FloodSAFE CALIFORNIA
DEPARTMENT OF WATER RESOURCES

DRAFT

Rural Levee Repair Guidelines

November 2013

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Preface

The *Rural Levee Repair Guidelines* were developed in response to needs identified in the 2012 *Central Valley Flood Protection Plan* (CVFPP) to develop a common, consistent set of rural levee repair guidelines to help local maintaining agencies plan, design, and construct these repairs efficiently and effectively. This effort contributes to the implementation of the State Systemwide Investment Approach as outlined in the 2012 CVFPP.

The process to develop the guidelines involved a collaborative effort with input from a diverse work group of representatives from the U.S. Army Corps of Engineers (USACE), the Central Valley Flood Protection Board (CVFPB), DWR, local maintaining agencies, subject matter experts, and interested parties.

California Department of Water Resources (DWR) would like to recognize voluntary contributions provided by work group members and interested parties. The work group was not conducted through a formal consensus-driven process. However, input from the work group about the guidelines and assistance in clarifying technical, institutional, and financial challenges were critical to development of these guidelines.

These *Rural Levee Repair Guidelines* establish the basis for certain rural levee repairs to mitigate known hazards and improve flood protection in an affected region. These *Rural Levee Repair Guidelines* may be updated in the future as needed.

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1.0 Introduction

These *Rural Levee Repair Guidelines* were developed as part of activities to implement the 2012 *Central Valley Flood Protection Plan* (CVFPP), which was developed by the California Department of Water Resources (DWR) and adopted by the Central Valley Flood Protection Board (CVFPB) in June 2012.

1.1 Background

Since the mid-1800s, catastrophic floods have caused destruction of economic activities and loss of lives in the Central Valley. These flooding events have prompted local, State of California (State) and federal entities to construct major flood control facilities along the Sacramento and San Joaquin rivers and tributaries to alleviate flooding conditions and reduce flood damages. Many of these facilities comprise the State Plan of Flood Control (SPFC).[1] Despite these actions, four recent floods in 1983, 1986, 1995, and 1997 have caused over $3 billion in damage in the Central Valley, shedding light on the susceptibility of growing communities to major flood events.

The devastation and loss of life resulting from Hurricane Katrina in 2005 further raised public awareness of catastrophic storm events throughout the nation. In response, California voters passed the Disaster Preparedness and Flood Prevention Bond Act (Proposition 1E) and the Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act (Proposition 84) in November 2006, authorizing the sale of nearly $5 billion in State bonds for flood management improvements throughout the state with $4.275 billion of this amount specifically earmarked for the repair and improvements to State and federal flood projects in the Central Valley.

In the latter part of 2007, the California Legislature passed, and the Governor signed, five interrelated bills known as the 2007 California Flood Legislation, which are aimed at addressing the problems of flood protection and liability, and helping direct use of the bond funds.

[1] The State Plan of Flood Control means the State and federal flood control works, lands, programs, plans, policies, conditions, and mode of maintenance and operations of the Sacramento River Flood Control Project described in Water Code Section 8350, and of flood control projects in the Sacramento River and San Joaquin River watersheds for which the Central Valley Flood Protection Board or the Department of Water Resources has provided the assurances of nonfederal cooperation to the United States, and those facilities identified in Water Code Section 8361.

Together, these bills outline a comprehensive approach to improving flood management at the State and local levels, with elements to address both the chance of flooding (e.g., improvements to reduce the probability that floods will occur) and the consequences when flooding does occur.

DWR prepared the 2012 CVFPP per 2007 California Flood Legislation, and subsequently, the CVFPB adopted the 2012 CVFPP in June 2012. The 2012 CVFPP describes the State's vision for a sustainable flood management system in the Central Valley. DWR is now progressing with implementation of the CVFPP, marking an important planning step toward in modernizing SPFC facilities to achieve sustainable flood management in the Central Valley.

The State Systemwide Investment Approach includes a targeted 200-year level of flood protection for urban and adjacent urbanizing areas protected by the SPFC, and a 100-year level of flood protection for small communities through a combination of physical improvements and non-structural actions. State investments in the remaining rural-agricultural areas focus on improving overall flood risk management and promoting sustainable rural-agricultural economies. Furthermore, the CVFPP identifies the need to develop a common, consistent set of rural levee repair guidelines to help local maintaining agencies plan, design, and construct these repairs efficiently and effectively.

When adopting the CVFPP, the CVFPB echoed the need for rural levee repair guidelines in its Resolution 2012-25, which states:

> *The Board will create an advisory committee, or other appropriate group, working with DWR, local maintaining agencies, interested stakeholders, and the USACE to develop rural levee repair and improvement criteria, to be applied to planned or emergency work. The Board intends for the advisory committee or group to produce draft criteria to be available by July 1, 2013. (CVFPB Resolution No. 2012-25, Section 11(h))*

1.2 Rural Levee Repair Guidelines

These *Rural Levee Repair Guidelines* support the design and implementation of certain repairs that apply to rural levees. Consistent with the flood management policy in the CVFPP, these guidelines have a focus on the regular operations and maintenance needs of local maintaining agencies. These guidelines do not apply to new levee construction, for achieving specific levels of flood protection, or for repairs to levees in urban or urbanizing areas.

These *Rural Levee Repair Guidelines* were developed using a template-based approach. These hazard-specific templates outline basic requirements for levee and structure repair without specifying design standards, such as seepage gradient, stability factors of safety, material gradation, and other parameters that may be best customized based on local conditions. Therefore, the implementation of the guidelines may require investigation, assessment, engineering judgment, and care to fulfill their intended application. The level of effort and basic requirements stipulated in these guidelines attempt to balance consideration of: existing overall levee conditions and their existing level of performance; current standards for levee repairs; and the ability of local maintaining agencies in rural-agricultural areas to implement these repairs.

These guidelines are intended to be used for rural levees, whether they are an SPFC facility or not. They are also intended for use by local maintaining agencies. Where applicable, DWR will use these guidelines as the basis for future repairs, and may incorporate the *Rural Levee Repair Guidelines* in future funding program guidelines. The use of these *Rural Levee Repair Guidelines* by other local maintaining agencies is subject to their discretion, applicable law, and regulations.

These *Rural Levee Repair Guidelines* are neither a funding program nor a financial commitment of the State. These *Rural Levee Repair Guidelines* provide a menu of repair templates as a basis of consideration and for further customization by rural local maintaining agencies in their maintenance practice. These repair templates have been prepared to address known distress conditions experienced in past high-water events, with the assumption that these alternatives would improve existing levee conditions. These repair templates are expandable alternatives and could be adjusted based on engineering evaluations and judgment. However, these *Rural Levee Repair Guidelines* are not a vehicle for obtaining permits for intended repairs. It is likely, through the permitting process, that additional repair features may be added to a selected design.

Potential implementation activities should be in accordance with permitting agency(ies) requirement(s). The following activities may be considered to improve the permitting process of various agencies:

- Coordinating with the CVFPB and USACE to explore additional opportunities for improving permitting efficiency based on these guidelines (i.e., procedural considerations).
- Coordinating with the development of the Central Valley Flood System Conservation Strategy and associated regional permitting strategy, in collaboration with the Interagency Advisory Committee that covers actions including anticipated flood system improvements

and operation and maintenance activities (i.e., long-term considerations).

- Coordinating with existing regulatory agency-collaboration forums (e.g., the Interagency Flood Management Collaborative) to promote these guidelines and their potential application in a program-level permitting strategy (i.e., near-term considerations).

1.3 Development of Guidelines

After CVFPP adoption, the CVFPB requested that DWR create a working group to develop these *Rural Levee Repair Guidelines* in coordination with USACE, local maintaining agencies, and interested parties.

The work group consists of representatives from USACE, DWR, the CVFPB and CVFPB staff, local maintaining agencies, subject matter experts and interested parties. The work group was not conducted through a formal consensus-driven process. However, input from the work group about these guidelines and assistance clarifying technical, institutional, and financial challenges were critical to development of these guidelines.

1.4 Organization of This Document

The document is organized into the following sections:

- Section 1.0 provides background about the development of these *Rural Levee Repair Guidelines*
- Section 2.0 describes the general guidelines and provisions of these *Rural Levee Repair Guidelines* that apply to all repairs. This section also describes special considerations for applying the templates.
- Section 3.0 describes the templates for certain repairs to mitigate flood hazards.
- Section 4.0 is a glossary of definitions used in this document.
- Section 5.0 lists contributing authors and work group members.
- Templates contain the repair alternatives drawings.

2.0 Rural Levee Repair Guidelines, General Guidelines

This section describes the general guidelines and provisions of these *Rural Levee Repair Guidelines* that apply to all repairs. This section also describes special considerations for applying the templates, including all applications of the standard templates described in Section 3.0.

2.1 Environmental Stewardship

Environmental Stewardship is a commitment to responsibly managing and protecting natural resources such as water, air, land, plants, animals and their ecosystems in a sustainable manner that ensures they are available for future generations. The 2012 CVFPP was developed by incorporating the concept of the environmental stewardship into the integrated flood management approach. The Conservation Framework, incorporated by reference into the 2012 CVFPP, is the basis for the Central Valley Flood System Conservation Strategy that is under development.

Environmental Stewardship recommends that a fully integrated approach be taken as soon as the project objectives are known – i.e. before the initial design is developed. It is about more than avoiding or mitigating the environmental impacts of a pre-defined design. Rather, it sets out to identify ways of achieving the project objectives by working with natural processes to deliver environmental protection, restoration, or enhancement outcomes. By adopting a determined and proactive approach from conception through to project completion, opportunities can be maximized and - importantly - frustrations, delays and associated extra costs can be reduced.

The standard templates in Section 3.0 do not explicitly indicate environmental stewardship features to be included in repair actions. All local maintaining agencies are encouraged to consider environmental stewardship during planning, design, and construction. These considerations may be required by certain permitting agencies, or may contribute during the permitting process. It may be the case that the scope of repairs identified in these Rural Levee Repair Guidelines offers limited opportunities to incorporate environmental stewardship features or to be cost-effective when applying these repair templates for regular maintenance purposes.

2.2 Customization Based on Local Conditions

The hazard-specific templates in Section 3.0 outline the requirements for levee and structure repair without specifying specific design guidelines such as seepage gradient, stability factors of safety, material gradation, and other parameters that may be best customized based on local conditions. However, some situations may require analysis based on professional engineering judgment.

When customizing a repair template for local conditions, local maintaining agencies should consider the following, to the extent possible:

- Acquiring sufficient right-of-way for facilitating future repairs and access
- Improving access for flood emergency response and flood fighting by providing all-weather access roads on levee crowns, with associated ramps and turnouts
- Improving visibility and accessibility by removing or modifying encroachments, where necessary
- Impact to routine maintenance activities

2.3 Assessment Water Surface Elevation for Repair Templates

These *Rural Levee Repair Guidelines* are not a design standard, and the scope of levee repair is not necessarily to restore the design capacity or reference to a certain design water surface elevation. The repair templates in Section 3.0 have been prepared to address common levee distress mechanisms that a levee may have experienced in the past. Therefore, it is assumed that the levee's assessment water surface elevation would correspond to water surface elevations associated with distress.

The repair templates in Section 3.0 have been prepared with the assumption they would improve existing levee distress conditions. However, the level of improvement may vary based on site conditions. Subsurface investigations and engineering evaluation would be required to assess the level of improvement. If the areas under consideration for repair need (or are desired) to be remediated for certain design water surface elevations (such as 1955/1957 profiles, 100-year, 200-year, etc.), the remediation design should be performed in accordance with the requirements of the regulatory or permitting agencies and these guidelines may not apply.

2.4 Application of Existing Law and Regulations

These *Rural Levee Repair Guidelines* present a menu approach for minor repair options based on common practice and engineering judgment. These guidelines are not codified law or regulation. These guidelines were prepared with stakeholders collaboratively; however, existing law and regulations still apply and must be considered during implementation of any repairs. Local maintaining agencies must acquire all applicable permits and permissions before making the repairs described in these guidelines.

2.5 Special Considerations

The following special considerations may affect implementation of any repair option.

2.5.1 Sacramento-San Joaquin Delta Levees

Levees in the Sacramento-San Joaquin Delta are primarily rural. Delta levees, similar to most other levees of the Sacramento and San Joaquin River Systems, are made of sediment dredged from adjacent channels, excavated from island interiors, or imported from other areas by truck or barge. The height of a levee surrounding any island is a function of the depth of subsidence and the magnitude of water elevation change, due either to tides or floods. Since subsidence occurred slowly over the last 100 years, the larger Delta levees "evolved," usually by addition of material on the top and sides, rather than being constructed all at one time. For this reason, few levees in the Delta meet current engineering standards. In addition, seismic vulnerability may exist in many areas.

While the physical characteristics of Delta levees are not unique, the regular presence of high water against the water side levee slopes require special consideration for inspection, repair and maintenance efforts. Inspection and maintenance of the water side slope of these frequently loaded levees become more difficult than for levees higher up in the system, as less of the levee is visible and available for dry-work. Similarly, for erosion repairs, land side alternatives (levee widening, setback levee, etc.) may be more favorable, as the in-water work can add permitting and construction difficulties. These frequently loaded levees are also more seismically vulnerable, with the higher saturated material being more susceptible to embankment instability. Therefore, when applying these guidelines to Delta levees, special care should be applied when accounting for poor materials, subsidence, or frequently-loaded conditions. It is likely that selected repairs may require more analyses and

exploration, thus exceeding the scope of repair these guidelines or standard repair templates can cover.

2.5.2 Multiple Repairs to One Levee System

When multiple repairs are required in a single levee system, local maintaining agencies are encouraged to consider a more prudent consolidated major repair project to address safety concerns. In many geographic areas in the Central Valley, failure of any vulnerable points in a levee system would result in similar damage. While it is possible to apply these *Rural Levee Repair Guidelines* at each repair site, local maintaining agencies are encouraged to consider a consolidated repair project for cost efficiency and a potential multiple-objective approach to improve long-term sustainable practice.

3.0 Rural Levee Repair Guidelines, Standard Templates

The levee repair templates below have been developed to address common levee distress mechanisms such as erosion, underseepage, through seepage, and slope instability. These repair components have been used to alleviate distress from past high water events and are expected to improve levee conditions for the applicable distress mechanisms. Narratives and templates for commonly used levee repair components are presented in this section. Table 3-1 lists the repair alternatives.

