially free of shale or other soft, poor durability particles.

## Compaction

The lack of proper compaction, due to either improper compaction specification or negligence in specification enforcement, is a major source of differential settlements within the bridge approach system. This is particularly true in confined areas near the abutment where only small compaction equipment can be used.

Studies by Road Research Laboratory (*17*) show that density of compacted soil varies for different thicknesses of lifts, and higher densities cannot be obtained throughout relatively thick lifts. As a result, the compaction specification includes both maximum lift thickness and the relative compaction of approach embankment materials. Table 1 gives lift thickness and relative compaction requirements for several agencies on

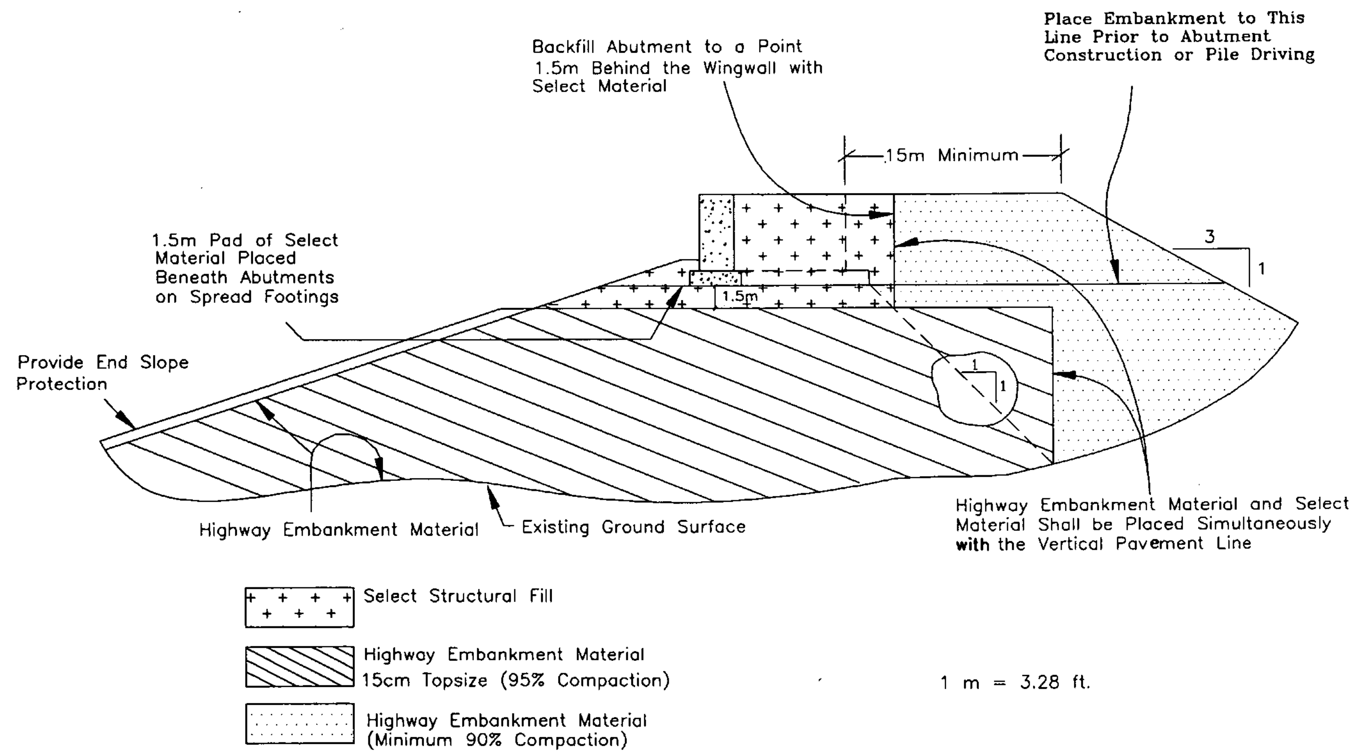


**FIGURE 1 Suggested approach embankment details (*16*).**

**TABLE 1 Maximum Lift Thickness and Relative Compaction for Embankment Material at Abutments**

| State | Maximum Lift Thickness (Loose Measurements) | Relative Compaction |
|---|---|---|
| Arizona | 20 cm | 95% AASHTO T99 (Standard) |
| Arkansas | 10 cm | 95% AASHTO T99 (Standard) |
| California | 20 cm | 95%* |
| Colorado | 15 cm | 95% AASHTO T180 (modified) |
| Connecticut | 15 cm | 100% AASHTO T180 (modified) D |
| Delaware | 20 cm | 95%* |
| Maine | 20 cm | 98%* |
| Michigan | 22 cm | 95%* |
| Missouri | ----- | 95% AASHTO T99 Method C |
| New Hampshire | 20 cm | 98% AASHTO T99 Method C |
| Ohio | ----- | 98% to 102 AASHTO T99 |
| Rhode Island | 25 cm | 95% AASHTO T180 Method A or D |
| South Carolina | 15 cm | 95%* |

** State Test Method*

*---- Not Specified*

*1 cm = 0.4 in.*

the basis of the survey of state highway agencies conducted by Wolde-Tinsae et al. (*15*).

Most agencies recognize that compaction of the approach embankment requires special care near the structure. Even if the area is accessible, not all engineers agree to use conventional compaction equipment near the wall. In most cases, agencies require the use of small mechanical and vibration devices to perform the compaction without endangering the vertical alignment of the structure. In the case of shoulder (full-height) abutment, the usual method is to build the embankment to its final grade, construct the abutment and the first span of the bridge, and finally place and compact the backfill materials around it. This procedure tends to eliminate abutment movement during compaction of the embankments and provide enough time for the foundation to consolidate under the embankment load.

