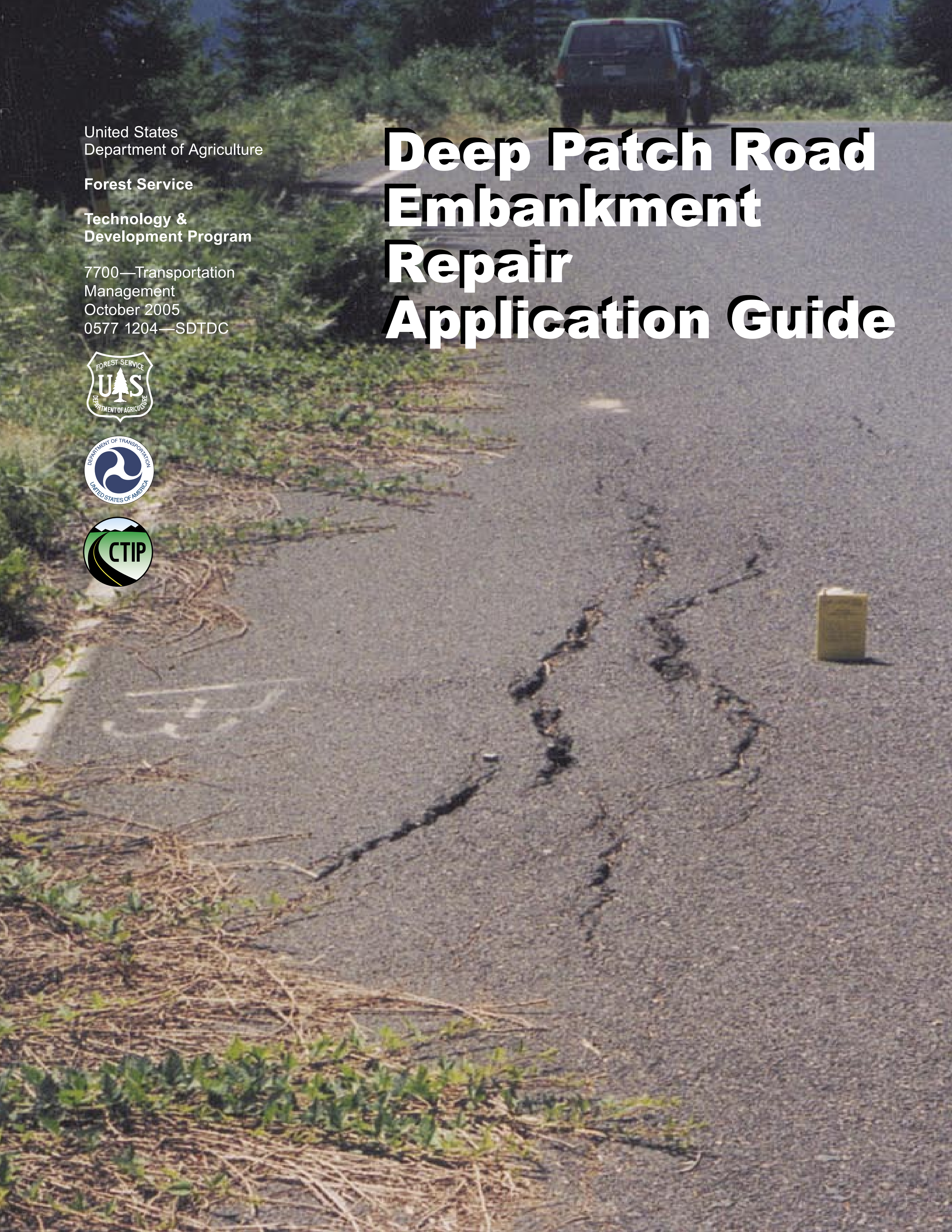

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Deep Patch Road Embankment Repair Application Guide

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by

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FOREWORD

This publication is the result of a partnership between the U.S. Department of Agriculture (USDA) Forest Service technology and development program and the U.S. Department of Transportation Federal Highway Administration (FHWA) Coordinated Federal Lands Highway Technology Improvement Program. Since 1990, engineers in Regions 5 and 6 have been using a design method for repairing road fillslopes with recompacted fill and reinforcement. They have used the term “deep patch” to describe this method.

According to an informal survey conducted in 2000, engineers on several forests in the States of Washington, Oregon, and California are using deep patch design without consistent design criteria. The USDA Forest Service *Retaining Wall Design Guide* (5) contains a brief description of a shallow deep patch, 3 feet deep. However, deep patches between 3 and 6 feet deep are being individually designed and built by forest engineers, with no appropriate published guidelines.

This application guide describes the background, performance, design, and construction details of the deep patch technique. This guide also details a consistent, simplified method for designing deep patches for use by engineers and technicians.

INTRODUCTION

Thousands of miles of low-volume roads exist on National Forest System lands. Past design methods for roads across hillslopes emphasized achieving road width with balanced earthwork, that is, equalized cut-and-fill quantities. Typically constructors removed material from the hillside (cut) and placed it along the outside edge of the road (fill or sidecast), with minimal keying or benching, or controlled compaction (figures 1 and 2).

Settlement or consolidation of the inadequately compacted fill material and/or downslope fill creep often caused subsidence and cracking. In addition, woody debris from the clearing and grubbing operation went into the sidecast fills. In some cases, logs and stumps supported the toe of the fills. The woody debris initially acted as reinforcement and probably improved the slope stability. Over time, however, the decomposing debris led to subsidence or even to total fill failure.

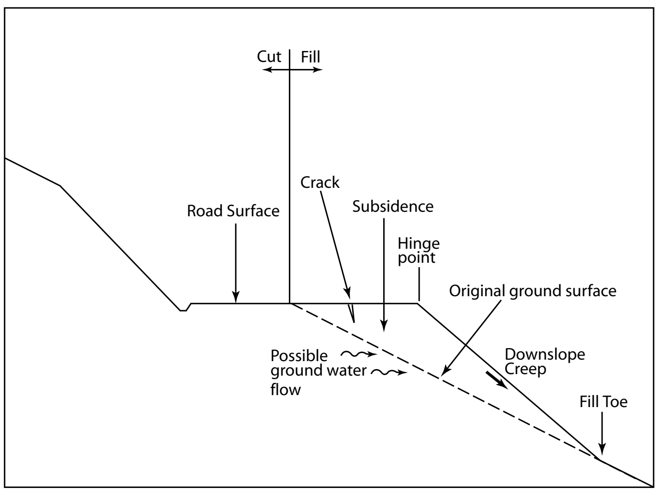


Figure 1—Cross section of typical sidecast road embankment fill.

Figure 2—Pavement cracking as evidence of sidecast fill settlement.

As forest roads have aged, the effects of decomposing woody debris and fill consolidation have become increasingly apparent. A single road can have numerous areas of cracking and subsidence. Typical methods for repairing fillslope settlement problems, such as reconstruction, realignment, or retaining structures can be expensive. The deep patch is a cost-effective technique for repairing and stabilizing the areas of roadways damaged by subsidence or cracking.

The deep patch design is a shallow, road-fillslope repair. Constructors excavate the upper 1.5 to 6 feet of the subsiding section of roadway, replace the fill material with compacted backfill, and reinfore the fill material with layers of geosynthetic material, typically geogrid. A typical deep patch repair is shown in figure 3

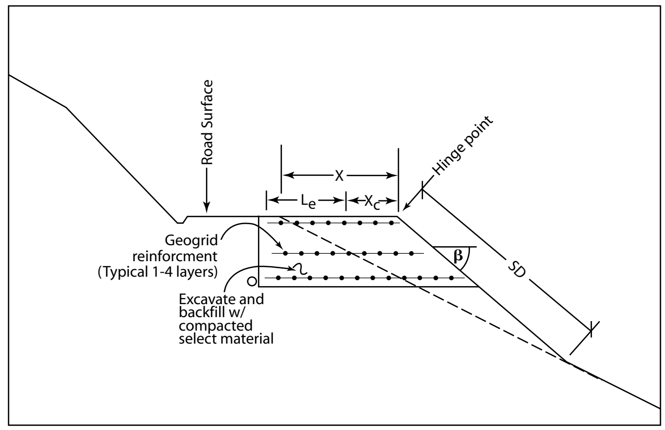


Figure 3—Cross section of typical deep patch road embankment repair.

The authors describe the structure of the deep patch, present a simplified design method, and describe construction guidelines and steps for use by engineers and technicians.

BACKGROUND

Use and Performance

USDA Forest Service and FHWA engineers have constructed at least 100 deep patch projects since the early 1990s in California, Oregon, Washington, and Colorado. Deep patches have been built on both graveled and paved roads, though primarily on paved ones. Deep patches are probably popular because maintenance operators can grade over cracks and areas of settlement on aggregate-surfaced roads during regularly scheduled road maintenance, thus covering the area but not correcting the problem.

Engineers also have used deep patches on some less common applications. Deep patches have reinforced sections of roads crossing areas of large-scale slope movement slowing, but not stopping slope surface movement. Road settlement and road maintenance costs have been reduced. Another use occurred in Alaska shortly after the November 3, 2002, earthquake. Sections of a highway fill had settled due to liquefaction of the ground underneath. Engineers constructed temporary deep patches for quick reopening of the highway. Over a year later and after numerous aftershocks, the FHWA has reported no settlement and, therefore, now considers the deep patches permanent repairs.

Various users have collected data on past and current uses of deep patches. The 2000 survey requested information about the history of use, including number, age, and performance of deep patches; design-analysis methodology; specifics of design; and construction details. The survey went to geotechnical engineers on national forests in Washington, Oregon, and California, and to FHWA engineers. The results of the survey are shown in table 1.