Table 3-1. Repair Alternatives for Common Levee Distress Mechanisms

Distress Mechanism	Repair Alternatives	Template
Erosion	Rock Slope Protection Repair for Major Erosion	E-1
	Rock Slope Protection Repair for Minor Erosion	E-2
	Widened Levee Repair for Erosion	E-3
Underseepage	Drained Seepage Berm Repair for Underseepage	US-1
	Undrained Seepage Berm Repair for Underseepage	US-2
	Ditch Fill for Underseepage	US-3
Through Seepage	Drained Toe Berm Repair for Through Seepage	TS-1
	Toe Berm Repair for Through Seepage	TS-2
Slope Stability	Drained Stability Berm Repair for Slope Stability	SS-1
	Undrained Stability Berm Repair for Slope Stability	SS-2
	Partial Levee Replacement Repair for Slope Stability (Embankment)	SS-3
	Partial Levee Replacement Repair for Slope Stability (Embankment and Foundation)	SS-4
	Landside Slope Flattening Repair for Slope Stability	SS-5
Combined Underseepage/	Combination Drained Berm Repair for Seepage Stability	COM-1

Table 3-1. Repair Alternatives for Common Levee Distress Mechanisms

Distress Mechanism	Repair Alternatives	Template
Through Seepage/ Slope Stability	Combination Undrained Berm Repair for Seepage Stability	COM-2
Crown Depression	Repair for Crown Depression	CD-1

3.1 General Implementation Guidelines for Repair Templates

Specific guidelines pertaining to repair alternatives are discussed in the applicable narrative sections in these guidelines, and major features are shown on the repair templates. Following are some general guidelines should be considered during implementation of repairs:

- An existing slope or ground surface should be prepared for embankment or berm material placement. Surface preparation may require removing selected vegetation, debris, downed timber or tree roots, rubbish, loose soil, and other obstructions. Stripping a minimum of 6 inches of a slope or ground surface would be required.
- Topographic and bathymetric information should be used when planning, designing and implementing repair alternatives, as considered appropriate based on engineering judgment. These data should be evaluated when selecting the extent of a repair alternative.

  Where available, topographic and bathymetric data collected by DWR, USACE, and local agencies for different system-wide studies should be considered during implementation of a repair alternative. Topographic and bathymetric data from other studies may not be always readily adoptable; therefore, engineering judgment should be used.
- Subsurface explorations at a levee's crown or landside may be needed to evaluate embankment and foundation conditions and to perform geotechnical analysis. The number and extent of these subsurface explorations would depend on the distress mechanism. Test pits at a levee's landside toe (excavated to a depth equal or greater than levee's height) may be used to reduce the number of subsurface explorations needed. However, test pits should not be attempted if the groundwater level is shallow or if the water level in the river or channel is high. Test pits, if used, should be backfilled with excavated material with compaction effort, as per USACE and DWR criteria.

Engineering judgment should be used in evaluating the need for and level of subsurface explorations and engineering analyses.

- Embankment and berm materials should be placed in lifts and compacted in accordance with applicable standards to achieve stable conditions.
- Determine whether adequate right of way is available and obtain the necessary right of way, if needed.

3.2 Erosion

Erosion damage to the waterside of levees is usually due to: (a) high velocity flows coupled with erosive levee materials and/or poor hydraulic conditions; (b) large waves developed by wind over large, open bodies of water like a bypass; (c) boat wakes; or (d) tidal fluctuations. In addition to these major causes, an erosion hazard may be increased by a number of factors, including:

- Compromised levee prism geometry
- Geomorphologic trends as indicated by channel migration and historical damage
- Loss or narrowing of the natural berm or river bank located between the levee and stream bank
- Stream flow velocity, depth, duration, and shear
- Wind-wave shear stress
- Fetch length for wind wave-induced erosion
- Levees constructed from erodible materials, particularly low-cohesion sands/silts or dispersive soils
- Soil types in river bank and levee foundation
- Detrimental hydraulic anomalies
- Absence of beneficial vegetation or other slope protection
- Tree-fall or the presence of deleterious materials in the levee embankment
- Lack of slope protection against erosion

Apart from many other actions, common erosion repair may consist of placement of materials that can withstand erosive forces, or levee widening such that even if erosion continues, an effective levee section will remain in place to provide flood protection.

Three erosion repair alternatives are discussed in this section: rock slope protection for major erosion, rock slope protection for minor erosion, and a widened levee.

3.2.1 Rock Slope Protection for Major Erosion

In the rock slope protection for major erosion repair alternative, the pre-erosion slope is re-established by placing embankment materials, and subsequently, rock is placed above the re-established slope to provide armoring. The toe at the repair site is stabilized by using a toe berm consisting of rock, referred to as launch rock.

Applicability

This repair alternative applies when erosion intrudes into the applicable levee prism and below the mean summer water level. Figure 3-1 should be used as a guide to determine whether existing erosion has intruded into the levee prism by 2 feet or more. In general, a crown width similar to undamaged levee sections adjacent to the erosion site should be used. The waterside slope for levee prism projection should match the undamaged levee section adjacent to the erosion site.

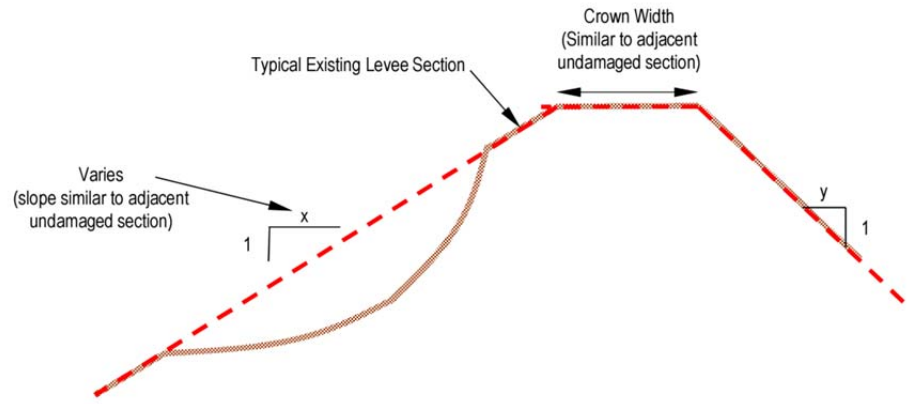

Figure 3-1. Levee Prism Projection for Evaluation of Erosion

Major Activities

Rock slope protection for erosion encroaching on the levee prism may include the following activities (see Template E-1):

- Placing rock in the launchable toe section up to the mean summer water elevation.

- Placing geotextile to prevent migration of soil into the submerged portion of the repair section. Geotextile should not be used as a drainage layer.
- Placing and compacting embankment material in the eroded portion to restore the levee slope to the slope of the adjacent undamaged levee or flatter.
- Placing a minimum 6-inch-thick bedding layer.
- Placing a minimum 18-inch-thick layer of rock. Rounded rock should not be used.

Implementation Guidance

The general implementation guidelines in Section 3.1 should be applicable to this repair template. Some specific guidelines for this template are described below:

- Riprap gradation based on anticipated erosive forces. Riprap should be capable of resisting anticipated erosive forces.
- If an erosion scarp creates an unstable slope condition, the existing slope may need to be evaluated to identify additional stabilization measures.
- If the repair encroaches more than 1 percent of the overall channel conveyance area, hydraulic analysis may be required.

3.2.2 Rock Slope Protection for Minor Erosion

In the rock slope protection for minor erosion repair alternative, located above mean summer water level, the pre-erosion slope is re-established by placing rock to provide armoring over a bedding layer.

Applicability

This repair alternative applies to erosion repair when erosion is considered minor, does not intrude into the applicable levee prism by more than 2 feet, when erosion is above the mean summer water level, and when erosion does not affect the levee's integrity. Use Figure 3-1Figure 3-1 should be used to determine whether existing erosion has intruded into the levee prism. As with rock slope protection for major erosion, a crown width similar to undamaged sections adjacent to the erosion site should be used. The waterside slope for levee prism projection should also be similar to the undamaged section adjacent to the erosion site.

If erosion is above water and it intrudes into the applicable levee prism, Section 3.2.1, and omit the launch rock feature.

Major Activities

Rock slope protection for minor erosion may include the following activities (see Template E-2):

- Establishing a riprap toe key-way.
- Placing a minimum 6-inch-thick bedding layer.
- Placing a minimum 18-inch-thick layer of riprap.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below.

- Riprap gradation based on anticipated erosive forces. Riprap should be capable of resisting anticipated erosive forces.
- If an erosion scarp creates an unstable slope conditions, the existing slope may need to be evaluated to identify additional stabilization measures.
- If the repair encroaches more than 1 percent of the overall channel conveyance area, hydraulic analysis may be required.

3.2.3 Widened Levee Repair for Erosion

In the widened levee repair for erosion repair alternative, the existing levee is widened on the landside to provide adequate levee prism geometry. The levee's width can be increased uniformly, or in a wedge shape that narrows at the levee crown.

Applicability

This repair alternative applies to erosion repair when the rate of erosion is slow and waterside repair is not preferred due to hydraulic, environmental, or other major constraints.

Major Activities

A widened levee repair for erosion may include the following activities (see Template E-3):

- Developing a widened levee prism section by projecting the existing waterside slope from the bottom of the erosion to the levee crown. Then, establishing appropriate crown width by constructing a new landside embankment.

  In general, a crown width similar to undamaged sections adjacent to the erosion site should be used. The waterside slope for levee prism

projection should also be similar to the undamaged section adjacent to the erosion site. Engineering judgment and economics should be used in establishing widened levee geometry.

- Preparing the existing slope surface and foundation key trench for embankment material placement. Excavation depth for the key trench should be a minimum of 3 feet, and may require deepening based on foundation conditions.
- Benching the stripped slope for better bonding with the new fill material.
- Placing an aggregate base (AB) surface on the levee slope to the thickness of the adjacent levee crown. The levee crown beneath the AB surfacing should be cambered to drain in both directions from the levee centerline to provide proper drainage (at a minimum of 2 percent).
- Widened levee embankment materials should have equal or greater permeability than the existing levee embankment materials. However, the materials should not be gap graded such that it would allow existing embankment materials to migrate into the widened levee. If the widened levee embankment soils have permeability less than the existing embankment permeability, a filter drain system including a chimney and blanket drain between the existing embankment and the new fill material will be required.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- Determine the requirements for widened levee materials, as the widened levee materials need to be equally or more permeable than the existing embankment materials to prevent seepage block conditions. Filter drain system, if needed, should be designed in accordance with the National Resources Conservation Service's (NRCS') *National Engineering Handbook* (Part 633 Chapter 26).
- Key trench materials should be compatible with surrounding materials to prevent seepage block or bathtub/ponding conditions.

3.3 Underseepage

Underseepage in pervious foundation layers beneath levees may result in (a) excessive hydrostatic pressures beneath an impervious top stratum on the landside foundation blanket, (b) sand boils, and (c) piping beneath the

levee, which may ultimately lead to levee failure. Underseepage conditions such as sand boils may remove foundation materials and may result in voids and unstable conditions in the levee foundation, which may lead to levee failure. Figure 3-2 illustrates aspects of underseepage mechanism in a levee due to foundation blanket condition.

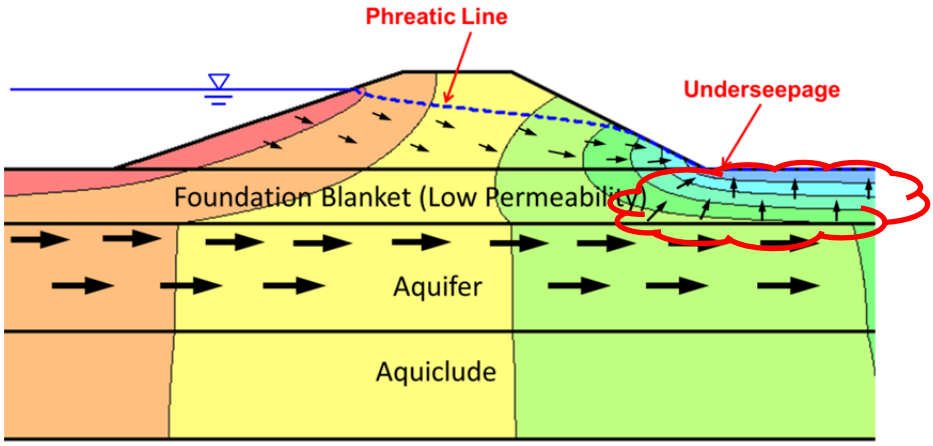

Figure 3-2. Underseepage Mechanism Due To Foundation Blanket Conditions

Three underseepage repair alternatives are discussed in this section: a drained seepage berm, an undrained seepage berm, and a landside ditch fill.

3.3.1 Drained Seepage Berm

A drained seepage berm consists of a wide landside berm constructed on a drainage system (chimney drain along the levee embankment and blanket drain over the ground surface). A drained seepage berm can reduce the underseepage hazard by providing (a) a controlled seepage path for the upward seepage through the drain layer, and (b) additional seepage path length to reduce uplift pressures at the toe of the berm to acceptable values. It also provides additional weight at the levee toe to increase safety against uplift pressure.

Applicability

This repair alternative mitigates foundation seepage, leading to a reduction in the formation of sand boils and piping, which develop due to the presence of a relatively thin foundation blanket layer. It may also prevent piping conditions at shallow layers in the absence of fine-grained blanket layers.

Major Activities

Constructing a drained seepage berm to address underseepage may include the following activities (see Template US-1):

- Placing a drainage system (chimney drain and blanket drain) that includes a minimum of a 12-inch filter layer and a 12-inch drain rock layer. A reduced thickness filter-layer may be justified based on engineering evaluations. A lower compaction effort should be used to avoid breaking and densifying the filter layer. A geotextile should be placed between the drain rock and berm soil to prevent movement of berm materials into the drain rock. Geotextile should not be used as a drainage layer.
- Placing soil to achieve a minimum total 5-foot height at the levee toe and a minimum of 3 feet at the berm toe. Given the presence of a drainage system and geotextile, the main role of the embankment berm is to provide weight. Consequently, there should be flexibility when selecting seepage berm materials based on borrow site availability.
- Extending the seepage berm to a minimum width of four times the levee's height. However, there may be instances where this width is not practical because of homes, infrastructure or other landside constraints. Engineering judgment, supported by analysis should be the basis for justifying a width narrower than four times the levee height. If a boil was observed at the repair site during past flood events, the seepage berm should extend 10 feet beyond the boil location. The seepage berm does not need to exceed 300 feet in width unless there are site-specific reasons for a larger berm. The width of the seepage berm may be reduced based on seepage analysis results.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- Material for the drainage system should be based on compatibility with foundation materials. Design the filter drain system in accordance with the NRCS' *National Engineering Handbook* (Part 633 Chapter 26).
- Identify surface and buried utilities and obstructions, and assess the effect of the seepage berm. If needed, these utilities may require relocation or upgrade.