## DRAINAGE SYSTEMS

The development of approach faults have often contributed to surface and subsurface erosion of the soil adjacent to the abutment and under the approach pavement. Therefore, special attention must be given to remove water from critical areas around the abutments and under the approach pavements by providing an adequate drainage system.

### Surface Drainage

A good surface drainage system is important in bridge construction. The surface water should be removed quickly and completely from the bridge deck and its vicinity. Trapped or ponded water, especially in cold climates, can cause a great deal of damage to a bridge (*18*).

Deck drain is generally permitted to drain through short vertical metal pipes and spill directly into the abutment slope (Figure 2) or run down the abutment wall through joints between the bridge deck and road surface. These practices initiate erosion on the abutment slope (Figure 3) and piping from under and behind the abutment and cause cracking and settlement of the approach pavement. The removal of earth from under and behind the abutment walls by piping is a common cause of the settlement of the highway pavement.

Basic conditions essential for development of piping are (a) sufficient water to cause drainage through cracks, (b) hydraulic head sufficient to move water through a subsurface route, and (c) outlet for flow. Thus, the concentration of runoff near bridges should be prevented, and the supply of water from the overlying bridge deck and roadway pavement must be intercepted and led to a water course channel in downspout circuits.

### Subsurface Drainage

The infiltrated free water must be removed from areas around the abutments and under the approach pavements by providing an adequate drainage system. Such a system includes a drainage layer behind the abutment and wingwalls that drains the free water vertically and a system of drainage pipes that carry the water to collection points outside the abutment. In

