AUSTRALIAN RAIL TRACK CORPORATION LTD

MANUAL ON WHAT TO DO AND WHAT NOT TO DO WHEN PERFORMING SUB-GRADE MAINTENANCE

Prepared by:

Cantrell Rail Services, Inc.
805 Willow Court
Keller, Texas, U.S.A. 76248

May, 2001

This Training Manual was adapted by Cantrell Rail Services, Inc., of Keller, Texas, U.S.A. for exclusive use by Australian Rail Track Corporation, Ltd. and their personnel.

This Manual on What to Do and What Not To Do When Performing Railroad Maintenance forms a part of a course on railroad embankment and track subgrade maintenance. It is intended to be used as a reference by railroad personnel or railroad contractors after they have completed the Training Course.

The Manual and the Training Course developed to accompany it are intended to provide guidance to railroad personnel and other professionals in recognizing factors that may contribute to railway embankment and subgrade problems. The Manual and course also provide guidance on remedial measures that railroad personnel may appropriately apply in some situations. The information contained in the Manual should not be relied upon as engineering for situation-specific facts and circumstances and is not intended to be a substitute for consultation with a civil engineer or other qualified professional.

Some of the material contained in this Manual was originally developed for the Burlington Northern Santa Fe Railroad by Shannon & Wilson, Inc., of Seattle, Washington, U.S.A. Cantrell Rail Services is indebted to BNSF and Shannon & Wilson for this invaluable assistance.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (cont.) **Page**

LIST OF FIGURES

Figure No.

TABLE OF CONTENTS (cont.) **Page**

SUBGRADE MAINTENANCE TRAINING MANUAL

1.0 PURPOSE OF THIS COURSE

Chronic *instability* of existing railroad track substructures and embankments cause track deflections that require frequent maintenance, speed restrictions, and overall inefficiency of railroad operations. Substructure *instability* can be caused by weak subgrade soils, ballast breakdown, poor-quality ballast, or inadequate thickness of the ballast and top formation layers. Typical problems that develop are subgrade *shear failure*, *ballast pocket* formation, and *fouled ballas*t. Problems may also develop through well intended but inappropriate maintenance actions such as oversteepening of a slope by *bank widening* or toe of slope removal.

Through proactive maintenance and proper repair of “soft track” areas, less money would be wasted returning to the same spot to restore the track, and speed restrictions due to track settlement or misalignment could be removed, which would increase train speeds. Also, costly derailments could be prevented or their probability of occurrence reduced. Faster operating speeds lower operating costs. Fewer derailments also lower operating costs but, more importantly, decrease the potential for harm to railroad personnel, the public, and the environment. Therefore, benefits to the railroad, railroad personnel, and the public can be realized through eliminating or reducing the frequency of soft track impacts on the railroad.

This course has been created to educate ARTC personnel on various aspects of subgrade and embankment maintenance and repair – primarily with regard to the prevention and treatment of embankment *slope failures*, track settlement, or other “soft track” issues. This course is designed to train railroad personnel to identify potential causes of soft track, to assist them in deciding how to best proceed to restore the track, and to provide guidelines for reducing the frequency of occurrence of soft track conditions. General guidelines are presented for treating potential and existing problem areas using surface drainage and *trench drain*s.

2.0 WHAT THIS COURSE COVERS

This course is geared toward prevention and correction of situations that may result in soft subgrades or embankment damage.

In this course we will discuss:

< Common causes of subgrade problems

< Recognizing these causes

< Remedies that may be used in typical soft subgrade or embankment *instability* situations

< Actions that qualified ARTC personnel can take to prevent these problems from developing and to address these problems once they have developed.

We will also discuss situations for which a geotechnical engineer or other qualified professional should be contacted to provide assistance in evaluating the causes of the track movement or to develop recommendations for repairs.

For the purposes of this course, we will refer to soft subgrades, settlement, grade deformations, embankment failures, loss of cross-level, *mud pumping*, shoulder loss, etc. as “soft track”. While not necessarily a strict application of this term, it is nonetheless a common railroad usage. When describing a “soft track” situation to others or for documentation purposes the most accurate description of the condition should be recorded since the term “soft track” is too general.

3.0 WHAT THIS COURSE DOES NOT COVER

This course will not discuss restoration of track caused by track geometry defects such as railhead defects, ballast breakdown, fouled shoulders, low joints, and other non-subgrade related factors. In some cases, track geometry defects caused by these problems may be difficult to distinguish from defects caused by track subgrade problems.

Also, this course will not discuss treatment of soft subgrades in tunnels or design and construction of:

< *Buttresses*

< *Retaining walls* or other slope retention systems

< Specialty deep drainage systems (e.g., *horizontal drain*s)

< Specialty soil stabilization techniques (e.g., *jet groutin*g, lime, or *cement treatment* , etc.)