3.3.2 Undrained Seepage Berm

An undrained seepage berm does not include any filter drain system like the one included in a drained seepage berm. An undrained seepage berm

can reduce underseepage hazard by providing (a) the additional weight needed to counteract upward seepage forces, and (b) the additional length required to reduce uplift pressures at the toe of the berm to tolerable values.

Applicability

This repair alternative mitigates seepage through the levee's foundation that may lead to sand boils and piping due to the presence of a relatively thin foundation blanket layer. It may also prevent piping conditions at shallow layers in the absence of fine-grained blanket layers.

Major Activities

Constructing an undrained seepage berm to address underseepage may include the following activities (see Template US-2):

- Selecting seepage berm materials considering their compatibility with the blanket and levee materials. Seepage berm materials should be of equal or greater permeability than the existing blanket and levee. The berm materials should also prevent movement of the underlying materials through the berm materials. Movement may occur if gap-graded, coarse-grained materials are used as berm material.
- Placing soil to achieve a minimum 5-foot height at the levee toe and a minimum of 3 feet at the berm toe. If a fine-grained seepage berm is constructed directly on top of a coarse-grained shallow foundation, the seepage berm may need to be wider and thicker. For coarse-grained levee embankments, a fine-grained seepage berm may create a seepage block condition, and should be avoided.
- Extending the seepage berm to a minimum width of four times the levee's height. However, there may be instances where this width is not practical because of homes, infrastructure or other landside constraints. Engineering judgment, supported by analysis should be the basis for justifying a width smaller than 4H. If a boil was observed at the repair site during past flood events, the seepage berm should extend 10 feet beyond the boil location. The seepage berm does not need to exceed 300 feet in width unless there are site specific reasons for a larger berm. The seepage berm width may be reduced based on seepage analysis.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- Seepage berm material gradation should be based on their compatibility with blanket and levee materials. NRCS' *National Engineering Handbook* (Part 633 Chapter 26) should be used to evaluate seepage berm materials.
- Identify surface and buried utilities and obstructions, and assess the effect of the seepage berm. If needed, these utilities may require relocation or upgrade.

3.3.3 Ditch or Depression Fill

Ditches or depressions adjacent to levees can be filled with suitable material to address underseepage. This repair alternative may require relocating an existing ditch or canal.

Applicability

This repair alternative applies to an underseepage repair when the existing landside or waterside ditch or depression thins, or removes the upper impermeable blanket. Filling the ditch or depression with suitable material may reduce underseepage potential. If underseepage potential is high even with a filled-in ditch or canal, other underseepage repair measures may be required.

Major Activities

Filling a ditch or depression may include the following activities (see Template US-3):

- Preparing the existing ditch or canal surface for fill material placement.
- Placing soil in lifts up to the adjacent ground surface. Compaction effort should be similar to those in the general guidelines in Section 3.1.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- Topographic and bathymetric (if needed) survey to identify the dimensions of the ditch or depression fill.
- Geotechnical evaluation indicating that the ditch or depression fill material would reduce underseepage potential. If high underseepage potential exists even after ditch or depression fill material, other underseepage repair measures may be required.

- Ditch or depression fill materials should be compatible with subsurface conditions such that they do not create a seepage block condition or create a condition for blanket material to pipe into the fill material. NRCS' *National Engineering Handbook* (Part 633 Chapter 26) should be used to evaluate ditch or depression fill materials.

3.4 Through Seepage

If a phreatic surface daylights on the landside levee slope, and if the embankment materials consist of low-plasticity erodible soils (such as sand and silt), it may indicate a potential for through seepage. Through seepage can soften a levee embankment, causing sloughing and erosion of the landside slope, erosion, and/or internal piping. Low plasticity erodible soils are more susceptible to internal piping than plastic soils (i.e. clays, clayey sands, clayey gravels, etc.). Figure 3-3 illustrates aspects of through seepage mechanism in a levee.

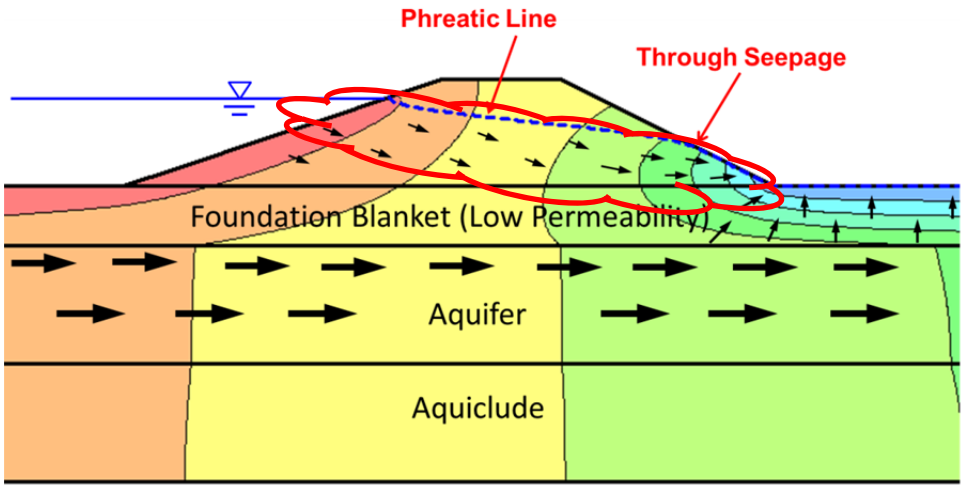

Figure 3-3. Through Seepage Mechanism in Low Plasticity (Erodible) Soils

Two through seepage repair alternatives are discussed in this section: a drained toe berm and an undrained toe berm.

3.4.1 Drained Toe Berms

A drained toe berm consists of a narrower berm placed on a chimney drain along the levee slope that is continued with a drainage blanket along the natural ground. A drained toe berm can reduce through seepage hazard by providing a controlled seepage path through the levee embankment that exits the levee face using a filter drain system. It can also prevent surficial sloughing and internal erosion due to through seepage.

Applicability

This repair alternative applies to levees constructed of low-plasticity erodible soils where the phreatic surface is exiting above the landside toe. Construction of a drained toe berm mitigates through seepage, which can lead to piping and sloughing of the levee slope.

Major Activities

Constructing a drained toe berm to address through seepage may include the following activities (see Template TS-1):

- Placing a drainage system (i.e., chimney and blanket drains) that includes a minimum of a 12-inch filter layer and a 12-inch drain rock layer. A reduced thickness filter-layer may be justified based on engineering evaluations. A lower compaction effort should be used to avoid breaking and densifying the filter layer. A geotextile should be placed between the drain rock and overburden soil to prevent movement of berm materials into the drain rock.
- Placing soil in lifts to achieve minimum height and width. The drained toe berm's height should be a minimum of 2 feet above the phreatic surface breakout (or to the assessment water surface elevation if the phreatic surface breakout is unknown) and should not be less than one-third the levee's height. Width of the drained toe berm should be a minimum of one equipment width, or 8 feet.
- Given the presence of a drainage system and geotextile, there should be flexibility when selecting seepage berm materials based on borrow site availability.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- Drainage system gradation should be based on compatibility with embankment materials. Filter drain system should be designed in accordance with the NRCS' *National Engineering Handbook* (Part 633 Chapter 26).
- Identify surface and buried utilities and obstructions and assess the effect of the drained toe berm. If needed, these utilities may require relocation or upgrade.

3.4.2 Undrained Toe Berm

An undrained toe berm does not include any filter drain system like the one included in a drained toe berm. An undrained seepage berm can reduce through seepage hazard by providing the (a) additional length required to reduce phreatic surface breakout and (b) preventing surficial sloughing due to through seepage.

Applicability

This repair alternative mitigates through seepage conditions created by the presence of low-plasticity (i.e., erodible) soils in the levee embankment.

Major Activities

Constructing an undrained toe berm for through seepage may include the following activities (see Template TS-2):

- Selecting toe berm materials considering their compatibility with blanket and levee materials. Toe berm materials should be of equal or greater permeability than the existing foundation blanket and levee. Berm materials should also prevent movement of underlying materials toward the undrained toe berm. This condition may develop due to use of gap-graded, coarse-grained materials.
- Placing and compacting soil in lifts to achieve minimum height and width. The drained toe berm height should be a minimum of 2 feet above the phreatic surface breakout and should not be less than one-third the levee's height. The height of the berm should be to the assessment water surface elevation if no seepage analysis is performed. The width of the undrained toe berm should be a minimum of two times berm height. As this berm does not include a drainage system, additional width may be required to reduce phreatic surface breakout based on berm materials.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- The berm should be constructed of material with equal or greater permeability than the levee material. Identify surface and buried utilities and obstructions and assess the effects of drained toe berm. If needed, these utilities may require relocation or upgrade.

3.5 Landside Slope Stability

Slope stability problems are associated with a reduction of shear strength, or an increase in shear stress, or both. This may occur in a levee's embankment or foundation due to pore water pressure, inadequate levee slope, or soil strength in the embankment and/or foundation. Unsatisfactory slope stability performance in levees can be observed in the forms of shear failure, surface sloughing, and excessive deformation. A shear failure involves a sliding portion of an embankment, or an embankment and its foundation, relative to the adjacent mass. Excessive deformations in slopes may be observed under certain soil conditions. Large cracks are often indicative of shear failure or excessive deformation. Surface sloughing is considered a maintenance problem, as it usually does not affect the levee's structural integrity. Underseepage- and through seepage-related slope stability problems caused by high water levels in the channel or river can be also addressed using the measures described in Sections 3.3 and 3.4. Figure 3-4 illustrates a slope circle on landside of a levee.

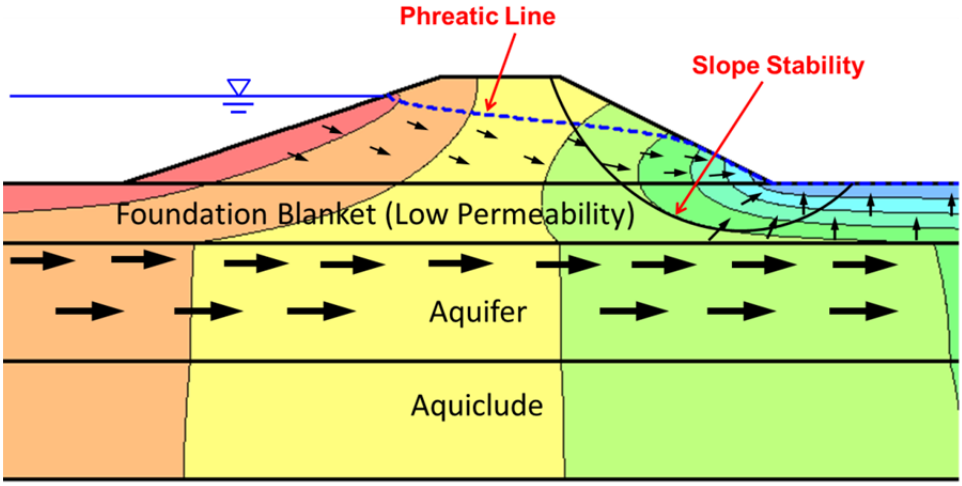

Figure 3-4. Slope Stability Mechanism in Levees Due To Seepage

Four slope stability repair alternatives are discussed in this section: a drained stability berm, an undrained stability berm, a partial levee repair, and slope flattening.

3.5.1 Drained Stability Berm

A drained stability berm consists of soil berm constructed on a drainage system (chimney and blanket drain). A drained stability berm can reduce a slope stability hazard by (a) increasing the factor of safety against shear failure through increasing resistance force, (b) increasing the resistance to sliding of the levee slope by adding mass at the levee toe, and (c) reducing pore water pressure in the levee embankment by lowering the phreatic surface breakout.

Applicability

This repair alternative applies to the repair of slope stability problems due to seepage through the levee embankment and foundation. It also applies to repairing slope stability problems due to steep slopes or high pore water pressures in the levee's embankment or foundations.

Major Activities

Constructing a drained stability berm to address seepage-related slope stability concerns may include the following activities (see Template SS-1):

- Placing a drainage system (chimney and blanket drains) that includes a minimum of a 12-inch filter layer and a 12-inch drain rock layer. A reduced thickness filter-layer may be justified based on engineering evaluations. A lower compaction effort should be used to avoid breaking and densifying the filter layer. A geotextile should be placed between the drain rock and overburden soil to prevent movement of berm materials into the drain rock. Geotextile should not be used as a drainage layer.
- Placing and compacting soil in lifts to achieve minimum height and width. The top of the drained stability berm should match the design or assessment water surface elevation. The width of the drained stability berm should be a minimum of one equipment width, or 8 feet. The slope of the stability berm should be a minimum of the original slope or flatter.
- Given the presence of a drainage system and a geotextile, there should be flexibility when selecting seepage berm materials based on borrow site availability.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- The foundation and embankment should be evaluated for suitability to support additional loads.
- Drainage system gradation should be based on compatibility with embankment and foundation blanket materials. Drainage system should be designed in accordance with the NRCS' *National Engineering Handbook* (Part 633 Chapter 26).
- Slope stability evaluations to develop the width and slope of the drained stability berm.
- Identify surface and buried utilities and obstructions and assess the effect of a drained stability berm. If needed, these utilities may require relocation or upgrade.

3.5.2 Undrained Stability Berm

An undrained stability berm does not include any filter drain system like the one included for a drained stability berm. An undrained stability berm can reduce slope stability hazard by (a) increasing the factor of safety against shear failure through increasing resistance force, (b) increasing the resistance to sliding of the levee slope by adding mass at the levee toe, and (c) providing an extended path to reduce phreatic surface.

Applicability

This repair alternative mitigates slope stability problems resulting from the presence of low-strength soils on a weak foundation. It also applies to repairing slope stability problems due to steep slopes or high pore water pressures in the embankment or foundation.