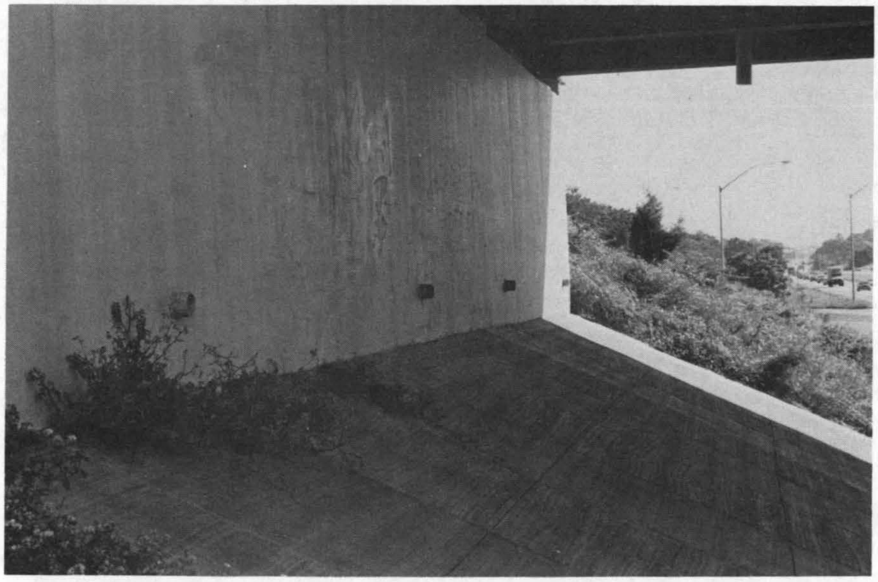

**FIGURE 2 Short vertical metal pipe that spills directly onto abutment slope.**

many causes the drainage system also includes a lateral drainage layer, usually but not necessarily the base that carries the infiltrated water to transverse collector drains installed at critical sections.

## Drainage Layer

To remove free water from the pavement structure either vertically or laterally to the system of drainage pipes, a high-permeable drainage layer is required. Such required permeabilities can be supplied by using coarse materials surrounded by filters. Some states use asphalt-treated permeable material or cement-treated permeable material as drainage layer. California uses asphalt-treated and cement-treated permeable materials with the gradings presented in Table 2 (*19*).

## Geocomposite Drainage System

New prefabricated drainage systems, called geocomposite drains, have been developed for drainage behind the abutment. The geocomposite drains are made from various types and configurations of polymeric drainage cores covered by geotextile filters that are bonded directly into the cores. The drainage system completely covers the backfilled side of the abutment with the geotextile filter attached to the side of the core facing the backfilled soil. The solid portion of the drain-

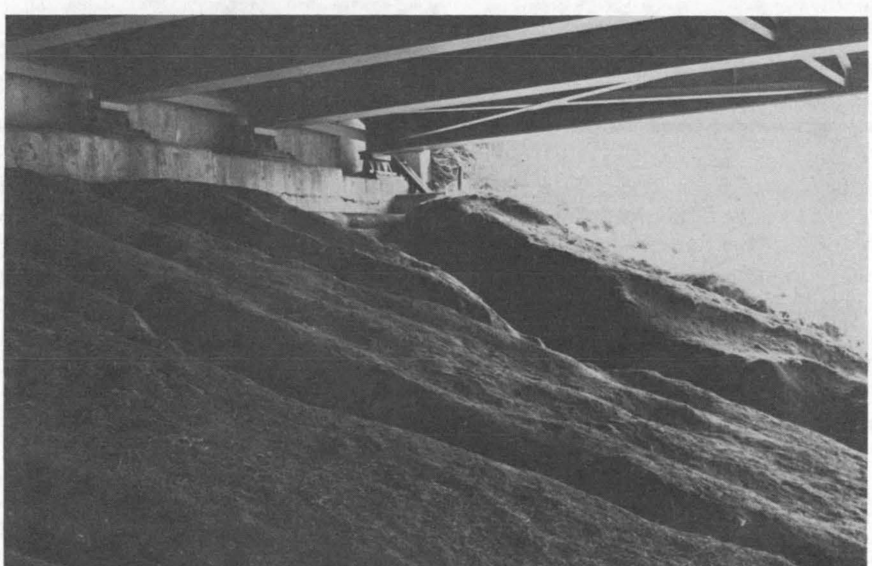

**FIGURE 3 Soil erosion on abutment slope due to deck drainage.**

TABLE 2 Grading of Asphalt-Treated and Cement-Treated Permeable Base (California)