Analysis methods and design specifics have varied. Procedures have ranged from onsite professional judgment to indepth stability analysis with computer modeling. Excavation depths have ranged from 3 to 6 feet with from one to three reinforcement layers. Lengths of reinforcement embedment (L_e, length of reinforcement behind the crack) have varied from none to a length equal to the distance from edge of fill (hinge point) to the crack (X_c). Everyone surveyed used geogrid reinforcement, though types and strengths varied. Others used reinforcement materials such as geotextiles (woven and nonwoven), chain-link fabric, and welded-wire mats.

Construction methods had few variations. Operators excavated and backfilled the target areas with compacted and reinforced in-place fill material, pitrun or crushed rock, or select borrow material. They paved the patch either immediately after construction or during the next construction season.

Even with the variety of analysis techniques, designs, and construction methods and materials, very few sites have had recurrences of cracking or settlement. Although the sites where cracking has recurred probably had insufficient reinforcement embedment (L_e), no design or as-built records exist. One site purposely constructed within a large slope failure has continued to settle, though at a slower rate than the unreinforced fill within the same site.

Typical costs for deep patches

The cost of repairing a road embankment failure with the deep patch method depends on backfill material (type and source), type and number of reinforcement layers, and drainage (if needed). However, when compared to other methods (such as road realignment or reconstruction, or retaining structures), the deep patch generally will be the least expensive option.

Engineers can roughly estimate the costs of conventional excavation and recompaction of soil materials to estimate the cost of a deep patch. Deep patch repairs include costs for the earthwork, for reinforcement material and shipping, and for labor and time for installing the reinforcing grid. In addition, imported backfill may be necessary if the existing fill is unacceptable. The added cost of the reinforcement grid and installation on several recent projects has been about 15 to 25 percent over the earthwork costs.

Alternatively, since 1998, forest engineers for deep patch projects in northern California and Oregon report total project costs at $50 to $120 per square yard of road surface area, depending on depth, necessary reinforcement, backfill importation, and paving. Project cost ranges from $20 to $30 per square yard of geogrid for the patch.

For remote or less accessible sites, equipment mobilization and demobilization and material delivery can affect costs substantially. In every case, the engineer should obtain and compare bids for several alternative repair schemes and use the least expensive method that gives the desired result.

Full-Scale Model Testing

In 1994 researchers at the University of Colorado at Denver conducted a full-scale model test based on the USDA Forest Service deep patch. This test looked at the effect of reinforcement on a “slice” of deep patch. Some of the parameters of the model (depth, number of geosynthetic layers, and type of reinforcement material) differed from the typical USDA Forest Service west coast design. However, the results provide useful qualitative data (8).

In this experiment, the height of the fill (corresponding to depth of deep patch) was 6 feet, which is greater than the typical depth of 3 feet but equal to the maximum depth of 6 feet. Nonwoven geosynthetic fabric, instead of geogrid, was placed with 1 foot vertical spacing in five layers, although most deep patch projects have one to three layers of geogrid. The sides of the testing apparatus were essentially frictionless to avoid lateral drag or support of the fill during testing. The floor of the apparatus was split, to allow lowering of the front section, mimicking settlement of a fillslope.

Researchers ran the test both with and without reinforcement. They instrumented each test section. In the unreinforced test, a crack developed near the top of the slope at the first base displacement of 0.2 inches. By the final displacement, 11 inches, the crack was about 1 foot deep and about 1 foot wide at the top, essentially breaking the fill in half.

An obvious difference showed in the test with the reinforced fill. Although minor cracks developed along the fillslope surface, the cracks did not propagate during continued base displacement. The most severe crack was about 10 inches deep. In the reinforced test, the researchers measured significant stress redistribution during the lowering of the base plate-a significant difference from the unreinforced test. In addition, the normal stress near the edge of the moveable section increased substantially during the unreinforced test, but not in the reinforced test (8).

Despite the differences between the model and the typical USDA Forest Service deep patches, reinforcement of the fill clearly has a positive effect. This effect includes strengthening the fill, thereby increasing the safety factor of the slope.

DEEP PATCH ALTERNATIVES COMPARISON

Numerous techniques exist for correcting unstable road fillslopes ranging from basic road-surface maintenance that treats the symptoms of the problem to road reconstruction. Traditional design options for unstable fillslopes include band-aid repairs (for example grading or patching), removal of unstable fill material (pullback), removal and replacement of unstable fill material (fill reconstruction), moving the roadway into the cutslope (realignment), and constructing retaining structures. The deep patch design falls somewhere between maintenance and reconstruction. It identifies the causes of the fill instability and reduces the instability but does not eliminate all causes of instability.

Certain maintenance approaches often are considered inexpensive methods of dealing with settlement because road maintenance crews can do the work as part of their normal routine. Such methods usually consist of grading over the areas of settlement and cracks (aggregate-surfaced roadway) or filling cracks and adding asphalt (paved roadway) to level the road surface. While these approaches temporarily restore the road's driving surface, the cause of the cracking and continual settlement in the road remains untreated. Grading does not stop the settlement either, but begins a long-term commitment to continual roadway repair. Additionally, accumulations of layers of asphalt or compacted aggregate on the already unstable fillslope add weight to the fill and may accelerate its settlement.

Removing unstable, settling fillslope material (pullback) that eliminates stability concerns for the removed material, is sometimes the best choice. However, pullback removes all vegetation, including trees, from the slope, leaving an exposed erosion-prone slope. Also, pullback can produce a roadway too narrow to meet design criteria, including traffic safety.

Removal and reconstruction of unstable fill material is another viable method. Many USDA Forest Service roads, however, are on steep ground with long, sliver fills that are difficult to remove and more difficult to rebuild. This expensive method, like pullback, removes all vegetation from an existing fillslope.

Realignment of a roadway into a cutslope can be simple if the cutslope is low, if vegetation is sparse or small, and if little or no ground water exists. Otherwise, realignment can develop into a major project with significant impacts and costs.

Although retaining walls or structures may offer the most complete solution, the size and cost can vary widely, depending on their size and complexity. On steep slopes, retaining structures can become tall, large, and expensive.

Table 2 compares these alternatives to the deep patch. In some cases, the ratings are expressed as ranges, because they vary according to site specifics. Costs, for instance, may range from low to high, depending on the amount of excavation required.

Table 1—Use and performance of deep patch projects

User	Reason for use	Number of Sites	Year Built	Depth	Road Surfacing	Builder	Performance	Comments
Olympic NF	settlement and cracks in ac-paved road	17	1997	3 ft	ac	contractor	good	Used design method in (6), L_e=X, one-layer of grid.
Plumas NF	minor fillslope problems and one at top of a large slide	4 to 5	2000	3 to 5 ft.	ac pavement and native soil	road crew & contractor	good	One to three layers of fabric, one patch used welded wire mattress. Engineer feels deep patches make a marginally unstable site, marginally stable.
Umpqua NF		12	1997 to 2001	4 ft	ac pavement	contractor	good	Designed grid strengths using XSTABL, used two-layers of grid, L_e=0 to 70 ft. Paving was done following field season. Two sites with minor renewed cracks due to insufficient anchorage (L_e).
FHWA (CO)	road shoulder repair	~12	mid 1990s?	±6 ft	ac pavement	contractor	good	Using three layers of grid, L_e=3 ft, have been built on USDA Forest Service and U.S. Department of the Interior National Park Service roads.
Siuslaw NF	fill settlement	20 to 25	~1996	3 to 5 ft	aggregate and ac pavement	contractor	mixed	L_e=2 ft, reinforcement every 2 ft, using grid, L_e=1/2X
Gifford Pinchot NF	cracks in outside half of road	2 to 3 designed and several each year by road crew	late 1980s	≤5 ft.	aggregate and ac pavement	road crew & contractor	mixed	Road crew locates and builds using general guidel lines, L_e=X, using grid. Combines deep patch with sidecast pullback when appropriate, designed ones are working well. Some of earlier nondesigned projects failed due to insufficient anchorage (L_e) (cracking, no subsidence). Initially designed with XSTABL but found simplified wedge analysis just as good.
Willamette NF	settlement and cracks in ac-paved road	~12	1990+	3 ft	ac pavement	contractor	good	Two layers of grid, constructed 1:1 fill slopes
Mt. Hood NF	fill settlement		1990+	3 to 6 ft	ac pavement	contractor	good	One-deep patch constructed within hillslope failure reduced rate of subsidence, using geogrid, one to three layers of reinforcement.

NOTE: Survey performed in 2000
ac = asphalt concrete
L_e = length of embedment behind innermost crack
XSTABL = Design program used with deep patch projects

Table 2—Comparison of alternatives to deep patch repair

ALTERNATIVE	**FACTOR**										
	CONSTRUCTION										
	Design Needs	Cost	Complexity	Waste produced	Borrow needed	Ground Disturbance	Long-term Costs	Design Life	Slope Stabilization	Effect on Roadway	Planning Complexity
MAINTENANCE											
Band-aid (patch)	none	low	low	no	no	none	high	temporary	none	temporary smoothing	none
Sidecast pullback	minimal	moderate to high	low	yes	no	high	unknown	unknown	low to high	narrows roadway	moderate to high
DEEP PATCH	minimal	low	low	maybe	maybe	low	low*	long	moderate	repair roadway	low to moderate
RECONSTRUCTION											
Fill reconstruction	moderate	moderate to high	moderate	yes	yes	high	low	long	high	repair roadway	,moerate to high
Realign into cutslope	moderate to high	low to high	low to high	yes	no	high	unknown	long	low to high	repair roadway	low to high
Retaining wall	high to high	high to high	high	yes	yes	high	low	long	high	repair roadway	,moerate to high

* Deep patches have been in place and functioning for about 15 years. The actual design life is unknown. Maintenance costs for a well-functioning deep patch are virtually nil.