Major Activities

Constructing an undrained stability berm to address slope stability may include the following activities (see Template SS-2):

- Selecting toe berm materials considering their compatibility with blanket and levee materials. Toe berm materials should be of equal or greater permeability than the existing levee embankment and foundation blanket materials. The berm materials should also prevent movement of underlying materials toward the undrained stability berm. This condition may develop due to use of gap-graded, coarse-grained materials.

- Placing and compacting soil in lifts to achieve minimum height and width. The top of the undrained stability berm should match the design or assessment water surface elevation. The undrained stability berm's width should be a minimum of one equipment width, or 8 feet. The stability berm's slope should be a minimum of the original slope or flatter.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- The berm should be constructed of material with equal or greater permeability than the levee material. Undrained stability berm material based on compatibility with foundation blanket and levee embankment materials. NRCS' *National Engineering Handbook* (Part 633 Chapter 26) should be used to evaluate the undrained berm materials.
- Identify surface and buried utilities and obstructions and assess the effects of drained toe berm. If needed, these utilities may require relocation or upgrade.

3.5.3 Partial Levee Replacement

A partial levee replacement includes excavating levee and foundation (as applicable) and rebuilding. This repair alternative can reduce slope deficiencies by (a) removing unsuitable materials and (b) rebuilding levee with adequate factor safety against slope stability failure.

Applicability

This repair alternative applies primarily to past slope stability failures. However, it can also be used to improve slope stability conditions.

Major Activities

Constructing a partial levee replacement to address slope stability may include the following activities (see Template SS-3 and SS-4):

- Removing slide debris and excavating the existing levee embankment and foundation (as needed).
- Preparing the subgrade and the remaining slope face for embankment construction.
- Selecting levee replacement materials considering their compatibility with the blanket and existing levee materials. If the existing levee and foundation materials are fine-grained soils, the partial levee materials should be acceptable levee embankment material that is coarser than

the existing levee material to assure proper drainage. If the existing levee and foundation materials are coarse-grained soils, the partial levee materials should be of equal or greater permeability than the existing levee. However, fine-grained materials can be used against a coarse-grained levee if a drainage system is used or a wider levee is constructed.

- Re-establishment of the levee slopes to be flatter or match the pre-failure slope angle, as supported by slope stability analysis. The required slope may be flatter based on the embankment materials in the replacement levee and existing levee and foundation materials.
- Placing and compacting soil in lifts to achieve required height and width. The replacement levee height and width should be selected based on evaluation of the failure shape and should encompass the entire failure plane. It should extend beyond the failure shape and may extend beyond the soil layers contributing to the slope stability problems.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- The foundation and embankment should be evaluated to assess the causes for slope failure and to identify the extents of the partial levee replacement. The subsurface data should also be evaluated to assess the suitability of the existing levee and foundation to support the compacted replacement levee, which may be heavier than the failed portion of the levee.
- Replacement levee material based on compatibility with levee and foundation materials. NRCS' National Engineering Handbook (Part 633 Chapter 26) should be used to evaluate the undrained berm materials.
- Identify surface and buried utilities and obstructions and assess the effects of drained toe berm. If needed, these utilities may require relocation or upgrade.

3.5.4 Slope Flattening

Slope flattening entails enhancing a levee's landside stability by flattening its landside slope. This repair alternative can reduce the risk of slope stability deficiencies by increasing the factor safety against slope stability failure.

Applicability

This repair alternative applies primarily to levees with past slope stability failures or to levees with over-steepened landside slopes. This repair can be used to improve slope stability.

Major Activities

Constructing slope flattening to address slope stability may include the following activities (see Template SS-5):

- Develop a flattened landside slope levee prism section based on engineering analyses. In general, a minimum crown width equal to undamaged sections adjacent to the erosion site should be used. Engineering judgment should be used when establishing levee geometry.
- Preparing the existing slope surface and foundation key trench for embankment material placement. Excavation depth for key trench should be a minimum of 3 feet and may require deepening based on foundation conditions.
- Benching the stripped slope for better bonding with the new fill material and improved constructability.
- Placing an AB surface on the levee slope to the thickness of the adjacent levee crown. The levee crown beneath the AB surfacing should be cambered to drain in both directions from the levee's centerline to provide proper drainage (at a minimum of 2 percent).
- Levee embankment materials should have an equal or greater permeability than the existing levee embankment materials. However, the materials should not be gap-graded such that it would allow existing embankment materials migrate into the widened levee. If levee embankment soils have a permeability that is less than the existing embankment's permeability, a filter drain system including a chimney and blanket drain will be required between the existing embankment and the new material.

Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- Determine the requirements for new levee materials, as the levee materials need to be equal to or more permeable than existing embankment to prevent seepage blocking conditions. A filter drain system, if needed, should be designed in accordance with the NRCS' *National Engineering Handbook* (Part 633 Chapter 26).

- Key trench materials should be compatible with surrounding materials to prevent seepage blocking or bathtub/ponding conditions.

3.6 Underseepage and Through Seepage/Slope Stability

If a site has both underseepage and through seepage or underseepage and slope stability hazards, a combined drained berm or a combined undrained berm can be used. See Template COM-1 for a typical combined drained berm and Template COM-2 for a combined undrained berm. Design of the berm's width should be based on the same principles as those used to design drained or undrained seepage berms. Design of the berm's height should be based on the same principles as those used to design drained or undrained toe berms (for through seepage) and drained and undrained stability berms (for slope stability). Major activities and requirements should be a combination of items from Sections 3.3.1, 0, and 3.5.1 for a combination drained berm. For an undrained combination berm, major activities and requirements are a combination of items from Sections 3.3.2, 3.4.2, and 3.5.2.

3.7 Crown Depression

A crown depression may occur due to settlement or removal of levee embankment or foundation materials.

3.7.1 Applicability

This repair applies to repair crown depressions that can be repaired without significant modification to the existing levee geometry.

3.7.2 Major Activities

Constructing a crown depression repair may include the following activities (see Template CD-1):

- Removing the existing AB surface and stripping the top layer (minimum 6 inches).
- Backfilling levee materials with maximum 8-inch lifts (loose) to match the upstream and downstream crown elevation.
- Placing a minimum 4-inch-thick AB surface.

3.7.3 Implementation Guidance

The general implementation guidelines in Section 3.1 should apply to this repair template. Some specific guidelines for this template are described below:

- Topographic information to identify the extent of the crown depression both in the transverse and longitudinal directions.
- Selecting levee materials based on depression depth and existing levee materials. If the depression repair extends below design water surface elevation, embankment material should prevent through seepage. The levee material should match the material in the existing levee and should be compacted similar with the material in the existing levee.

4.0 Definitions

Berm material means soil used to construct seepage berm, stability berm, or toe berm. The material types of berm are variable and are specific to the purpose of the berm and compatibility with the embankment and foundation soils.

Central Valley Flood Protection Plan means the 2012 Central Valley Flood Protection Plan, and its subsequent updates, prepared by the Department of Water Resources per requirements the Central Valley Flood Protection Act of 2008. The Central Valley Flood Protection Plan describes the state's vision for a sustainable flood management system in the Central Valley, focusing on the areas protected by the State Plan of Flood Control facilities. The Central Valley Flood Protection Board adopted the 2012 Central Valley Flood Protection Plan in July 2013.

Facilities of the State Plan of Flood Control means the levees, weirs, channels, and other features of the federal- and state-authorized flood control facilities located in the Sacramento and San Joaquin river drainage basin for which the Central Valley Flood Protection Board or the California Department of Water Resources has given the assurances of nonfederal cooperation to the United States required for the project, and those facilities identified in Section 8361 of the California Water Code (Public Resources Code Section 5096.805(e)).

Flood risk is the likelihood and consequence of inundation. The consequence may be direct or indirect economic cost, loss of life, environmental impact, or other specified measure of flood effect. Flood risk is a function of:

- Loading, which is the frequency and magnitude of flood discharge or stage
- Limits to exposure to the loading due to flood defense measures
- Consequence

Therefore, flood management actions may reduce risk by changing loading, exposure, or consequence. For clarity, flood risk is commonly quantified within an identified area for a specified climate condition, land-use condition, and with a flood management system (existing or planned) in place.

Foundation blanket layer means a top stratum of fine-grained soils (clayey and/or silty soil) extending landward of the landside levee toe that has low vertical permeability in comparison to the horizontal permeability of the underlying coarser-grained soils.

Geotextile means a permeable fabric, when used in association with soil, have the ability to separate a finer-grained soil layer from a coarser-grained soil or rock. Geotextile cannot be used as a drainage system in levees. However, these can be used as a separator to prevent movement of upper finer-grained soil layers to lower coarser-grained soil layers, which may have more void spaces.

Key-in means an over-excavated and re-compacted portion of the widened levee, toe berm, undrained stability berm, or slope flattening to provide an improved foundation for material placement. The materials for key-in portion should be selected such that it does not create a bathtub or seepage block condition.

Levee means a man-made barrier constructed of soil along a watercourse for the primary purpose of providing flood protection.

Levee system means one or more discrete reaches of levee and/or floodwall and other flood management structures along one or more streams that together provide flood protection to a common, defined area (i.e., the protected area). The level of protection is variable and specific to the levee system.

Levee toe means the most landward point of the levee where the landside levee slope meets natural ground (see Figure 4-1).

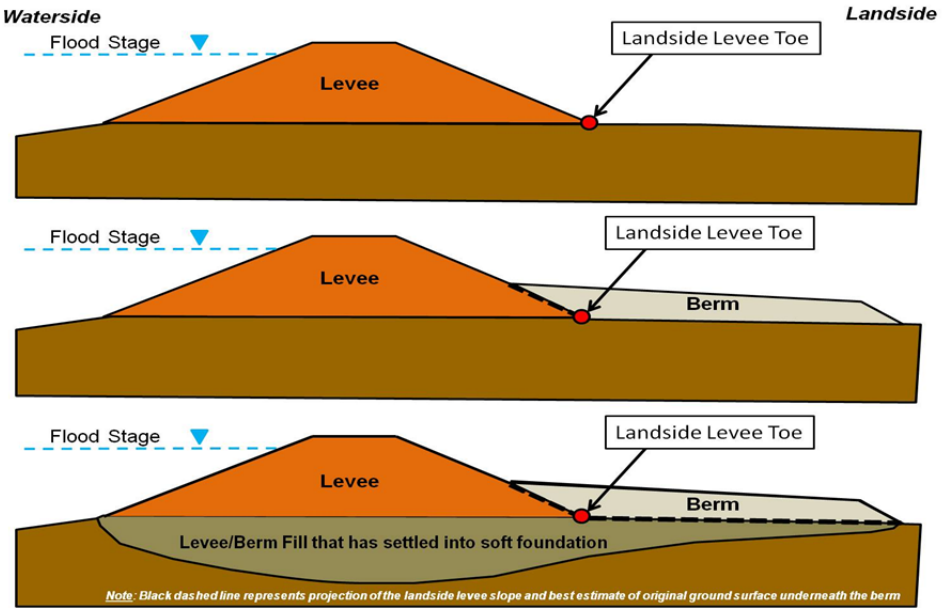

Figure 4-1. Levee Toe Schematic for Three Cases: Levee without Berm, Levee with Berm, and Levee with Berm on Soft Foundation

Phreatic surface breakout indicates the location where a phreatic surface of the levee or saturation front breaks out on the landside of the levee. The zones below the phreatic surface are saturated or contain pore water pressure.

Rural Levee Repair Guidelines means guidance developed for repair of documented rural levee performance problems.

Section 408 Permit means approval by the United States Army Corps of Engineers for alterations/modifications to a United States Army Corps of Engineers flood damage reduction project as described in United States Code Title 33, Section 408. There are two types of Section 408 permits: a major Section 408 permit and minor Section 408 permit.

5.0 Contributing Authors and Work Group Members

DWR developed the *Rural Levee Repair Guidelines* to establish guidelines for local maintaining agencies and their repair needs, taking into consideration input from work group members, interested parties, and the general public.

5.1 Coordination and Technical Support Team

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5.2 Rural Levee Repair Guidelines Work Group

The *Rural Levee Repair Guidelines* were developed to establish a set of guidelines to assist local maintaining agencies with their repair needs. The Rural Levee Repair Guidelines Work Group was established to collaboratively develop the guidelines, representing the interests of local maintaining agencies, DWR, USACE, the Board and interested parties. The work group would like to recognize the contribution of voluntary efforts provided by the following members.