| ASPHALT-TREATED | | CEMENT-TREATED | |
|---|---|---|---|
| Sieve Sizes | Percentage Passing | Sieve Sizes | Percentage Passing |
| 25 mm (1)" | 100 | 7.5 mm (1-1/2") | 100 |
| 19 mm (3/4") | 90-100 | 25 mm (1") | 88-100 |
| 12.5 mm (1/2") | 35-65 | 19 mm (3/4") | X-15 |
| 9.5 mm (3/8") | 20-45 | 9.5 mm (3/8" | X-15 |
| 4.75 mm (No.4) | 0-10 | 4.75 mm (No.4) | 0-16 |
| 2.36 mm (No.8) | 0-5 | 2.36 mm (No.8) | 0-6 |
| 75 um (No.200) | 0-2 | | |

*X = The gradation which contractor propose to furnish for the specific sieve size (for 19 mm, X=52 to 85; and for 9.5 mm, X=15 to 38)*

age core supports the geotextile and maintains an open volume for free movement of water.

### Subsurface Drainage Pipe

The collection system consists of a set of perforated or slotted pipes to remove water from the pavement and convey it to suitable outlets outside the roadway limits. The design of drainage pipes include (a) type of pipe used; (b) location, depth, slope, size, and outlet of pipe; and (c) provision for adequate filter protection to provide sufficient drainage capacity.

Plastic piping systems are appropriate for drainage of transportation facilities and have shown satisfactory performance (*20*). Lack of brittleness and resistance to salts and aggressive soils have made plastic piping systems more suitable than concrete and corrugated metal buried piping systems.

### Filters

If the drainage layer and piping system are to remain functioning for a satisfactory period, clogging must be prevented. This can be achieved by using a filter between the drain and adjacent material.

Aggregate filters have been used for a long time and, if properly constructed, will perform well. Grain-size distribution of a graded aggregate filter creates its pore structure that, in turn, controls filtration performance. There are well-established criteria for specifying the grain size distribution of aggregate filters (*21*). These criteria based on theoretical relations among particle size, pore size, and retention ability of granular materials have proved adequate through decades of use.

The use of geotextiles in filter applications has become widespread in the past 20 years. They can be effective in protecting soil from erosion while permitting water to pass through the fabric to the drain. There are more than 600 geotextiles that consist of woven and nonwoven fabrics (*22,23*) available in the United States.

Geotextile filters have two advantages over aggregate filters: (a) they do not store a significant amount of water in the fabric layer and (b) there is more flexibility in the selection of the type and material properties desired.

The major properties of geotextile filters that should be considered in drainage application are

- Flow Rate—Permeability of the fabric filter must be greater than that of the backfill soil placed against it. This is to ensure that the fabric accept the flow coming from the backfill soil.
- Opening Size—The voids of the fabric filter must be fine enough to retain erodible soil. As the fines within backfill soil get smaller, the opening size of the fabric filter must also get smaller.
- Strength Consideration—The fabric filter must support the backfill soil without collapsing into the core thereby blocking flow. This necessitates some requirements on its mechanical properties, such as puncture strength, grab strength, and tear strength. Table 3 gives the mechanical properties of geotextile filters (*24*).

## CONSTRUCTION METHODS

The construction methods used for approach embankments could considerably affect the performance of the bridge approaches (*25,26*). Careful consideration must be given to the construction of embankments placed over side-hill foundations. Benching of sloping ground is important to avoid lateral movement and provide horizontal foundation for the embankment. Granular material and perforated pipes should be used for drainage under an embankment on side hills, to collect and drain the wet-weather seepage and prevent the possible saturation of the embankment.