PROJECT DEVELOPMENT

Site Selection

Appropriate site selection for a deep patch design is important because it will not solve all fillslope stability problems. For instance, deep patch design will not stabilize large-scale slope instabilities of which a road is merely a part. Although the deep patch probably will slow the rate of road subsidence, it will not stabilize the slide. Deep patches will not provide support where the fillslope is eroded beneath a roadway. For example, if a stream is eroding the toe of a fillslope, undermining the fill and causing road settlement, a deep patch alone is not appropriate.

The deep patch works best on roads originally constructed with the cut-and-fill or sidecast technique, where the subsidence is in the outer part, or fillslope portion, of the road. Sites often are on a section of road crossing steep hillsides, with 1 1/4:1 to 1:1 fillslopes constructed on 60 to 70 percent natural slopes. Fillslope settlement typically is related to downslope creep of the fill on the steep slopes, consolidation of inadequately compacted materials, decomposition and settlement of woody debris in the fill material, or some combination of all three. Groundwater migrating through or under the fill also may adversely influence the fillslope stability.

Those investigating and analyzing a road repair must first determine the scope of the problem. Cracking and subsidence usually is due either to hillslope instability, that is, mass wasting, or to more localized problems within the road embankment. Sites with mass wasting are poor candidates for deep patch.

Investigation of the fillslope and toe of fill often can reveal localized causes, for example, stream erosion, fill material resting against deteriorating stumps or logs with over-steepened slopes below, or even woody-debris protruding from the fill material. Indicators of water affecting stability include ponding water in the ditchline, ground water seeping from the cutslope or fillslope, water-thriving plants, or wet areas indicating abnormally wet conditions.

Sometimes, with no obvious reasons for the settlement, engineers should construct a cross section of the road from above the top of the cut to below the toe of the fill. If the problem is fillslope settlement, examining the cross section, (with an understanding of the road construction technique) will often show the balance point between cut-and-fill to be at, or just inside, the line of cracking or settlement.

If the cracking or subsidence is fillslope-related, the site is a candidate for the deep patch. A typical deep patch site will have a crack or series of cracks along the outside to near the centerline of the road, usually disappearing into the slope of the fill (figure 4). Vertical or horizontal displacement may be evident. Often, these sites have been settling for years and require chronic road maintenance.

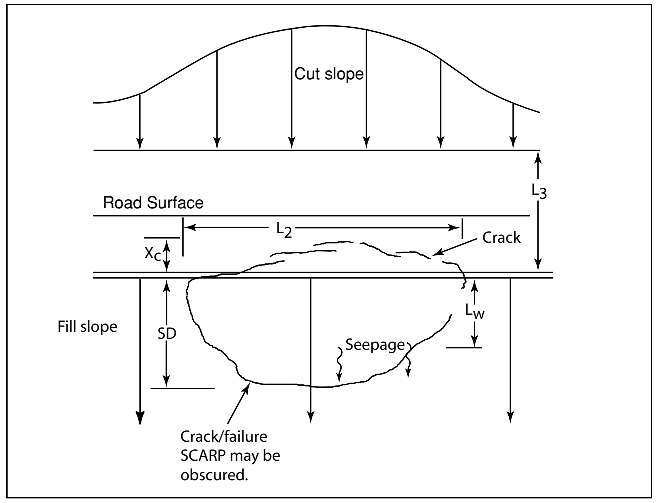


Figure 4—Pavement surface cracking indicating fill subsidence.

Field Data Collection

Successful application of the deep patch design depends on characterizing the project site accurately, including both the cause and location of the feature. Accurate field measurements are necessary to locate and define the zone of movement. Careful site mapping allows construction of the reinforcement in the right place, so an accurate field-developed cross section is critical.

In surveying and evaluating a deep patch project, it is important to determine the location of the innermost extent of instability (usually not the line of cracks in the roadway). The plane of movement is along the cut-fill interface. As movement along this plane nears the road surface, the cracking propagates vertically. As a result, the cracks, while near the cut-fill interface, are actually between that point and the outside of the road (see figure 5). The two lines usually are so close that this design guide will treat them identically.

Engineers or technicians may use the field data form (figure 5) to record site information. Site measurements may be recorded on the dimension list and the drawing. The drawing should include vegetation (especially trees within excavation limits), bedrock or large rocks, road alignment and grade, and any other aids to characterize the site or that possibly could affect construction.

For inspecting and classifying the typical soil and rock within the project area, the engineer should use the Unified Soil Classification System (1, 2) and the Unified Rock Classification System (7). Generally, this will be a visual classification, with brief written notes of the general characteristics of the soil and rock.

Water, whether surface flow or ground water, plays a major role in slope stability. Investigating a potential deep patch site calls for evaluating water conditions. Ground water is obvious if seepage comes from the cutslope or fillslope. Other less obvious clues to the presence of either seasonal or persistent water in the site include:

- Water-thriving plants on the cutslope, fillslope, or roadway.
- Topographic features such as swales, benches, or tension cracks.
- Low points in the ditchline or roadway where water can pond.
- Erosional (scour) or washout features in the project area, especially downslope.

If water is expected to affect the project site (including interception of ground water during excavation), engineers need to incorporate drainage into the deep patch design-because the design is based on drained conditions. The following drainage techniques may be required:

- Installing cut-off drains (such as French drains or geocomposite drains).
- Regrading ditches.
- Constructing ditch relief culverts (or waterbars) to deflect surface water.

The drainage design needs to reflect the volume and location of the water. Constructing a deep patch without managing or removing the ground water greatly increases the potential for failure.

Field Measurements

Field measurements define the geometry of a project site. See figure 5 for illustration of the measurements.

- X is the distance from the edge of fill (sometimes called the hinge point) to the point at which the road fill changes from cut to fill, that is, the projection of the original ground line on the roadway. Pinpointing the exact location of this point is difficult, even with a surveyed cross section of the road. Although the analysis is based on X, the measurement of X_C also can be used for deep patch design.

- X_C is the distance from the edge of fill to the innermost crack in the road. This measurement is used if X is unknown. X_C also is necessary for monitoring. For example, if cracking occurs after deep patch construction, knowing the location of the original cracking helps determine whether or not the new cracking is a reoccurrence of the original cracking.

- β is the slope angle of the fillslope measured in degrees.

- SD is the slope distance from the edge of fill to the lower limit of the zone of settlement (or toe of failure). When this point is indiscernible, the engineer needs to measure down to the toe of the fillslope.

- L_2 is the maximum length of cracking measured parallel to the road. Typically, the crack will leave the roadway and disappear down the slope of the fill. Sometimes, however, the crack exits the road but continues along near the top of the fillslope, parallel to the roadway. Use professional judgment to determine whether to include the area of off-roadway cracking in the deep patch. Measuring the vertical settlement distance also has monitoring value, although it is not used for design.

- L_3 is the width of the roadway (measured from edge of fill to inside edge of the road).

- L_W is the slope distance from the top edge of the fill to the location on the slope where groundwater emerges. L_W helps determine the height of ground water in the road fill. If the ground water is high enough for the deep patch to intercept it, then the design must include drainage.

Site Rating

When numerous project sites exist along a road, rating each site can help prioritize the projects. The field data form includes a rating method for evaluating the risk to traffic safety (from vertical displacement of the roadway), the potential for a slope failure, and the consequences of a failure. In each category, the site is rated high (H), medium (M), or low (L). Failure refers to the complete displacement of the fillslope material and potential downslope damage from the slope failure. Failure could include impassability on the road or deposition of sediment into a stream. Overall site priority summarizes the site importance in relation to others nearby with similar stability problems.

DEEP PATCH
Field Data Form*

Road Number ____________________ Date ____________________

MP/Station ____________________ Recorder ____________________

Location T_____R_____Sec________

Site Description: ____

____

____

____

Cross-Section	***Plan View***

Dimensions

X ____________ SD ____________

X_c ____________ L_2 ____________

β ____________ L_3 ____________

L_w ____________

* Adapted from (6)

1

Figure 5—Deep patch field data form.

Site Drawing

Site Characteristics Description

Soil Classification

Fill Slope		
Cut Slope		
ϕ(Fill Slope Material)		

Water Presence at Site

Ponding in Ditch:	Y	N	
Seepage on Cut Bank:	Y	N	
Seepage on Fill Slope:	Y	N	
Other:	Y	N	

Traffic Safety Risk: H M L
Potential for Slope Failure: H M L
Consequences of Failure: H M L
Overall Site Priority (circle one): H M L

2

Figure 5—Deep patch field data form (cont).

DESIGN METHODOLOGY

There are several ways to analyze a fillslope for a deep patch design. Traditionally, for detailed analysis engineers have used geotechnical investigation and computer modeling, such as XSTABL, or a slope stability analysis methodology such as the simplified wedge analysis. At the other end of the spectrum, the USDA Forest Service *Retaining Wall Design Guide* (5) describes a deep patch design for a single layer of nonstrength-specified geogrid, 3-foot excavation depth, and a length of reinforcement behind the innermost crack (L_e) equal to the distance X_c.

This guide does not develop a new method of slope stability analysis but provides a partially completed analysis for producing a relatively site-specific deep patch design using traditional slope analysis. The results are plotted on graphs (graph method) that allow the user to quickly determine design parameters based on their site dimensions. The method assumes that no water is in or at the site, that is, either the site is dry or the engineer has incorporated adequate drainage in the design.