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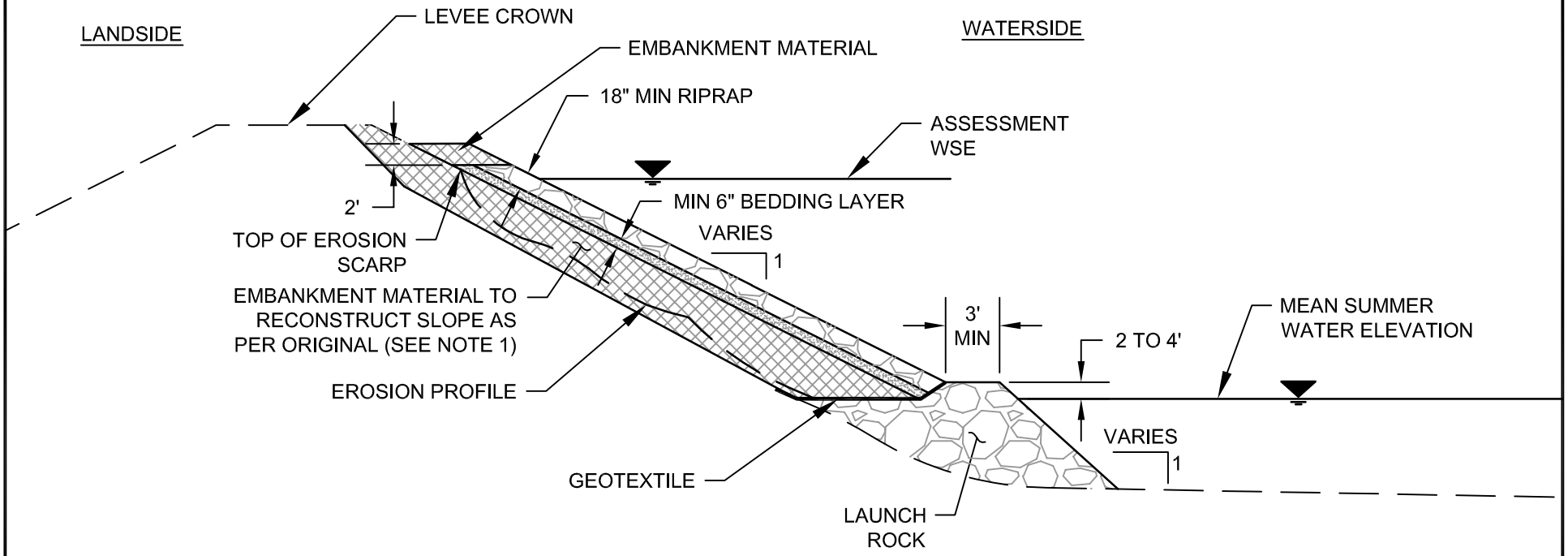
Distress Mechanism	Repair Options	Narrative Section	Template
Erosion	Typical Rock Slope Protection Repair for Major Erosion	3.1.1	E-1
	Typical Rock Slope Protection Repair For Minor Erosion	3.1.2	E-2
	Typical Widened Levee Repair For Erosion	3.1.3	E-3
Underseepage	Typical Drained Seepage Berm Repair For Underseepage	3.2.1	US-1
	Typical Undrained Seepage Berm Repair For Underseepage	3.2.2	US-2
	Typical Ditch Fill For Underseepage	3.2.3	US-3
Through Seepage	Typical Drained Toe Berm Repair For Through Seepage	3.3.1	TS-1
	Typical Toe Berm Repair For Through Seepage	3.3.2	TS-2
Slope Stability	Typical Drained Stability Berm Repair For Slope Stability	3.4.1	SS-1
	Typical Undrained Stability Berm Repair For Slope Stability	3.4.2	SS-2
	Typical Partial Levee Replacement Repair For Slope Stability (Embankment)	3.4.3	SS-3
	Typical Partial Levee Replacement Repair for Slope Stability (Embankment and Foundation)	3.4.3	SS-4
	Typical Landside Slope Flattening Repair For Slope Stability	3.4.4	SS-5
Combined Underseepage/Through Seepage/Slope Stability	Typical Combination Drained Berm Repair For Seepage-Stability	3.5	COM1
	Typical Combination Undrained Berm Repair For Seepage-Stability	3.5	COM2
Crown Depression	Typical Repair For Crown Depression	3.6	CD-1

NOT TO SCALE

** SEE SECTION 3.1.1 FOR GUIDANCE.



NOTE:

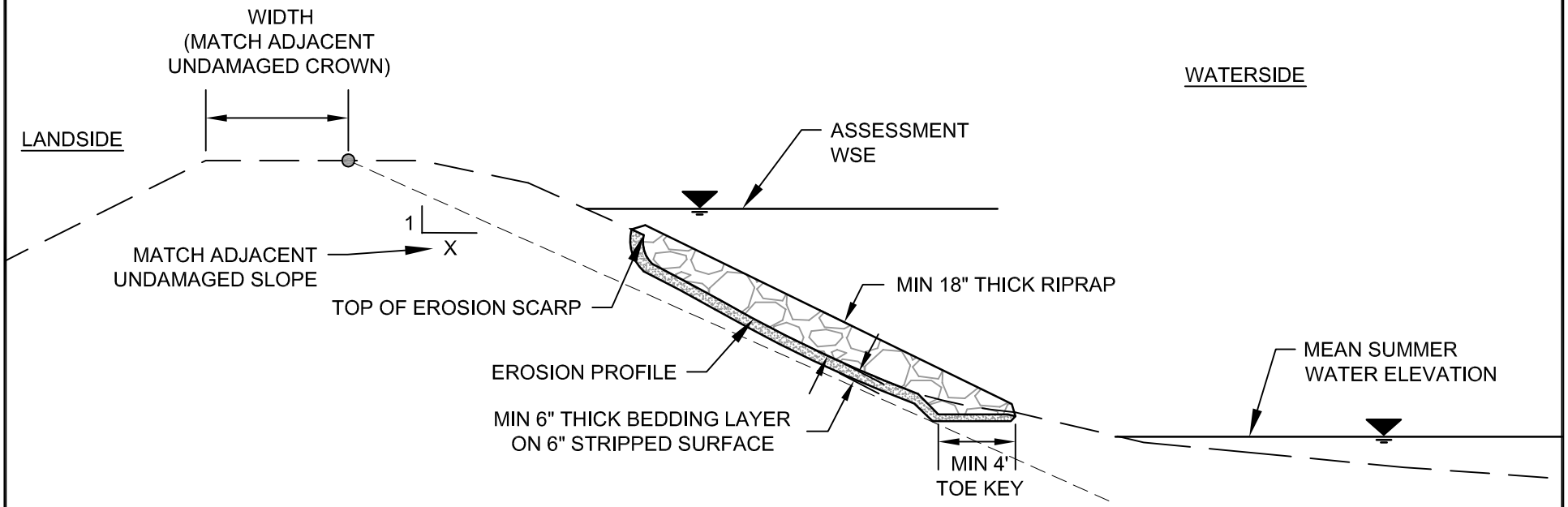
1. FOR FINE-GRAINED CLAYEY/CLAY EMBANKMENT A BENCH MAY BE REQUIRED TO PROVIDE BONDING BETWEEN NEW MATERIAL AND EMBANKMENT SOIL.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL ROCK SLOPE PROTECTION REPAIR FOR MAJOR EROSION	TEMPLATE E-1

PLOT BY: BRIAN_BOEN - Nov 19, 2013 - 7:16:14pm
DRAWING: \\SACDATA01\Projects6\DWR-8101-FSRP\WorkZone\TO U112 - Feasibility Studies\Rural Levee Repair Guidelines\First Draft\Drawing TemplaTemplate.dwg

** SEE SECTION 3.1.2 FOR GUIDANCE.



NOTE:

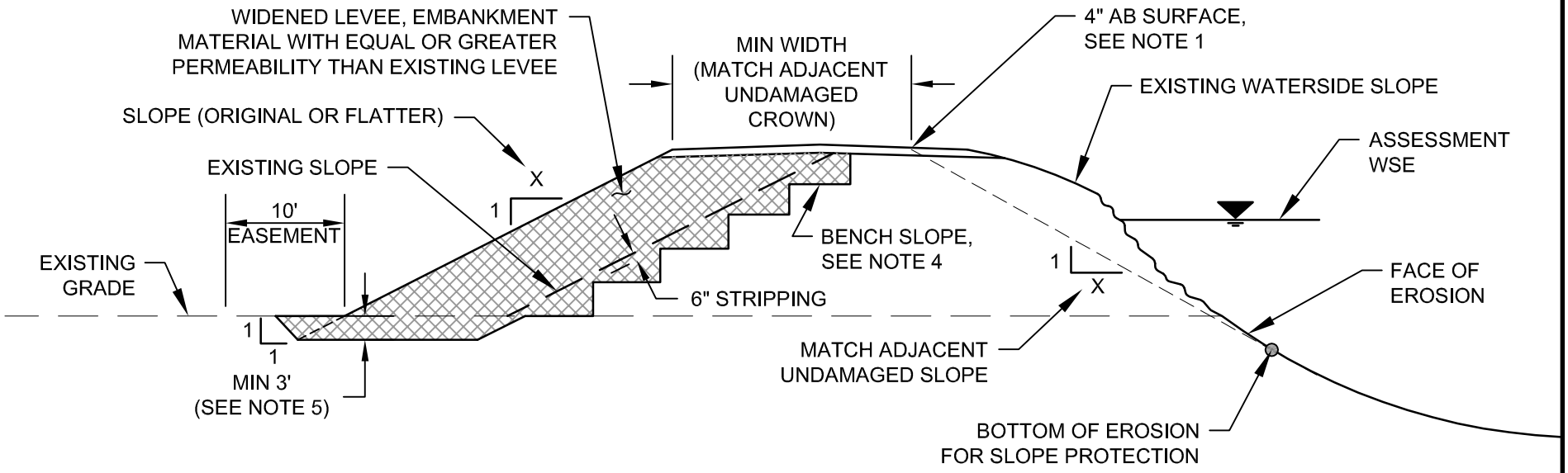
1. IF EROSION CUTS MORE THAN 24 INCHES INTO THE LEVEE PRISM, TEMPLATE E-1 TYPICAL ROCK SLOPE PROTECTION REPAIR FOR MAJOR EROSION, SHOULD BE USED.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL ROCK SLOPE PROTECTION REPAIR FOR MINOR EROSION	TEMPLATE E-2

PLOT BY: BRIAN_BOEN - Nov 19, 2013 - 7:16:18pm
DRAWING: \\SACDATA01\Projects6\DWR-8101-FSRP\WorkZone\TO U112 - Feasibility Studies\Rural Levee Repair Guidelines\First Draft\Drawing TemplaTemplate.dwg

** SEE SECTION 3.1.3 FOR GUIDANCE.



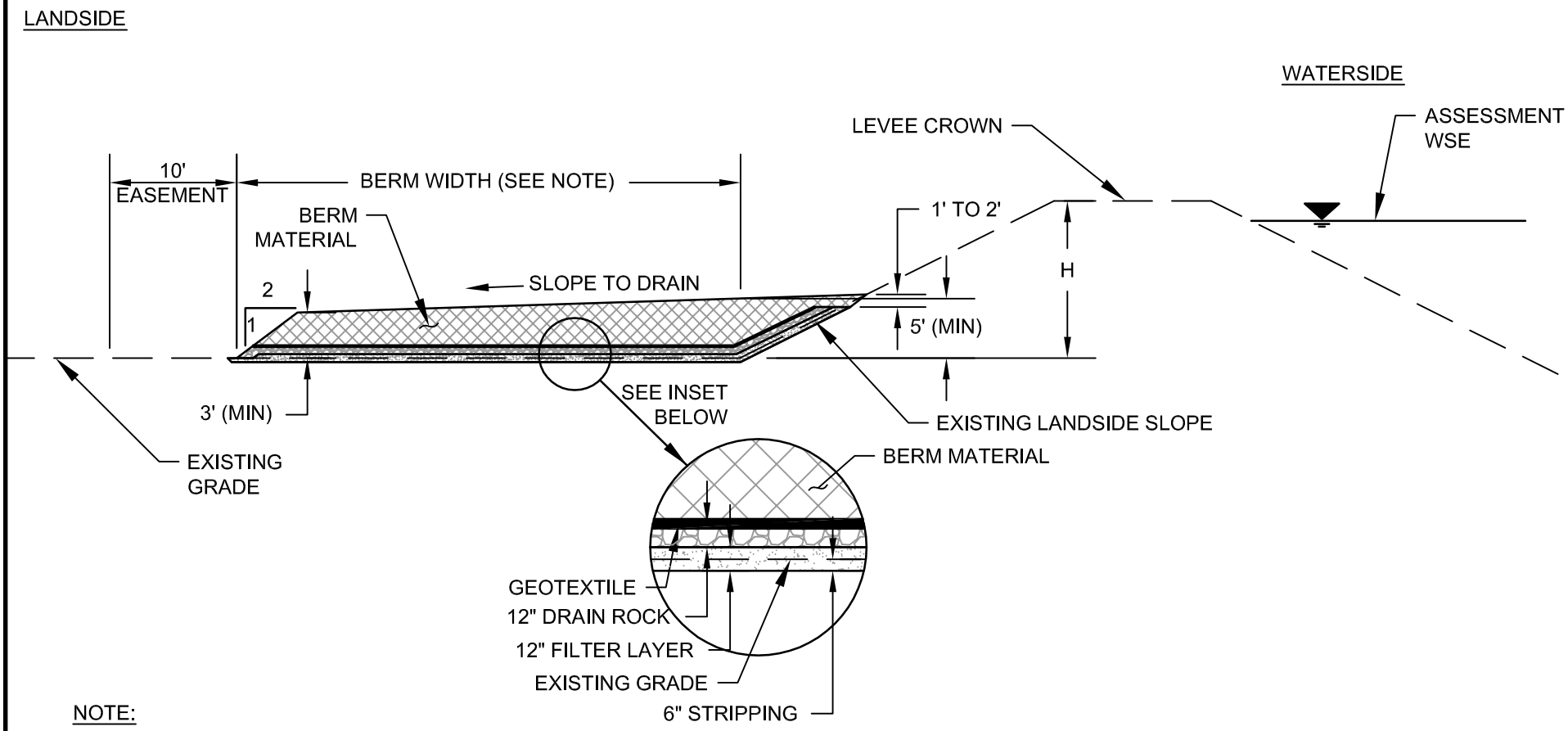
NOTE:

1. CROWN SLOPED MIN 2% FOR DRAINAGE.
2. EMBANKMENT AND FOUNDATION CONDITIONS SHOULD BE EVALUATED FOR SUPPORTING WIDENED LEVEE.
3. IF WIDENED LEVEE PERMEABILITY IS LESS THAN EMBANKMENT PERMEABILITY, A FILTER DRAIN SYSTEM IS REQUIRED ON SUBGRADE AND LEVEE LANDSIDE SLOPE.
4. BENCH MAY BE REQUIRED TO ACHIEVE MINIMUM WIDTH FOR COMPACTION.
5. KEY-IN MATERIAL SHOULD BE SIMILAR TYPE AS FOUNDATION BLANKET AND SHOULD NOT CREATE A BATHTUB OR SEEPAGE BLOCK CONDITION.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL WIDENED LEVEE REPAIR FOR EROSION	TEMPLATE E-3

** SEE SECTION 3.2.1 FOR GUIDANCE.



NOTE:

1. SEEPAGE BERM WIDTH SHOULD BE MIN OF 4H; OR IF BOIL WAS OBSERVED AT THE REPAIR SITE, THE SEEPAGE BERM SHOULD EXTEND 10 FEET BEYOND THE BOIL LOCATION, UP TO A MAXIMUM OF 300 FEET

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL DRAINED SEEPAGE BERM REPAIR FOR UNDERSEEPAGE	TEMPLATE US-1

PLOT BY: BRIAN_BOEN - Nov 19, 2013 - 7:16:29pm
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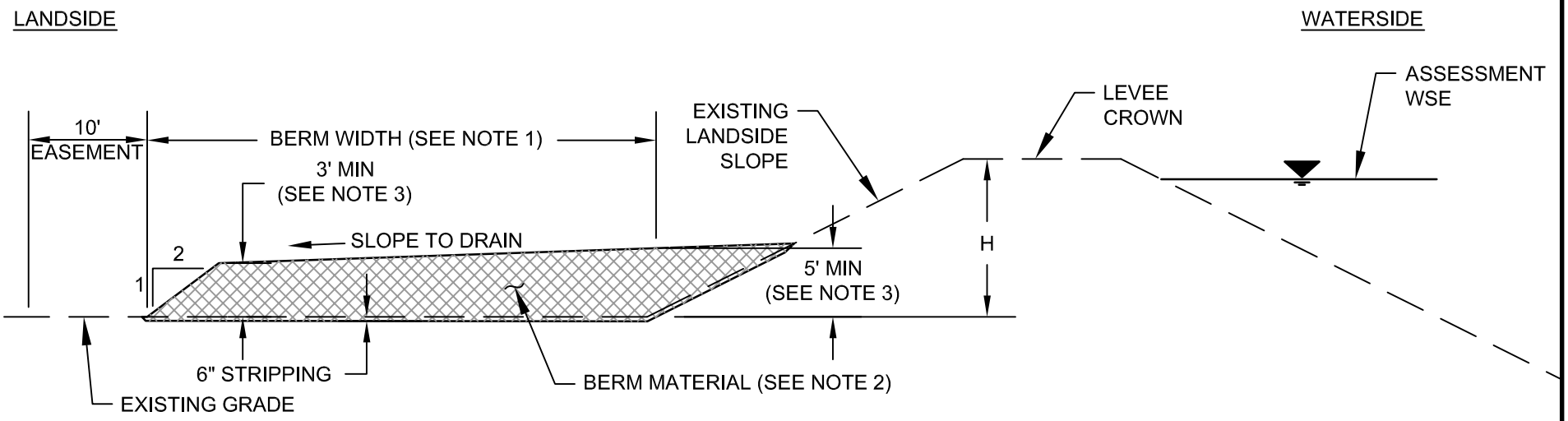
** SEE SECTION 3.2.2 FOR GUIDANCE.