< Asphalt underlayments

< Geosynthetic reinforced subgrades, top formations, or ballast (e.g., geocells)

< Landslide stabilization measures

A geotechnical engineer should be employed to design systems that use these techniques to improve subgrade performance or increase embankment stability.

Although some of the repair methods discussed in this course may be applicable to the following situations and may even be described in such a manner that persons completing this course could conceivably implement them, a geotechnical engineer or professional should also be consulted prior to implementing repairs on embankments that:

< Are greater than 3 meters high,

< Have cracks in them,

< Have settled more than 25 millimeters at a time,

< Require raising or cross-level adjustment more than once over a 4 month period,

< Have shifted horizontally,

< Have heaved,

< Have heaved ground adjacent to the tracks, or

< Cross a known or suspected landslide.

4.0 SOFT TRACK

4.1 What is “Soft Track?”

Several different types of failure are commonly referred to as “soft track” by railroaders. These include:

< Ballast failure and pumping track

< Top Formation failure

< Shallow subgrade failures (sometimes caused “track squeezes”)

< Rigid layer pumping problems (sometimes called *“mud pumpin*g”)

< Embankment failure

< Larger ground failure (landslide)

While all of the above can produce cross-level and vertical and horizontal alignment defects, they often have different causes and different cures. Considerable experience is required to differentiate between these different failure types and to select an appropriate remedial measure to correct the problem. No single remedy has been identified to correct all of these problems; but since most of these failure modes involve water, drainage improvement is almost always part of the remedy. In some situations ballast *undercutting* or shoulder cleaning may be best. However, it is important to recognize that ballast *undercutting* and shoulder cleaning also improve track drainage.

4.2 Causes of “Soft Track”

4.2.1 Track history

When assessing the causes of soft track it is important to consider the impact of construction and subsequent maintenance on the performance of the current *track structures*. Most of the main lines in Australia were constructed many years ago and many are greater than 100 years old. The emphasis was often placed on speed of construction rather than quality of construction. Furthermore, initial construction was for train traffic that was lighter, slower, and more infrequent than today’s traffic.

Trains are also limited to relatively flat grades when compared with the grades that automobiles can use. Because of this limitation, in many if not most cases, selecting a track alignment that crossed "better" ground was not practical. Many railroads follow rivers or streams; are constructed on poorly draining or moisture-sensitive, fine-grained soils; or were constructed across ancient landslides or landslide susceptible terrain.

Railroad embankments constructed adjacent to waterways are commonly undercut by water flowing in the waterway. In many situations moving to "better" ground was and is not even a remote possibility because many areas that require rail service are underlain by moisture-sensitive clays, or soils subject to severe cracking when dry and which are severely weakened when wet.

In the vast majority of cases, the railroad substructure probably performed satisfactorily for many years. However, many of the embankments still in use are much beyond their original design life and have for many years been subject to frequent, periodic, or infrequent maintenance by railroad personnel. Progressive failure of underlying soils, development of *ballast pockets*, periodic raising of the embankment, poor drainage practices, collection of water in the embankment, increased train weights, and increased train traffic have resulted in embankment and subgrade conditions that are less than ideal (see Figure 1).

Maintenance and repair of the *track structure*, if it is to be effective, should take into consideration the track's original construction, its maintenance history, and its current use.

4.2.2 Track components and functions

4.2.2.1 General

The *track structure* is made up of the rails, sleepers, ballast, top formation, and subgrade (Figure 1a). Each of these components contributes to the primary function of the *track structure*, which is to support the train and to safely transfer train loads to the subgrade. Of primary importance for this course and in practice is the transfer of train loads to soil subgrades and the distribution of these loads (problems with rock subgrades are relatively infrequent).