The graph method uses typical soil characteristics and road construction geometries found on USDA Forest Service low-volume roads. These include fillslope angles of 34 degrees (1-1/2:1) and 39 degrees (1-1/4:1); soil strength friction angles of 25, 30, and 35 degrees; soil cohesion, C=0; various fillslope lengths; and no ground water. Data evaluation is based on the simplified wedge method of limit equilibrium analysis (4). This analysis determined the necessary reinforcement strength that the fill soil required to obtain a factor of safety equal to 1.2. The existing slope was given a factor of safety of 1, which assumed that the slope was on the verge of failure in lieu of site-specific investigation. These sites might be more stable than a factor of safety equal to 1 would suggest, as they typically stand in their settled/cracked condition for several years.

The graph method allows engineers or technicians to perform a relatively site-specific design without having to run numerous computer analyses. Graphs 1 through 8 show the results of several runs of this analysis. The graphs incorporate the factor of safety of 1.2.

Graph Method

The following section describes the design steps for the graph method:

1. Determine that onsite cracking or subsidence is due to fillslope settlement (that is, determine the settlement cause and decide whether a deep patch is suitable). If possible, include removing any excess fillslope material during deep patch construction.

2. Evaluate the role of surface and ground water, design drainage if needed.

3. Measure dimensions of cracked area:
   - Distance of the innermost crack from the hinge point or edge of fill (X_C).
   - Slope distance from hinge point to toe of failure (if unable to determine toe of failure, measure to toe of fillslope) (SD).
   - Distance between the ends of the crack(s) where they leave the road (the reinforcement should extend a minimum of 5 feet beyond endpoints of the crack or cracks).
   - Fillslope angle (degrees) to determine dimension of reinforcement at its embedment elevation - measured perpendicular to road length (β).
   - Estimate soil friction angle ϕ (degrees), of the fillslope material.

4. Use graphs to determine the required excavation depth and total required force (Tal) necessary for reinforcement (L_e=5 feet):
   - To determine depth use X_C, β, & SD (graphs 1 or 5 depending on slope angle).
   - To determine total T_{al} use X_C, SD, β, & ϕ (graphs 2 through 4 or 6 through 8).

5. From total T_{al} needed:
   - Determine number of reinforcement layers. (Typically, the number of layers range from one to four, depending on the depth of the deep patch. One layer is typically used for a 1.5-foot-deep excavation and two to four for deeper ones, up to 6 feet.)
   - Determine depth and spacing of layers
     - o Bottom layer typically placed on leveling course, 0.5 feet above bottom of excavation.
     - o Uppermost layer placed below road structure (surfacing and base), but not less than 1 foot below roadway.
     - o For ease of construction, geogrid layer spacing should be equal.
     - o For ease of construction, geogrid spacing should be an increment of layer-placed backfill, but greater than 1 foot.

An example of a deep patch design follows the graphs.

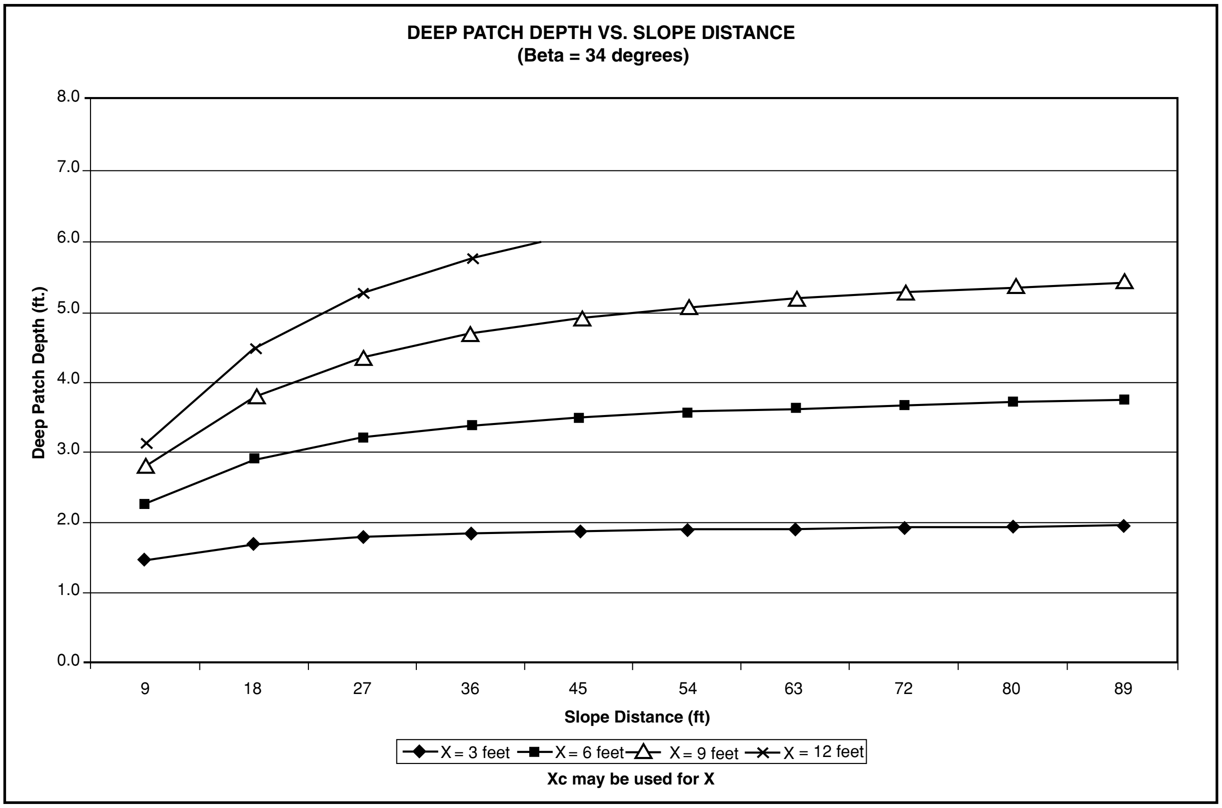


Figure 6—Deep patch vs. slope distance.

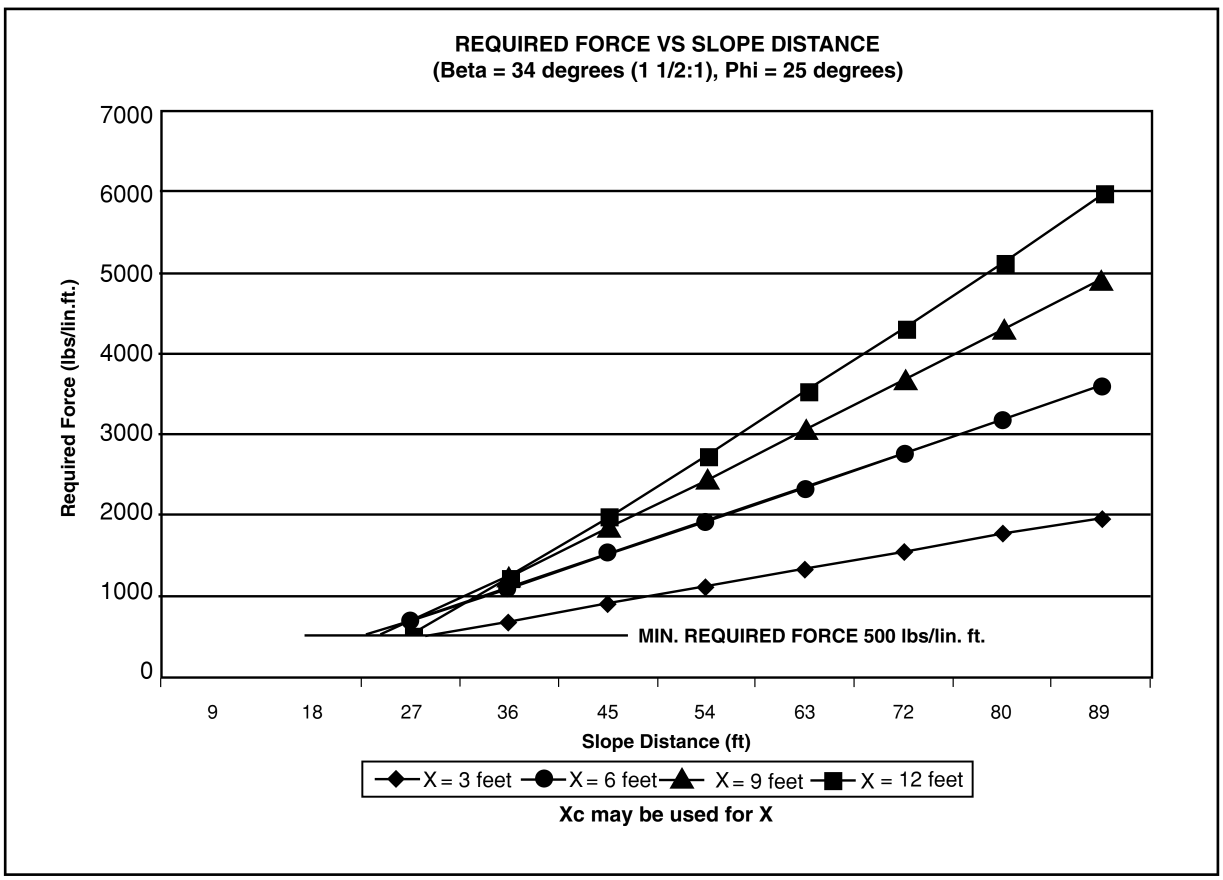


Figure 7—Required force vs. slope distance.