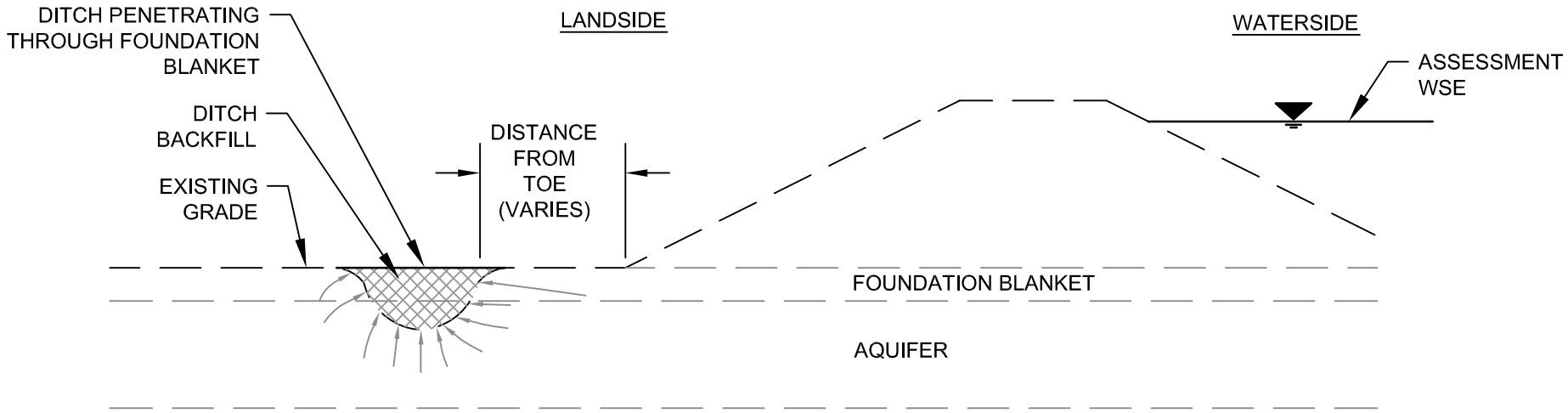
NOTE:

1. SEEPAGE BERM WIDTH SHOULD BE MIN OF 4H; OR IF BOIL WAS OBSERVED AT THE REPAIR SITE, THE SEEPAGE BERM SHOULD EXTEND 10 FEET BEYOND THE BOIL LOCATION, UP TO A MAXIMUM OF 300 FEET.
2. FOR COARSE-GRAINED LEVEE EMBANKMENT, BERM MATERIAL SHOULD BE EQUAL OR HIGHER PERMEABILITY THAN EMBANKMENT AND FOUNDATION BLANKET. HOWEVER, GAP GRADED MATERIALS THAT MAY ALLOW MATERIAL MIGRATION SHOULD NOT BE USED.
3. IF SEEPAGE BERM PERMEABILITY IS LESS THAN FOUNDATION BLANKET LAYER AND PRESENCE OF COARSE-GRAINED SOIL AT SURFACE IS LIKELY, SEEPAGE BERM MAY NEED TO BE THICKER AND WIDER.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL UNDRAINED SEEPAGE BERM REPAIR FOR UNDERSEEPAGE	TEMPLATE US-2

** SEE SECTION 3.2.3 FOR GUIDANCE.



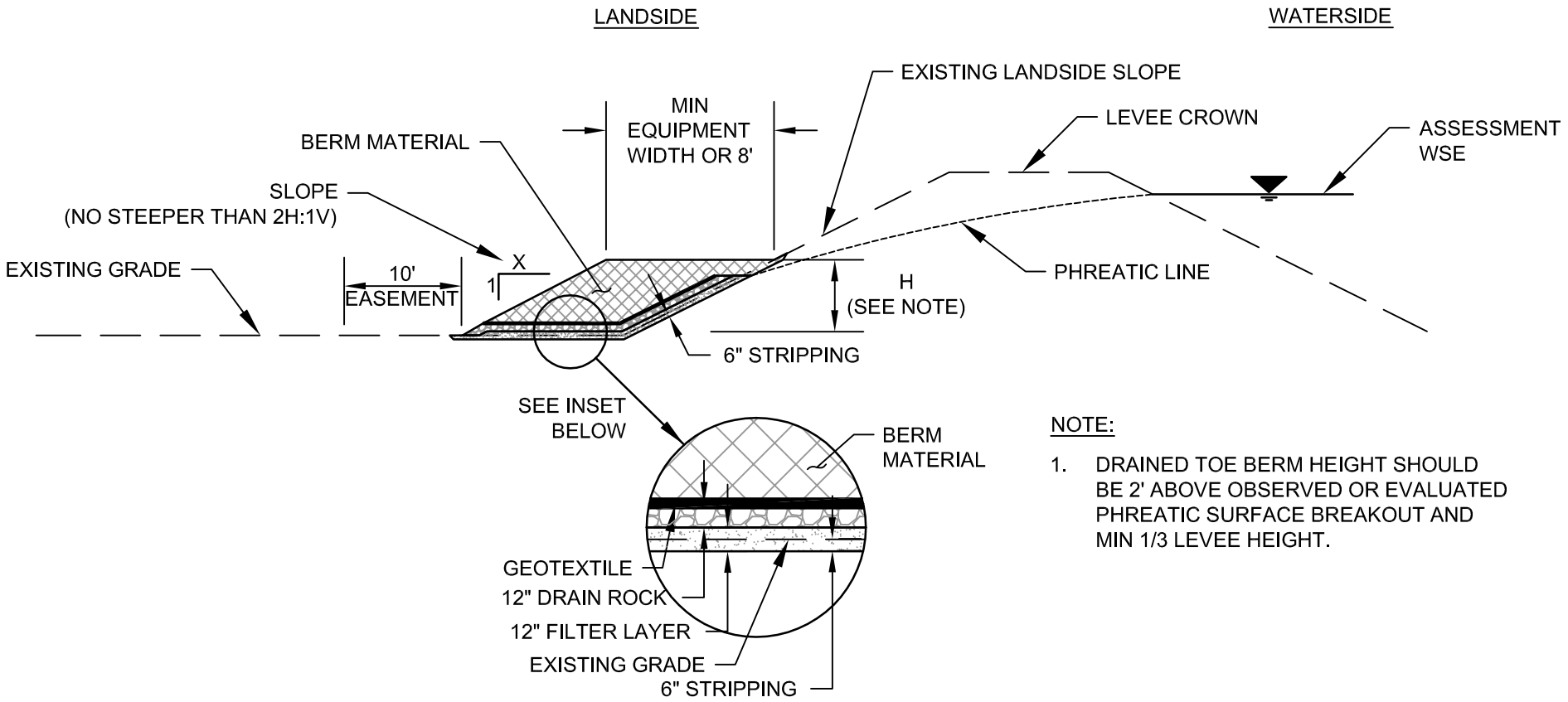
NOTE:

1. DITCH REDUCING FOUNDATION BLANKET THICKNESS MAY ALSO CREATE UNDERSEEPAGE DISTRESS AND THIS ALTERNATIVE CAN BE APPLIED FOR BLANKET THINNING CONDITIONS.
2. THE EXISTING DITCH/CANAL MAY REQUIRE RELOCATION OR CONVEYANCE BY OTHER MEANS (SUCH AS PIPES, ETC.).

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL DITCH FILL FOR UNDERSEEPAGE	TEMPLATE US-3

** SEE SECTION 3.3.1 FOR GUIDANCE.



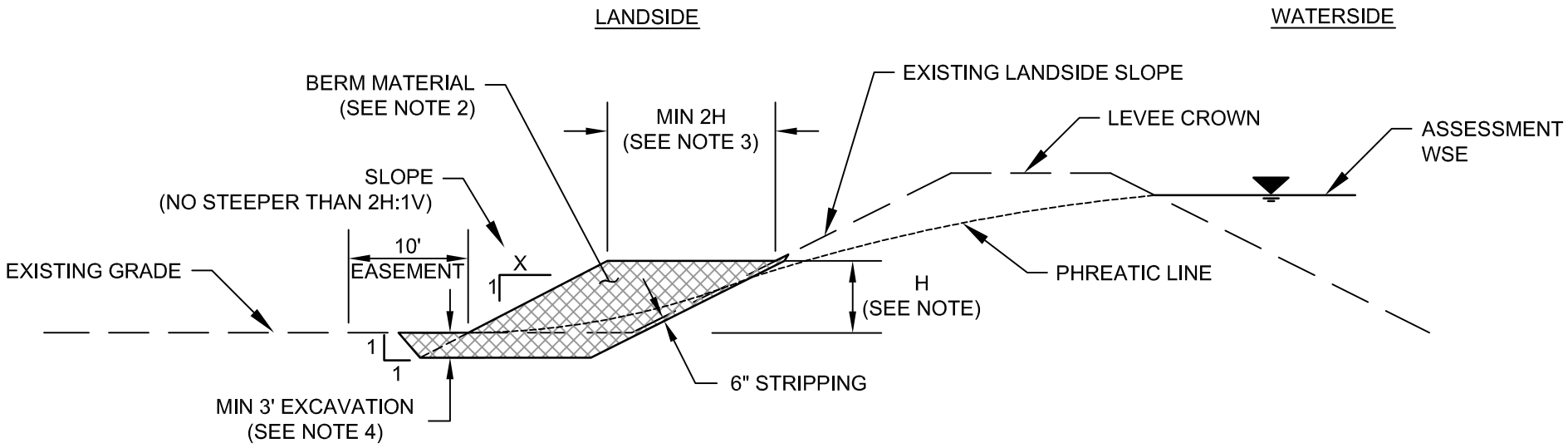
NOTE:

1. DRAINED TOE BERM HEIGHT SHOULD BE 2' ABOVE OBSERVED OR EVALUATED PHREATIC SURFACE BREAKOUT AND MIN 1/3 LEVEE HEIGHT.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL DRAINED TOE BERM REPAIR FOR THROUGH SEEPAGE	TEMPLATE TS-1

** SEE SECTION 3.3.2 FOR GUIDANCE.



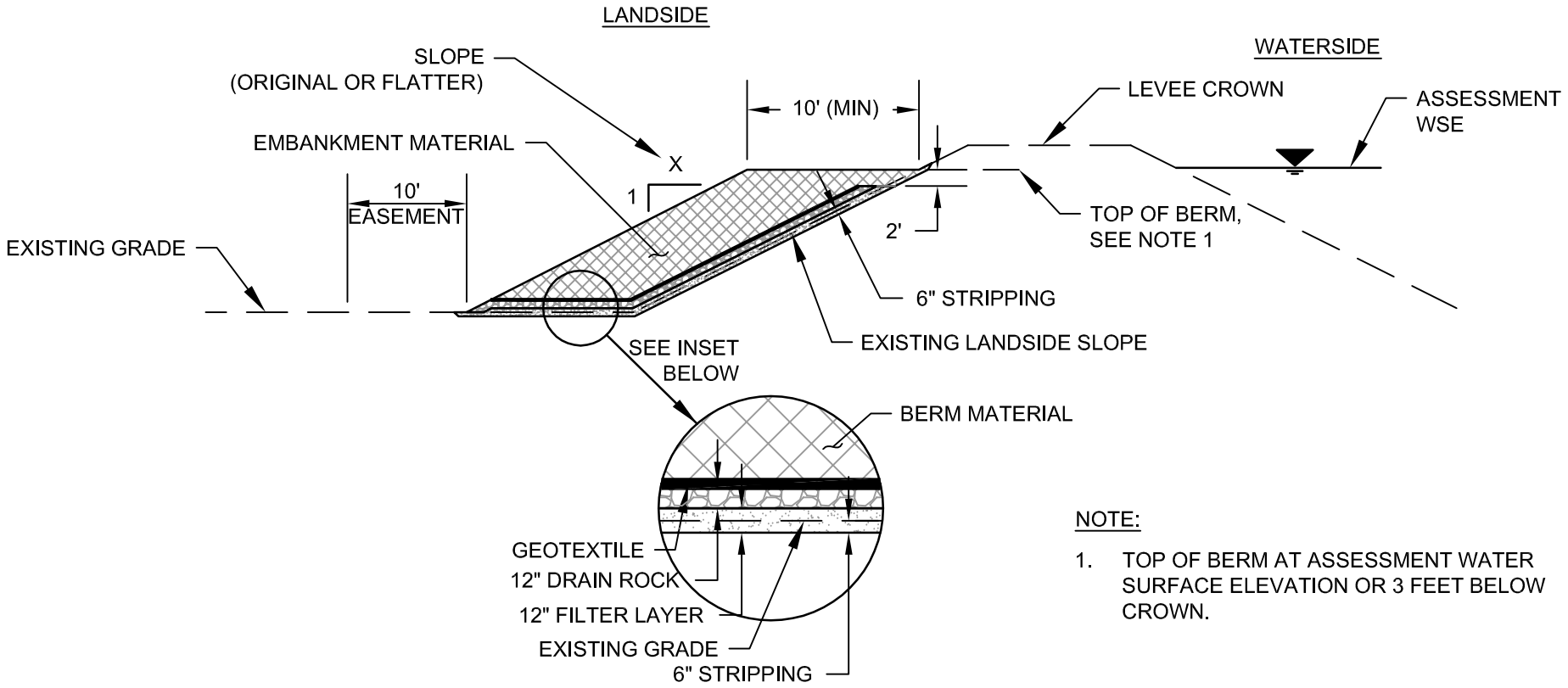
NOTE:

1. UNDRAINED TOE BERM HEIGHT SHOULD BE 2' ABOVE OBSERVED OR EVALUATED PHREATIC SURFACE BREAKOUT AND MIN 1/3 LEVEE HEIGHT.
2. BERM MATERIAL SHOULD BE EQUAL OR HIGHER PERMEABILITY THAN EMBANKMENT. HOWEVER, GAP GRADED MATERIALS THAT MAY ALLOW MATERIAL MIGRATION SHOULD NOT BE USED.
3. WIDTH SHOULD BE ADJUSTED SUCH THAT PHREATIC SURFACE DOES NOT DAYLIGHT ABOVE BERM TOE.
4. KEY-IN MATERIAL SHOULD BE SIMILAR TYPE AS FOUNDATION BLANKET AND SHOULD NOT CREATE A BATHTUB OR SEEPAGE BLOCK CONDITION.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL TOE BERM REPAIR FOR THROUGH SEEPAGE	TEMPLATE TS-2

** SEE SECTION 3.4.1 FOR GUIDANCE.



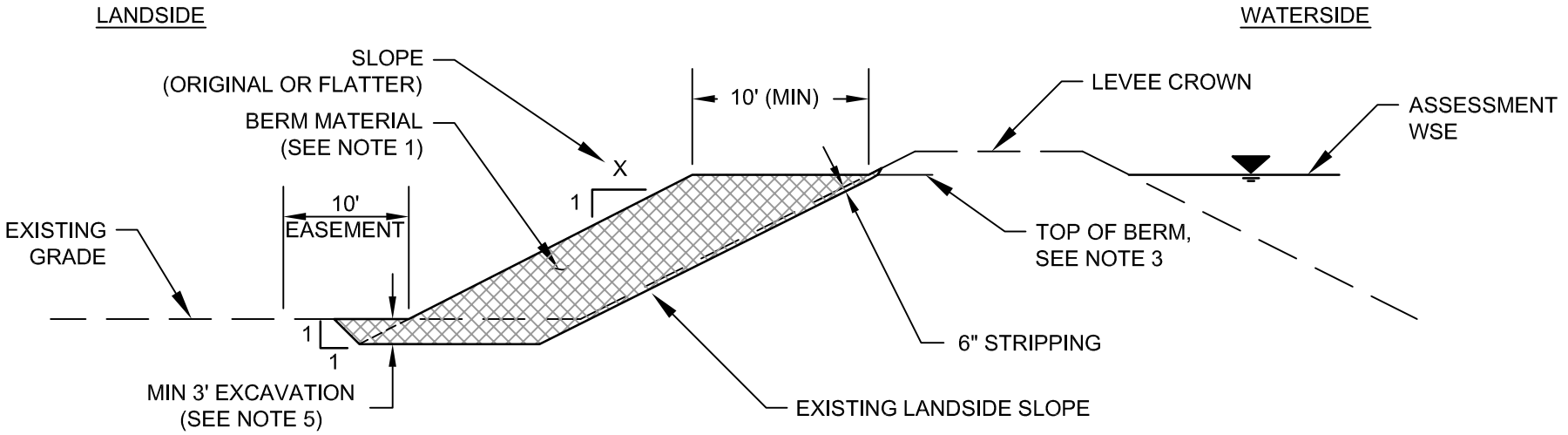
NOTE:

1. TOP OF BERM AT ASSESSMENT WATER SURFACE ELEVATION OR 3 FEET BELOW CROWN.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL DRAINED STABILITY BERM REPAIR FOR SLOPE STABILITY	TEMPLATE SS-1

** SEE SECTION 3.4.2 FOR GUIDANCE.



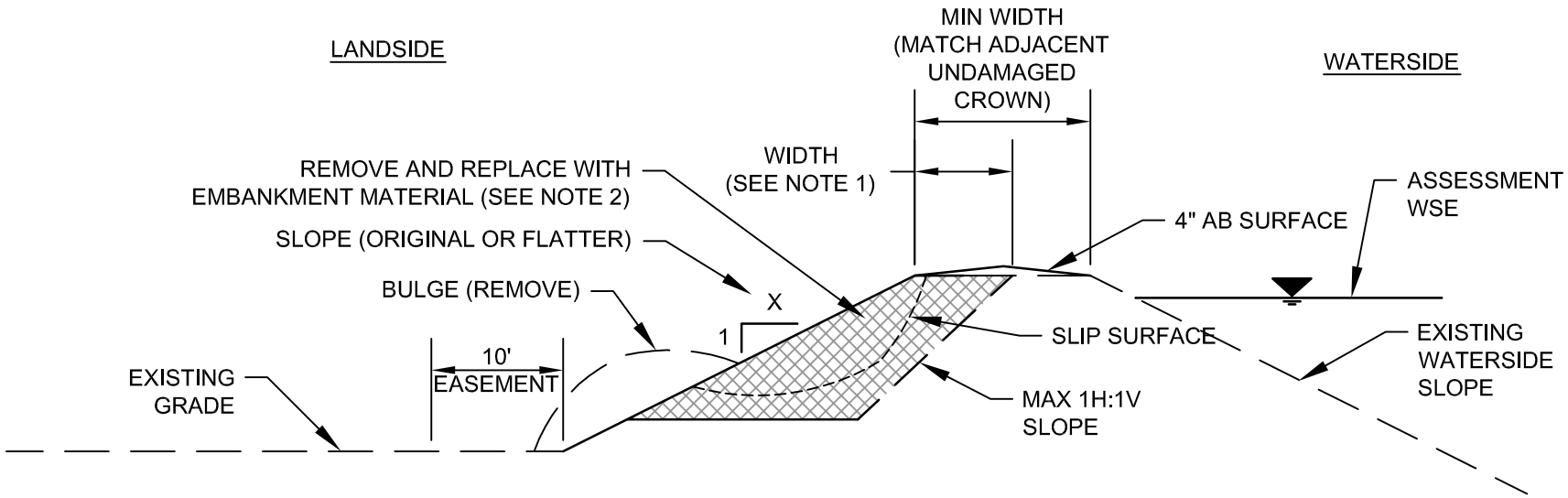
NOTE:

1. FOR COARSE-GRAINED LEVEE EMBANKMENT, BERM MATERIAL SHOULD BE EQUAL OR HIGHER PERMEABILITY THAN EMBANKMENT. HOWEVER, GAP GRADED MATERIALS THAT MAY ALLOW MATERIAL MIGRATION SHOULD NOT BE USED.
2. USE IN LOCATIONS WHERE THERE IS NO THROUGH SEEPAGE DEFICIENCIES.
3. TOP OF BERM AT ASSESSMENT WATER SURFACE ELEVATION OR 3 FEET BELOW CROWN, WHICHEVER IS HIGHER.
4. KEY-IN MATERIAL SHOULD BE SIMILAR TYPE AS FOUNDATION BLANKET AND SHOULD NOT CREATE A BATHTUB OR SEEPAGE BLOCK CONDITION.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL UNDRAINED STABILITY BERM REPAIR FOR SLOPE STABILITY	TEMPLATE SS-2

** SEE SECTION 3.4.3 FOR GUIDANCE.



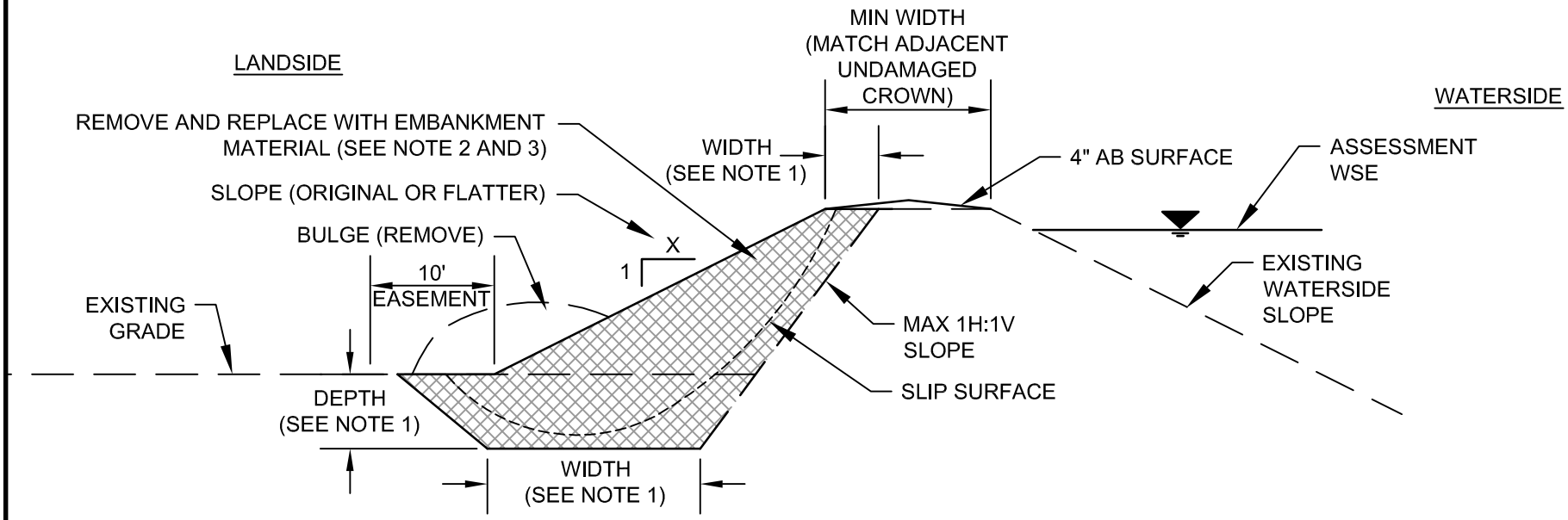
NOTE:

1. DEPTH AND WIDTH OF EXCAVATION SHOULD BE SELECTED BASED ON EVALUATION OF EMBANKMENT/FOUNDATION CONDITIONS CAUSING SLOPE INSTABILITY AND SHOULD ENCOMPASS THE ENTIRE FAILURE PLANE.
2. FOR COARSE-GRAINED LEVEE EMBANKMENT, EMBANKMENT MATERIAL SHOULD BE EQUAL OR HIGHER PERMEABILITY THAN EMBANKMENT. HOWEVER, GAP GRADED MATERIALS THAT MAY ALLOW MATERIAL MIGRATION SHOULD NOT BE USED.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL PARTIAL LEVEE REPLACEMENT REPAIR FOR SLOPE STABILITY (EMBANKMENT)	TEMPLATE SS-3

** SEE SECTION 3.4.3 FOR GUIDANCE.



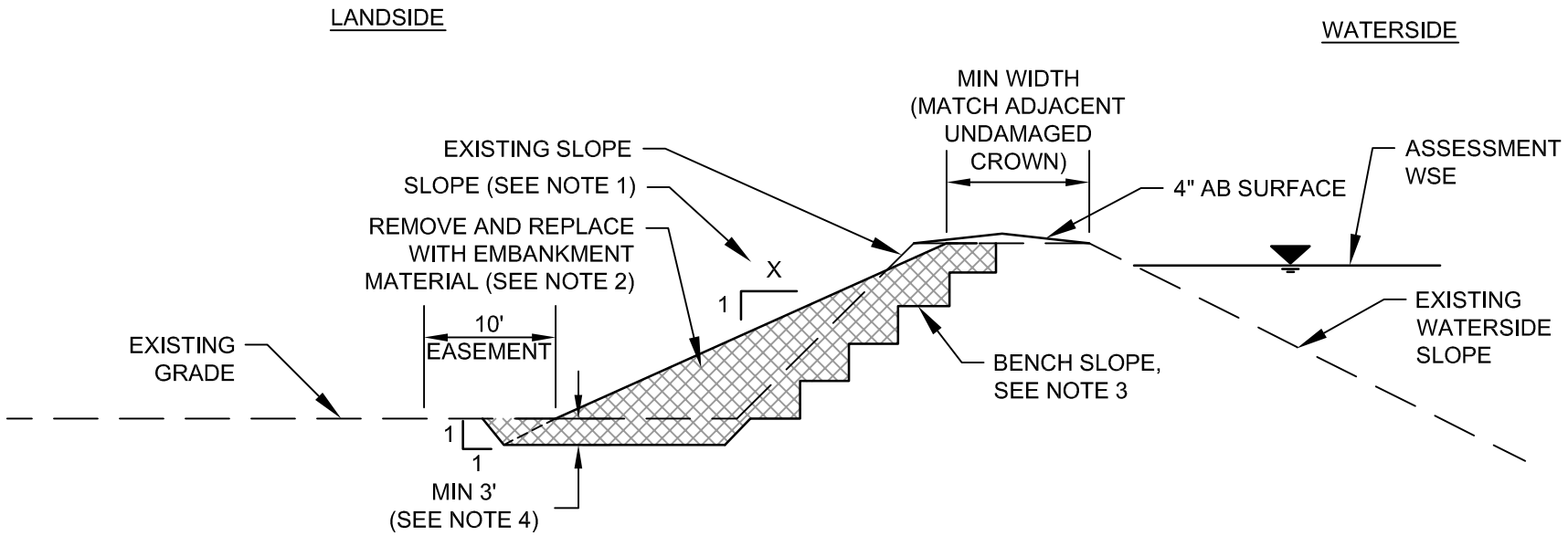
NOTE:

1. DEPTH AND WIDTH OF EXCAVATION SHOULD BE SELECTED BASED ON EVALUATION OF EMBANKMENT/FOUNDATION CONDITIONS CAUSING SLOPE INSTABILITY AND SHOULD ENCOMPASS THE ENTIRE FAILURE PLANE.
2. FOR COARSE-GRAINED LEVEE EMBANKMENT, EMBANKMENT MATERIAL SHOULD BE EQUAL OR HIGHER PERMEABILITY THAN EMBANKMENT. HOWEVER, GAP GRADED MATERIALS THAT MAY ALLOW MATERIAL MIGRATION SHOULD NOT BE USED.
3. FOUNDATION MATERIALS IN THE REPAIRED SECTION SHOULD BE EVALUATED FOR COMPATIBILITY WITH SURROUNDING SOIL CONDITIONS. IT SHOULD NOT CREATE A BATHTUB OR SEEPAGE BLOCK CONDITION.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL PARTIAL LEVEE REPLACEMENT REPAIR FOR SLOPE STABILITY (EMBANKMENT AND FOUNDATION)	TEMPLATE SS-4

** SEE SECTION 3.4.4 FOR GUIDANCE.



NOTE:

1. SLOPE SHOULD BE FLATTER THAN EXISTING SLOPE AND SHOULD BE SELECTED BASED ON EVALUATION OF EMBANKMENT AND FOUNDATION MATERIALS.
2. FOR COARSE-GRAINED LEVEE EMBANKMENT, EMBANKMENT MATERIAL SHOULD BE EQUAL OR HIGHER PERMEABILITY THAN EMBANKMENT. HOWEVER, GAP GRADED MATERIALS THAT MAY ALLOW MATERIAL MIGRATION SHOULD NOT BE USED.
3. BENCH MAY BE NEEDED TO ACHIEVE MINIMUM WIDTH FOR COMPACTION. BENCH MAY BE NEEDED FOR BONDING IN FINE-GRAINED EMBANKMENT. MINIMUM 6-INCH STRIPPING OF SLOPE SURFACE SHOULD BE PERFORMED, IF BENCHING IS NOT USED.
4. KEY-IN MATERIAL SHOULD BE SIMILAR TYPE AS FOUNDATION BLANKET AND SHOULD NOT CREATE A BATHTUB OR SEEPAGE BLOCK CONDITION.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL LANDSIDE SLOPE FLATTENING REPAIR FOR SLOPE STABILITY	TEMPLATE SS-5

PLOT BY: BRIAN_BOEN - Nov 19, 2013 - 7:17:13pm
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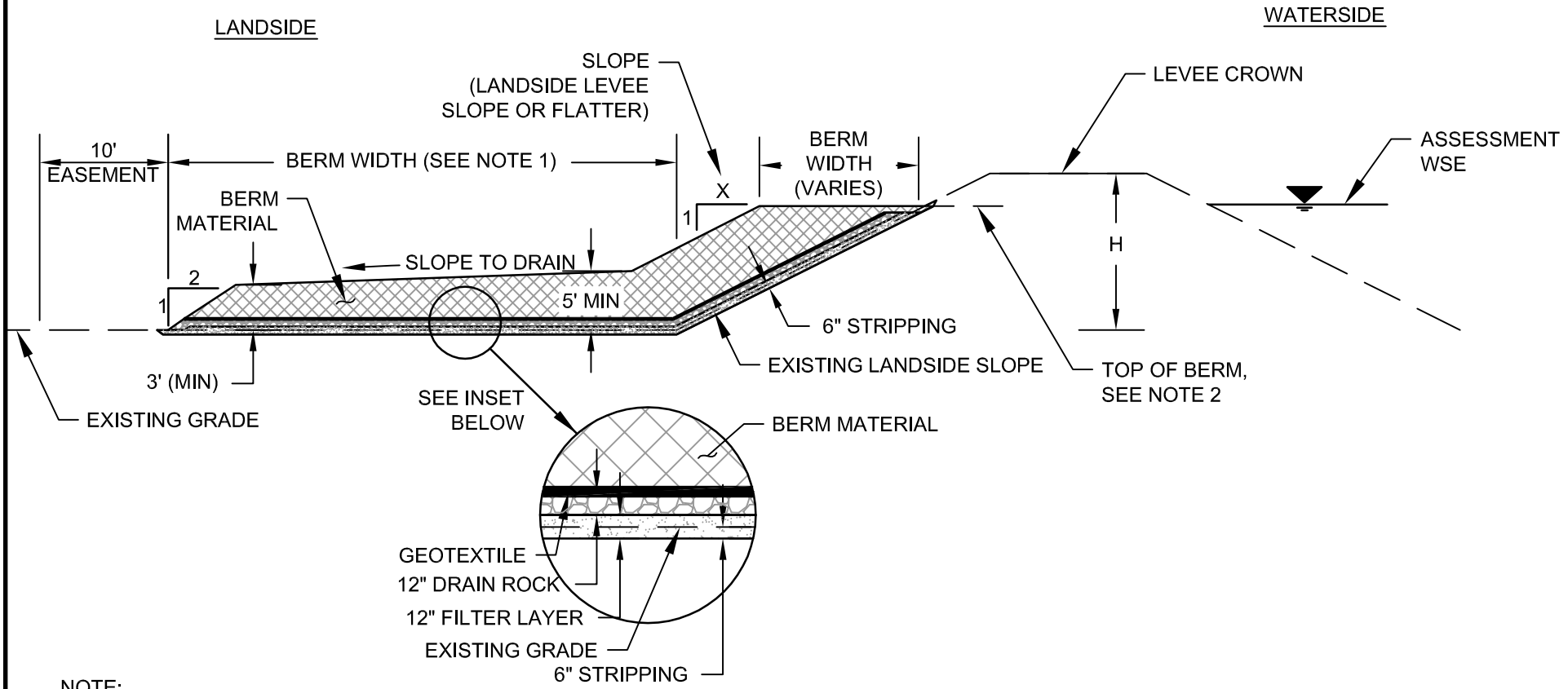
** SEE SECTION 3.5 FOR GUIDANCE.



NOTE:

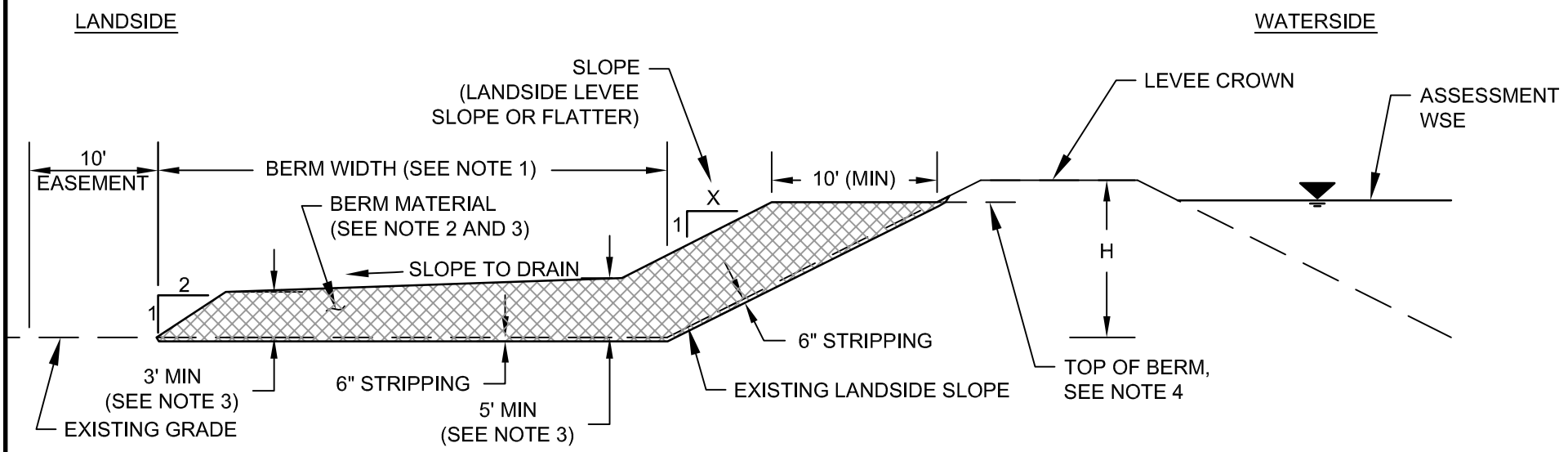
1. SEEPAGE BERM WIDTH SHOULD BE MIN OF 4H; OR IF BOIL WAS OBSERVED AT THE REPAIR SITE, THE SEEPAGE BERM SHOULD EXTEND 10 FEET BEYOND THE BOIL LOCATION, UP TO A MAXIMUM OF 300 FEET.
2. FOR SLOPE STABILITY, TOP OF BERM AT ASSESSMENT WATER SURFACE ELEVATION OR 3 FEET BELOW CROWN, WHICHEVER IS HIGHER. FOR THROUGH SEEPAGE, TOP OF BERM SHOULD BE 2 FEET ABOVE PHREATIC SURFACE BREAKOUT AND MIN 1/3 LEVEE HEIGHT.
3. BERM WIDTH SHOULD BE BASED ON THE IDENTIFIED DEFICIENCY.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL COMBINATION DRAINED BERM REPAIR FOR SEEPAGE-STABILITY	TEMPLATE COM1

PLOT BY: BRIAN_BOEN - Nov 19, 2013 - 7:17:19pm
DRAWING: \\SACDATA01\Projects6\DWR-8101-FSRP\WorkZone\TO U112 - Feasibility Studies\Rural Levee Repair Guidelines\First Draft\Drawing TemplaTemplate.dwg

** SEE SECTION 3.5 FOR GUIDANCE.



NOTE:

1. SEEPAGE BERM WIDTH SHOULD BE MIN OF 4H; OR IF BOIL WAS OBSERVED AT THE REPAIR SITE, THE SEEPAGE BERM SHOULD EXTEND 10 FEET BEYOND THE BOIL LOCATION, UP TO A MAXIMUM OF 300 FEET.
2. FOR COARSE-GRAINED LEVEE EMBANKMENT, BERM MATERIAL SHOULD BE EQUAL OR HIGHER PERMEABILITY THAN EMBANKMENT AND FOUNDATION BLANKET. HOWEVER, GAP GRADED MATERIALS THAT MAY ALLOW MATERIAL MIGRATION SHOULD NOT BE USED.
3. IF SEEPAGE BERM PERMEABILITY IS LESS THAN FOUNDATION BLANKET LAYER AND PRESENCE OF COARSE-GRAINED SOIL AT SURFACE IS LIKELY, SEEPAGE BERM MAY NEED TO BE THICKER AND WIDER.
4. FOR SLOPE STABILITY, TOP OF BERM AT ASSESSMENT WATER SURFACE ELEVATION OR 3 FEET BELOW CROWN, WHICHEVER IS HIGHER. FOR THROUGH SEEPAGE, TOP OF BERM SHOULD BE 2 FEET ABOVE PHREATIC SURFACE BREAKOUT AND MIN 1/3 LEVEE HEIGHT.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL COMBINATION UNDRAINED BERM REPAIR FOR SEEPAGE-STABILITY	TEMPLATE COM2

PLOT BY: BRIAN_BOEN - Nov 19, 2013 - 7:17:24pm
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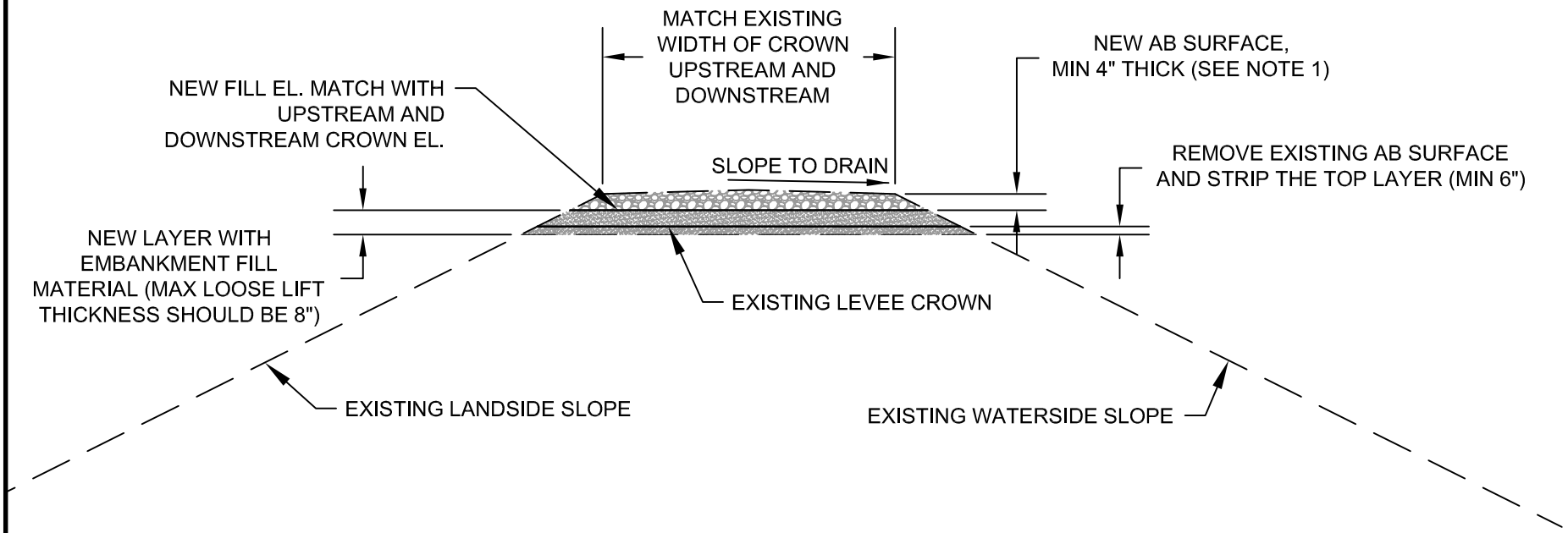
** SEE SECTION 3.6 FOR GUIDANCE.



NOTE:

1. EXISTING AB MAY BE REUSED.
2. SIDE SLOPE MAY NEED TO BE ADJUSTED.

NOT TO SCALE

Department of Water Resources Division of Flood Management	RURAL LEVEE REPAIR GUIDELINES	TYPICAL REPAIR FOR CROWN DEPRESSION	TEMPLATE CD-1