During construction it is essential to direct the surface water away from the abutments and retaining walls to avoid erosion of the adjacent soil. Embankments and backfill materials require careful control of the lift thickness, moisture content, and densification level. Compaction of the soil around abutments and walls should be done at the same time to prevent tilting of these structures. A good practice in approach em-

TABLE 3 Fabric Filter Survivability Requirements (*24*)

| Degree of Survivability | Puncture Strength Newton | | Grab Strength Newton | |
|---|---|---|---|---|
| | Woven | Nonwoven | Woven | Nonwoven |
| Medium | 310 | 180 | 800 | 510 |
| High | 450 | 340 | 1200 | 800 |

*1 Newton = 0.225 Pound Force*

bankment construction is to remove any unsuitable foundation soil and replace it with well-compacted material.

It is difficult to control moisture and density of embankments that have frozen materials. Therefore, construction during cold weather should be prohibited whenever silts, clays, or sands are used for the abutment embankment. Stripping or reconstructing the top layer of an embankment is necessary if the construction process is stopped because of bad or freezing weather.

## CURRENT PRACTICE IN CALIFORNIA

The survey of state highway agencies design and construction practices at approaches to bridges (*15*) revealed that a new approach slab concept developed in California provides a drainage system that minimizes the potential for water damage to the bridge approaches. This system is used on portland cement concrete pavements and on multilane asphalt concrete pavements in urban areas.

The old drainage system in California consisted of a vertical layer of permeable material 30 cm (1 ft) wide, drainage pipe near the bottom of the permeable material 20 cm (8 in.) in diameter, and weepholes through the abutment and wingwalls. Evaluation of this system (*13*) showed that

1. Simultaneous placement of the permeable layer and fill material is difficult and
2. Fines from the full tend to plug the permeable material and reduce its drainage efficiency.

It was also noted that the two other areas where water enters the fill and causes erosion and settlement problem (*13*) are (a) the joint between the slab and abutment and (b) the area along the junction of approach fill and abutment wingwall.

The new approach slab concept makes provisions for the drainage system to minimize the approach roughness due to water damage.

1. The old drainage system is replaced by a geocomposite drain system attached to the abutment backwall and wingwalls and a slotted plastic pipe drain encapsulated with treated permeable material (Figure 4). The pipe is placed along the base of the inside face of the abutment wall and carries the collected water where it will not cause erosion.
2. A treated permeable base 15 cm (6 in.) thick is placed under the approach slab and connected to the geocomposite drain along the abutment backwall (Figure 5).
3. In diaphragm-type abutments, the approach slab is placed in direct contact with the abutment and held firmly in place with reinforcing steel producing a water-tight joint.
4. The approach slab is extended laterally (cantilevered over the wingwalls) to coincide with the edge of the bridge deck and is separated from the wingwalls by a 10-cm (4-in.) gap to preclude unplanned vertical loading of the wingwalls when settlement occurs (Figure 6).

## RECOMMENDATIONS

### Embankment Foundation

Postconstruction consolidation of compressible foundation soils is the major cause of embankment settlement. It is suggested that

1. An adequate subsurface investigation be performed to provide information on the depth, thickness, and classification of all soils strata. Strength, compressibility, and permeability of critical strata must be determined.
2. The rate of primary consolidation and final settlement of the foundation soil be computed to estimate the amount of compression that will occur during the construction period