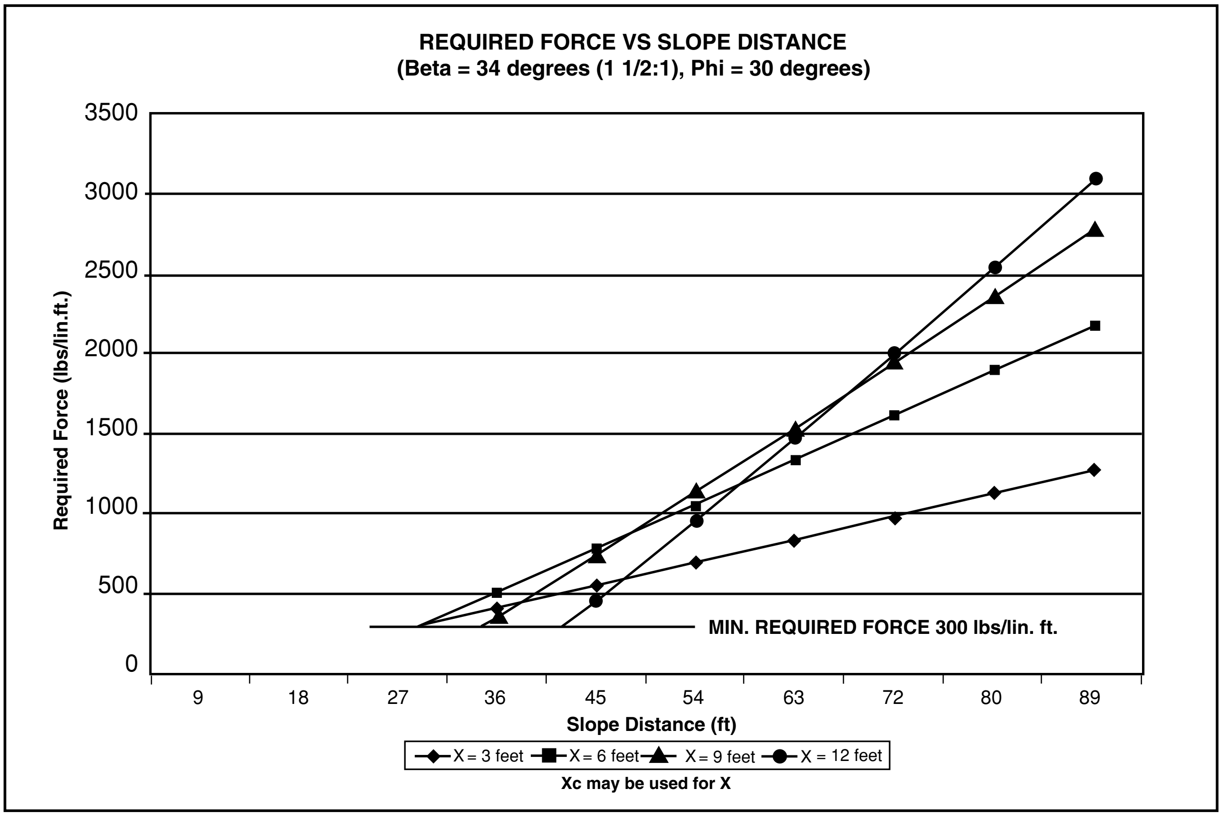


Figure 8—Required force vs. slope distance.

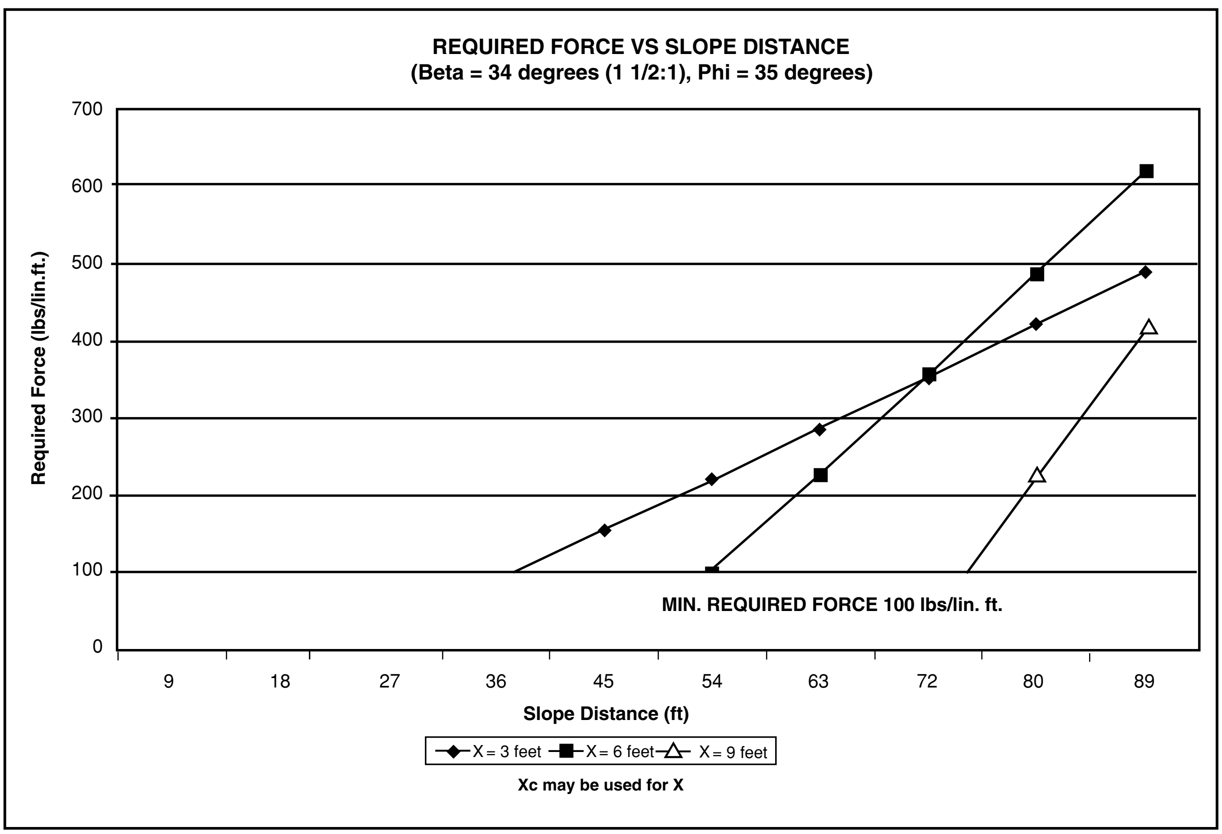


Figure 9—Required force vs. slope distance.

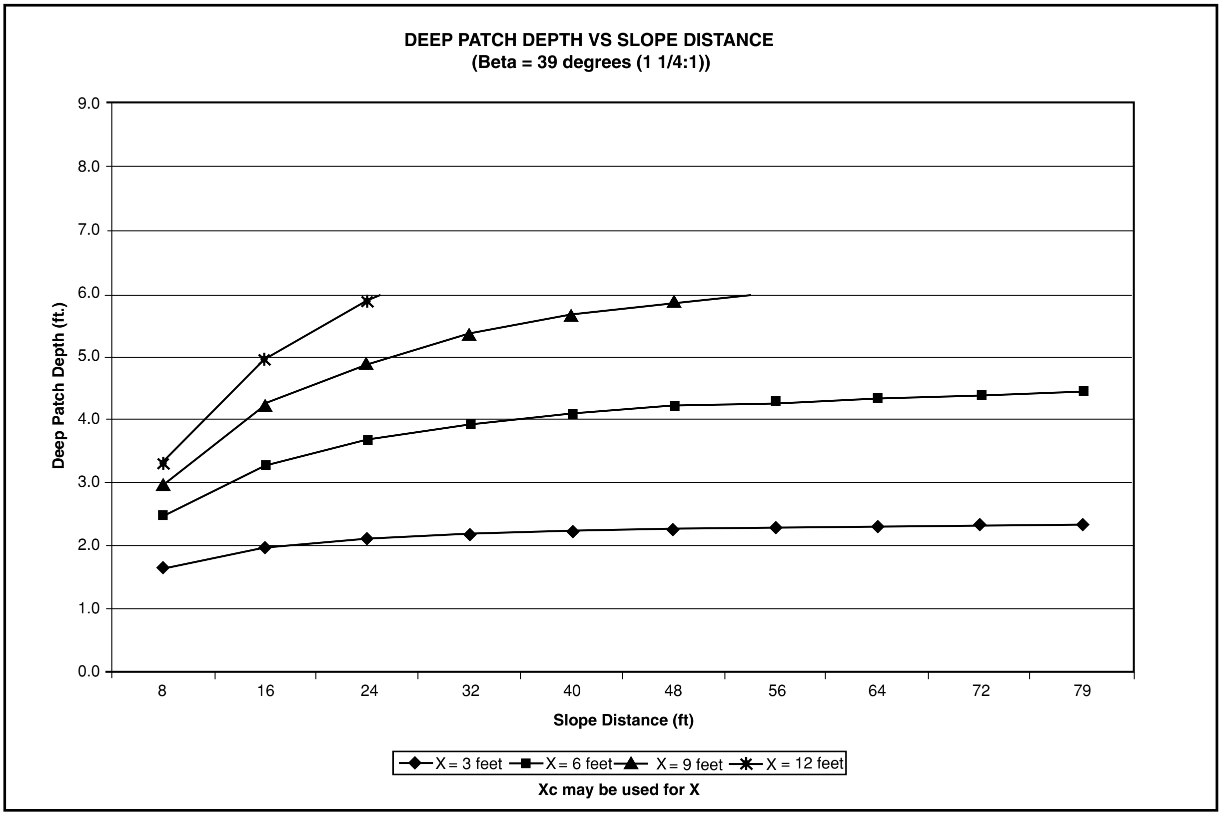


Figure 10—Deep patch depth vs. slope distance.

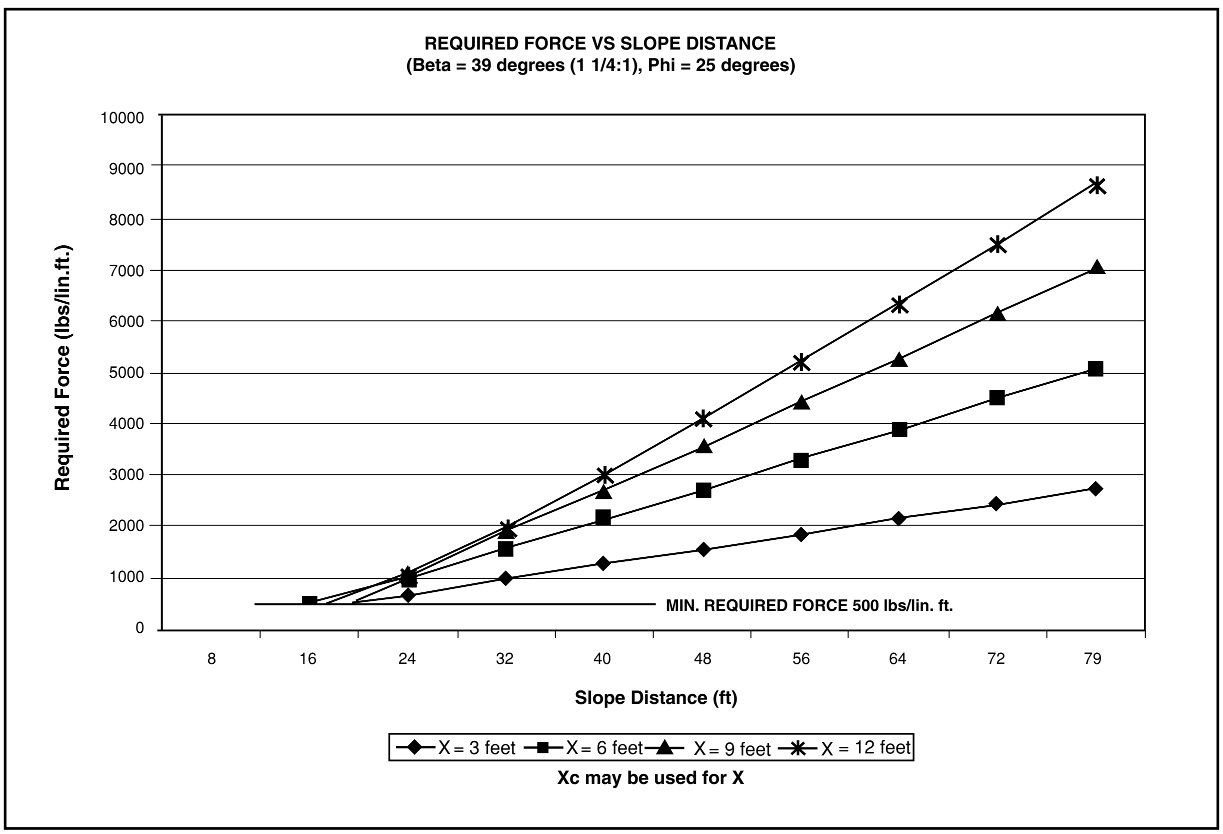


Figure 11—Required force vs. slope distance.

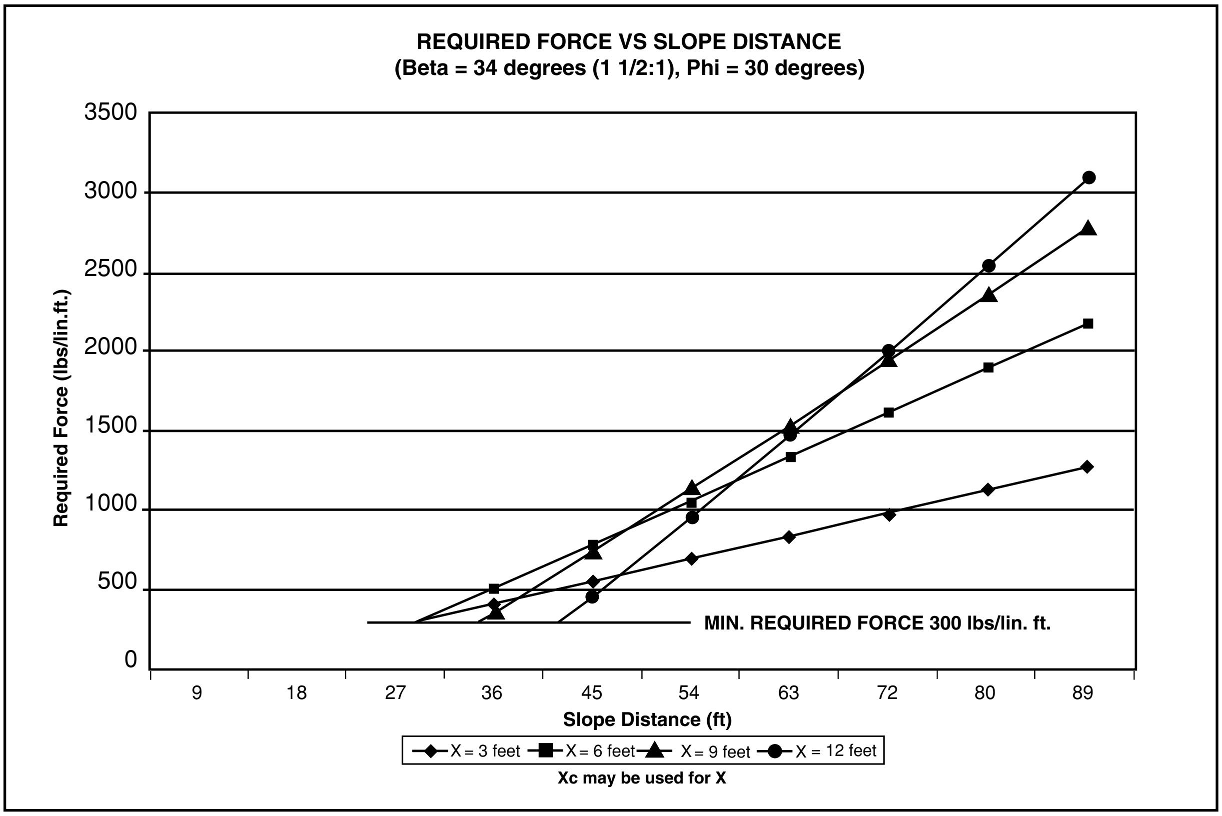


Figure 12—Required force vs. slope distance.

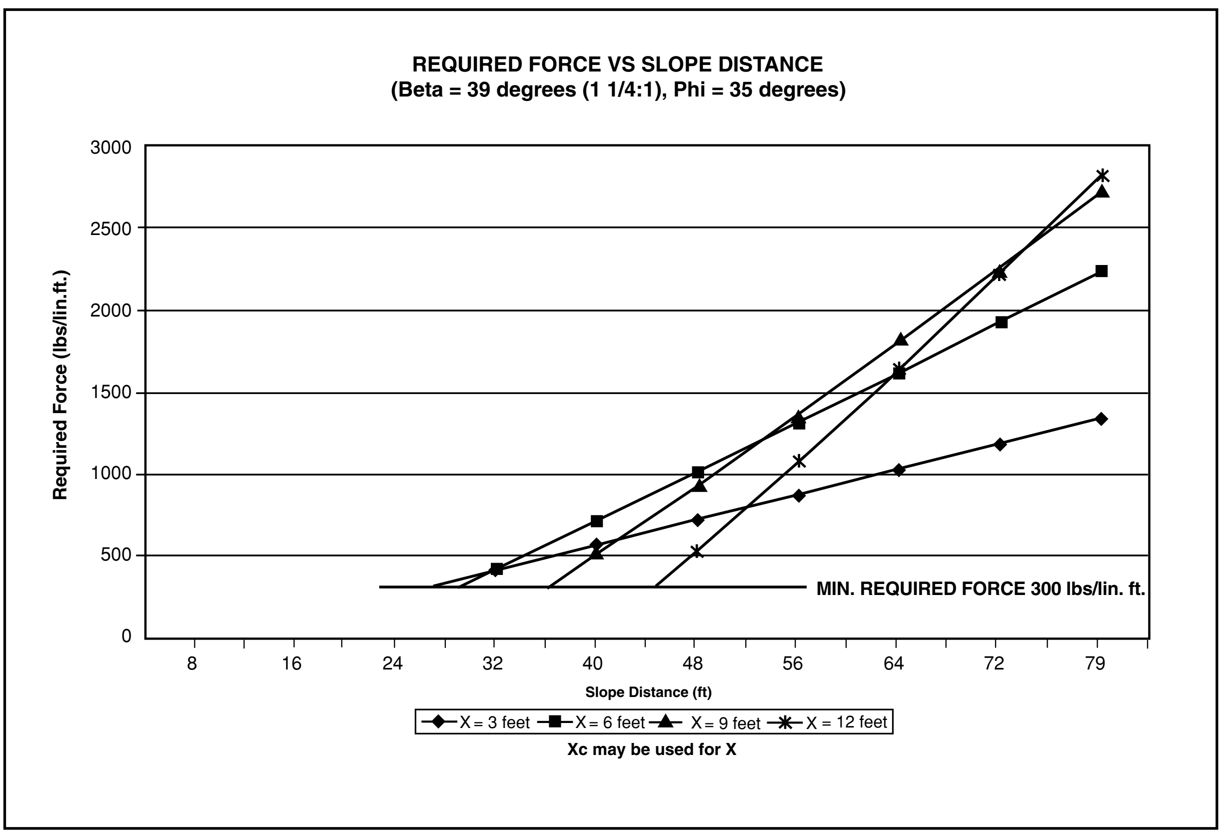


Figure 13—Required force vs. slope distance.