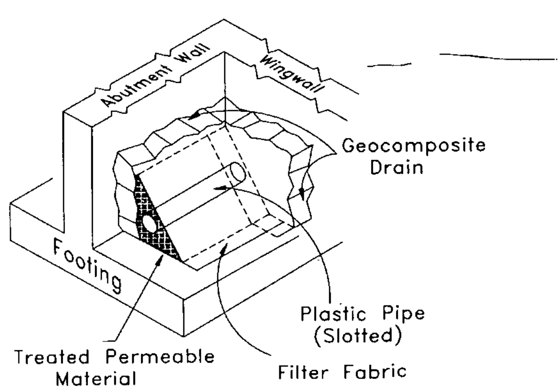


**FIGURE 4 Abutment drainage details (California).**

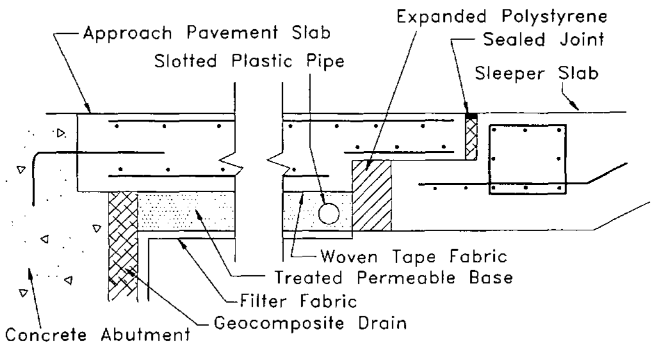


**FIGURE 5 Treated permeable base under approach slab (California).**

and assess the feasibility of minimizing postconstruction settlement by using special construction procedures.

3. When the behavior of a foundation soil is inadequate, the soil behavior be modified by the following methods:
   - Removal of a part or all of the unsatisfactory material and replacement with suitable borrow material.
   - In situ densification of foundation material when removal is uneconomical or impractical. The most commonly used methods are surcharges, vertical drains, waiting periods, and dynamic compaction.
   - Reduction in approach fill weight by using lightweight embankment material such as furnace slag, expanded shale, lightweight concrete, polystyrene foam, or other materials having small unit weight.

## Backfill

The use of marginal materials or inadequate compaction, or both, is the primary cause of approach problems. It is recommended that

1. Backfills be constructed with select borrow. In areas where select borrow is not available, breaker run aggregate is recommended as an alternative backfill material. The section of the approach embankment to be constructed with backfill material should be of sufficient length to accommodate standard construction equipment. The recommendation is to provide a longitudinal section projecting 1.5 m (5 ft) from the wingwall.
2. Approach embankments be constructed in 20-cm (8-in.) layers and compacted to 95 percent of standard proctor maximum dry density (AASHTO T99). The recommended tolerable range of moisture with regard to optimum moisture content is ±2 percent.
3. At a bridge approach site, project personnel be encouraged to increase inspection of materials, placement, and compaction. Furthermore, they should be alert for essential construction changes, such as the disposal of marginal materials and the need for granular backfill.

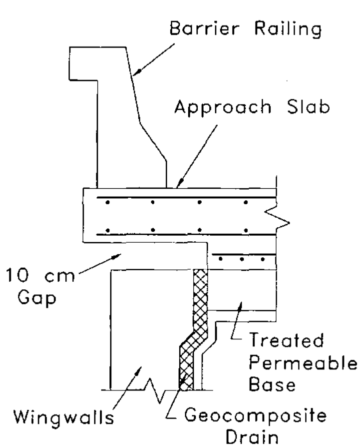


**FIGURE 6 Approach slab edge detail (California).**

## Drainage System

Special attention must be given to removing the water from critical areas around the abutments and under the approach pavement by providing adequate drainage systems. The following points should be considered.

1. Bridge deck and adjacent roadway drainage should be collected and dropped into a channel by means of drains similar to the gutter downspouts on houses. Drains should not be discharged directly on the faces of approach slopes. When deck drain is permitted to drain through short vertical pipes over the abutment slope, splash blocks should be placed directly under the drainage pipe to dissipate the energy of the falling water and prevent erosion of the fill.
2. The face of the slopes under the bridge should be covered with a geotextile drainage fabric or sand layer to minimize the loss of soil due to erosion and seepage. Concrete revetments, if used, should also be placed on top of a geotextile drainage layer to avoid internal erosion under the revetment.
3. A preformed permeable liner with a filter fabric face should be used behind the abutment and wingwalls to remove free water from approach structure to a system of drainage pipes (see Figure 3).
4. A permeable base should be provided under the approach slab and adjoining pavement.
5. A set of perforated pipes should be installed to carry the water to collection points outside the abutment. Water from these pipes should not be allowed to drain onto unprotected slopes of the approach embankment.

## ACKNOWLEDGMENTS

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