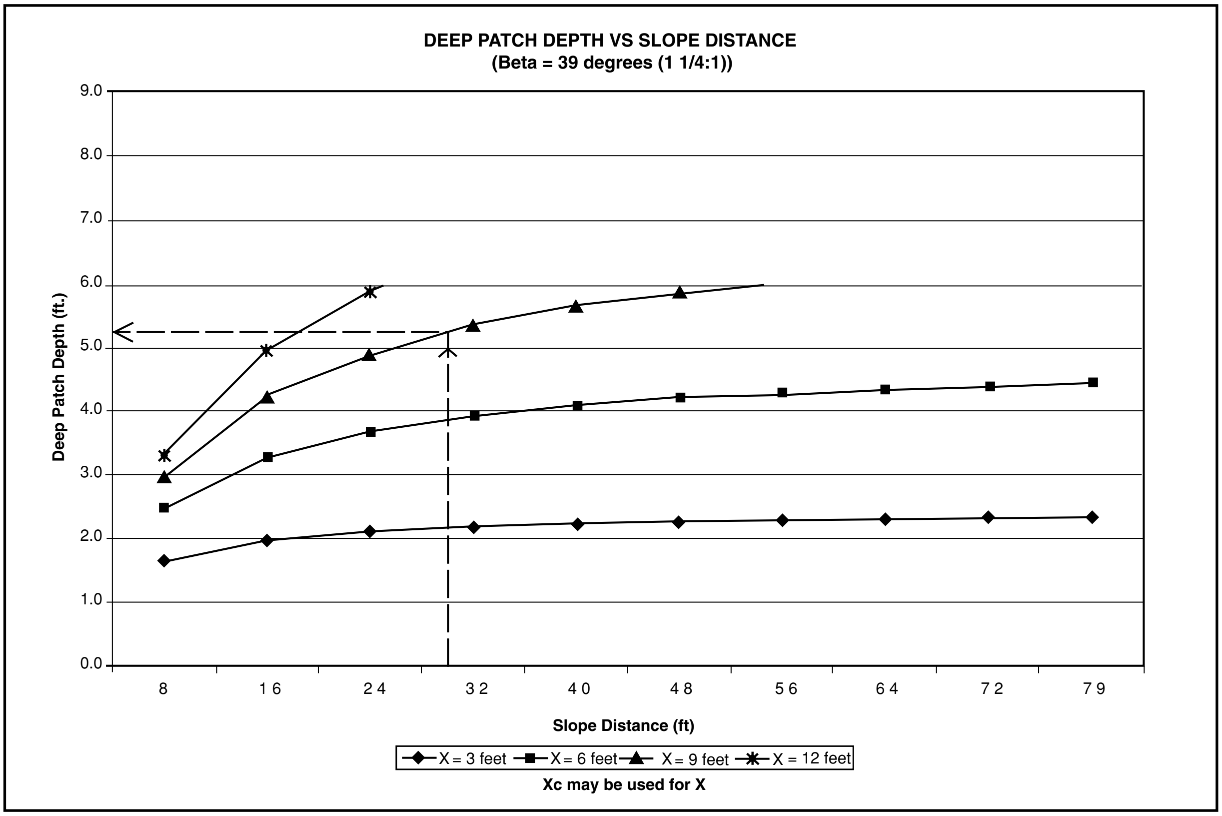


Figure 14—Deep patch depth vs. slope distance.

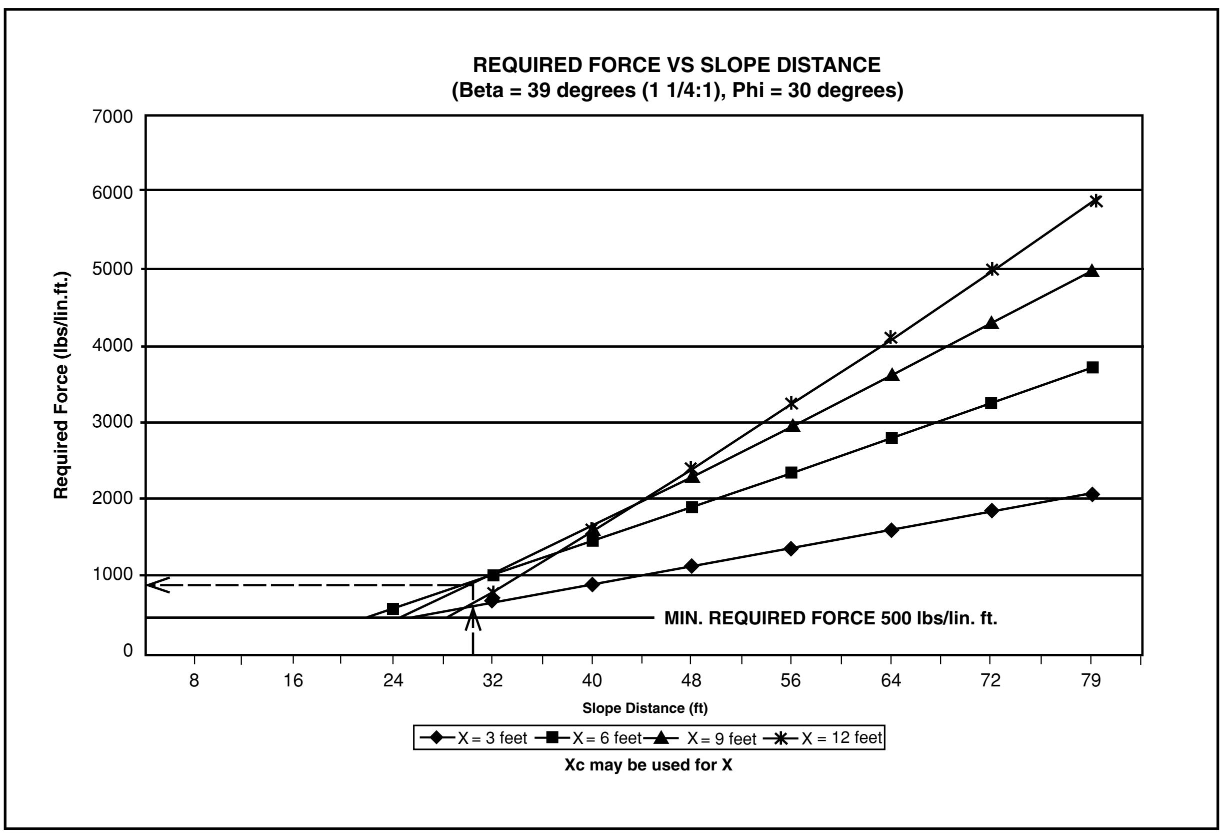


Figure 15—Required force vs. slope distance.

CONSTRUCTION GUIDELINES

Excavation

The minimum excavation width for a deep patch repair is typically 10 feet to accommodate construction equipment. Ramping on at least one end of the excavation allows for access of construction equipment.

Geogrid selection

Geogrid is preferable to geofabric due to its durability. If the uppermost reinforcement is too shallow, geogrid may not be able to develop its maximum pullout strength. Therefore using a lower strength grid for the uppermost layer and acquiring the remainder of the necessary T_{al} in the lower grids may be more economical. Use the graphs to determine the maximum pullout capacity of the grids at various depths. In deciding whether to use one or more strengths of geogrid, consider the following:

- Geogrid is sold in rolls. (If changing geogrid strength requires purchase of additional rolls, selecting a single type of geogrid on a project may save money.)
- If more than one type or strength of grid is on the jobsite, workers could mix them up and place them incorrectly.
- Grids below 500 pounds per foot tend to be more difficult to keep taut during construction.

Calculate TULT (TULTIMATE) by multiplying Tal by the reduction factors for durability, installation damage, and creep. Several resources can help determine these factors:

- Lab testing of proposed reinforcement materials (expensive and time consuming).
- Independent testing by others (such as the Washington State Department of Transportation).
- Manufacturers' test data.
- A default value of 7 (3).

Backfill and Compaction

Backfill costs for a deep patch vary widely. The backfill should consist of noncohesive granular material with no organics. If the onsite excavated material is suitable, it can be the least expensive backfill. *The Retaining Wall Design Guide* (5) specifies pitrun rock less than or equal to 6 inches, typically a medium-priced material, depending on haul distance. Select backfill or crushed aggregate backfill is the most expensive. These backfill materials have been used successfully in deep patches. However, backfill consisting of particles larger than 4 inches may damage the reinforcement members. Nonetheless, because of the low-tech, low-cost, low-risk characteristics of deep patches, such backfill still may be successful.

Compaction of the backfill is critical. A major reason for the original settlement usually is inadequate compaction, so construction of a deep patch without proper compaction is self-defeating. Place backfill in thin loose lifts, moisture-condition to near optimum moisture content, and mechanically compact the fill. Ideally, compact the backfill to a density equivalent to 95 percent of the maximum dry density determined by the AASHTO T-99 method of compaction. However, because deep patch is a low-tech/low-cost design, other methods of determining compaction may work. These include the number of passes of a particular piece of construction equipment or visual displacement, provided that achievement of adequate compaction can be demonstrated by the contractor.

Construction Steps

1. Excavate cut. If the road is paved, sawcut the pavement along the edges of the deep patch before excavation to minimize damage to adjacent pavement. Excavate the unsupported cut to the depth shown on the drawings (figure 6). Construct ramps at the ends of the excavation to provide equipment access. This guide limits deep patch depths to a maximum of about 6 feet.

Figure 16—Excavation of distressed area prior to deep patch construction.

2. Construct cutoff drains (as needed). Install cutoff drains in the proper location to control ground water (figure 17a). Cutoff drains should extend to the bottom of the deep patch or deeper if required. Outlet them for proper functioning (figure 17b).

Figures 17a and 17b—Cutoff drain installation: 17a is parallel to road, and 17b is outlet pipe exiting fill.

3. Shape and compact bottom of excavation. Outslope the bottom of the excavation 2 to 3 percent for drainage of any intercepted water. Compact the bottom of the excavation. (Compaction provides additional strength below the reinforcing layers of the patch.) Place geotextile on the bottom and sides of the excavation to separate poorer material from the deep patch backfill if needed. Then place the leveling course, an aggregate layer placed on the compacted excavation floor, and compact it to about 0.5 foot in thickness.

4. Place reinforcing layer. The reinforcing layer consists of geogrid materials placed, with the machine direction (direction of greater strength) perpendicular to the centerline of the road. While reinforcing layers (geogrids) in most cases are uniaxial, the top layer is sometimes biaxial. Place geogrids taut, laying flat, with no joints parallel to the centerline of the road. (Overlapping the geogrid is unnecessary, figure 18.)

Figure 18—Geogrid layer placed prior to backfilling.

5. Place backfill to level of next reinforcing layer. Layer-place and compact the backfill. Reuse excavated material for backfill, depending on the quality of the material (figure 19). Alternatively, use imported backfill material.

Figure 19—Backfill being placed over geogrid.

6. Place subsequent layers of reinforcing material and backfill. Layer-place and compact the backfill. Place subsequent layers of reinforcing material and backfill until the base course grade is reached. Unless spacing of the reinforcement is less than 1.5 feet or the face is wrapped, the angle of the newly constructed fillslope face is no steeper than 1.25H:1V.

7. Construct pavement structure. For waterproofing, use paving fabric below an asphalt pavement (figures 20a and 20b).

Figures 20a and 20b—Completed deep patches: 20a is paved, and 20b is left with gravel surfacing.

LIST OF SYMBOLS

- X is the distance from the edge of fill (hinge point) to the point at which the road fill changes from cut to fill, for example, the projection of the original ground line on the roadway.

- X_c is the distance from the edge of fill to the innermost crack in the road. This measurement helps determine whether any new cracking is a recurrence of the original cracking or not. X_c can also be substituted for X when evaluating a site, if X is unknown.

- β is the slope angle of the fillslope in degrees.

- ϕ Is the soil angle of internal friction in degrees.

- SD is the slope distance from the edge of fill (hinge point) to the lower limit of the zone of settlement. (When this point is indiscernible, measure down to the toe of the fillslope.)

- L_2 is the maximum distance, along the road, of the cracking. (Typically, the crack will drop off the roadway and disappear in the slope of the fill. However, sometimes the crack exits the road but continues along the top of the fillslope, parallel to the roadway.)

- L_3 is the width of the road.

* L_w is the slope distance from the top edge of the fill (hinge point) to the location on the fill where ground water emerges. (L_w helps determine height of ground water in the road fill for use in the design of drainage below the deep patch.)

- L_e is the length of embedment behind the innermost crack, used in Forest Service Retaining Wall Design Guide (5).

* T_{al} (Tallowable) is the long-term tensile strength required for the geogrid reinforcement (measured on a load per unit width of reinforcing basis). (This guide incorporates the FS=1.2 into T_{al}.)

DEEP PATCH DESIGN EXAMPLE

(Numbered steps correspond to those under graph method in text.)

1. By inspection, the cracking/subsidence is typical of a sidecast fill.

2. A wet area with several seeps indicates waterflow through the fill. This requires drainage design. Include a French or geocomposite drain along the inboard side of the deep patch repair at the same depth as the repair.

3. The dimensions of the area of distress are shown on attached Field Data Form.

4. X_c = 8.5 feet (measured) (use 9 feet) SD = 30 feet measured
   L_2 = 90 feet measured β = 39 degrees measured with an inclinometer
   ϕ = 30 degrees estimated

Using Xc, β, and SD, enter graph 5, obtain deep patch depth of 5.2 feet (use 5.5 feet).
Using Xc, β, SD, and ϕ, enter graph 7, obtain required force of 900 pounds per linear foot.

5. With a required force of 900 pounds per linear foot.
   Use two layers of geogrid with 500 pounds per linear foot, each.
   First layer located 5.0-feet below the finished surface.
   Second layer located 1.0-foot below finished surface.

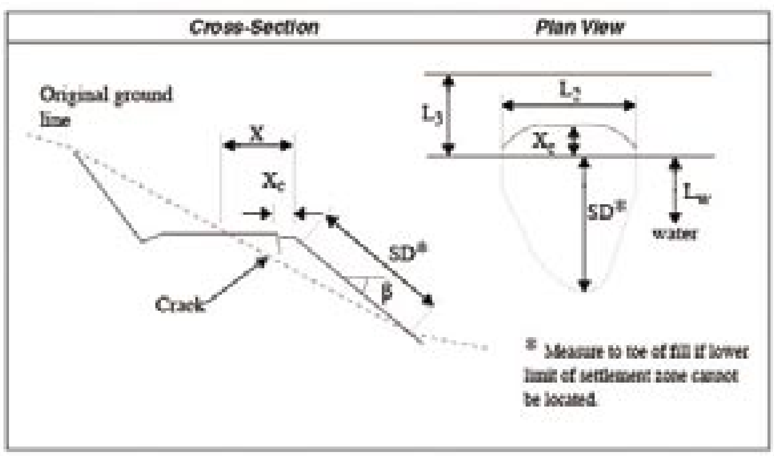


Figure 5
DEEP PATCH
Field Data Form*

Road Number: DESIGN EXAMPLE Date: 10/25/04
MP/Station: Recorder: C. ALDRICH

Location T____ R____ Sec______

Site Description: RELATIVELY STRAIGHT ROAD SECTION, NATURAL SLOPE APPROX 60%, PAVED W/ 3" AC OVER MIN. AGGR. BASE,AC CRACKED PARALLEL TO SLOPE, MAX. 8.5' IN FROM HINGE POINT, NO SEEPAGE ON CUT SLOPE, WET AREA/SEEPS ON FILL SLOPE, FILL SETTLEMENT APPROX. 1-3"

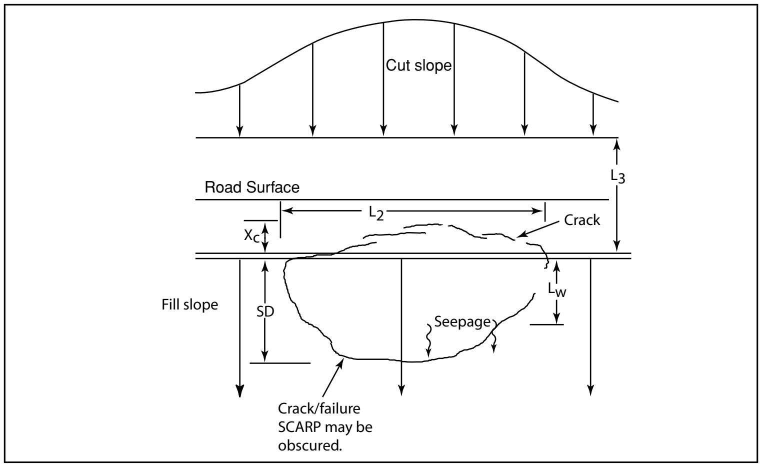
Dimensions

X 10' +/-
X_c 8.5' (use 9')
β 39°
SD 30'
L_2 90'
L_3 22'
L_w 14'

*Adapted from (6)

1

Site Drawing



Site Characteristics Description

Soil Classification

Fill Slope: FINE-MED. SAND, SOME SILT & GRAVEL

Cut Slope: FINE-COARSE SAND, SOME GRAVEL

ϕ(Fill Slope Material): 30° (estimated)

Water Presence at Site

Ponding in Ditch:	Y	**N**	
Seepage on Cut Bank:	Y	**N**	
Seepage on Fill Slope:	**Y**	N	WET AREA, SEEPS
Other:	Y	**N**	

Traffic Safety Risk: H M **L**

Potential for Slope Failure: H **M** L

Consequences of Failure: H **M** L

Overall Site Priority (circle one): H **M** L

2

Design Summary

Deep patch repair is 5.5-feet deep, 100-feet long (L_2+5'+5').

French drain is 100-feet long, 5.5-feet deep along inboard edge of repair depending on road slope; exits at one or both ends and possibly at the midpoint.

Place all fill in loose lifts of 8 inches or less; moisture conditioned to near optimum moisture content, and mechanically compacted to 95 percent of maximum dry density according to AASHTO T-99. Take care not to damage the geogrid or the drain materials.

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ADDITIONAL INFORMATION

Additional information regarding deep patch and other technologies may be found on the San Dimas Technology and Development Center Intranet Web site at: http://fsweb.sdtdc.wo.fs.fed.us/
Electronic copies of SDTDC's publications are available on the Internet at: http://www.fs.fed.us/eng/pubs/ .

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