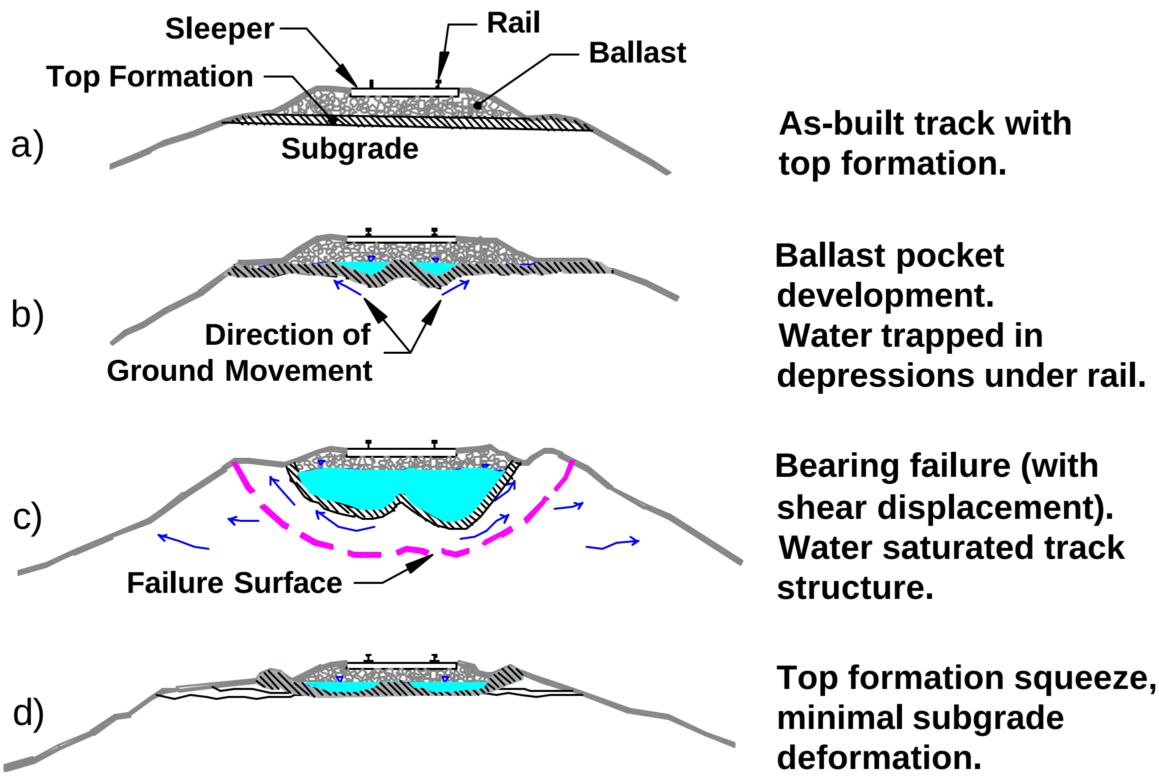


Figure 1. As-built track section and typical sections showing progressive failure.

Stresses applied to the soil subgrade from each engine or wagon axle are relatively high. Where wheels are close together, the wheel loads overlap, increasing stresses on the soil. These stresses are applied and released with each pass of a wagon's wheel. Over time these cycles of load application can add up. For example, over 10,000 cycles per day (3.6 million cycles per year) occur on a track that services twenty-five 100 wagon trains per day. Cumulative deformation of the subgrade from the repetitive application of these train loads leads to the formation of "*ballast pockets*" (Figures 1b and c), a contributing factor in many soft track situations.

4.2.2.2 Ballast

The six most important functions of ballast are [1] :

1. To resist vertical and longitudinal forces and hold the track in position.

[1] *Selig, E., 1998, "Ballast's part: Its key roles and qualities," Railway Track & Structures, Vol. 94, No. 3, pp. 21 – 26, 35.*

2. To provide energy absorption for the track.

3. To provide voids for storage and movement of fouling material in the ballast.

4. To facilitate adjustment of the track geometry.

5. To provide immediate drainage of water falling onto the track.

6. To reduce pressures on underlying materials by distributing loads.

Maintaining ballast in good condition so that it satisfactorily performs these functions also helps with maintenance of subgrades by reducing the frequency of occurrence of situations that lead to trapped water and overstressed subgrades.

4.2.2.3 Top Formation

Top Formation is the layer between the ballast and the subgrade (Figure 1a). It is primarily a coarse-grained material consisting of sand and gravel particles. The five most important functions of top formation are:

1. Further distribute loads from the ballast to the subgrade.

2. Prevent subgrade particles from entering the ballast and prevent ballast from being pushed into the subgrade.

3. Prevent wearing of the subgrade surface by ballast particles, which in the presence of water, produces a slurry that will pump into the ballast voids.

4. Intercept water flowing down through the ballast and direct it away from the subgrade.

5. Drain water that might be flowing upward from the subgrade.

Although top formation is generally placed in new construction it does not commonly occur below ballast in old tracks and is not usually placed or replaced following *undercutting* operations. Because of this, it is not uncommon for maintenance personnel to have never heard of top formation. In practice, on old lines and on lines in which ballast has been added without first removing old ballast, the *fouled ballast* that has built up over time serves some of the functions of top formation. However, this *fouled ballast* often does not adequately serve all of the intended functions of top formation, particularly with regard to drainage.

The absence of top formation, inadequate top formation and ballast thickness, and the use of poor top formation materials are contributors to the development of many soft track conditions. Additionally, progressive failure and development of *ballast pockets* may have begun prior to later applications of ballast above old *fouled ballast* layers.

4.2.2.4 Subgrade

The subgrade is the soil or rock below the top formation (Figure 1a). Subgrade soils may be in-place natural materials or have been placed to support the railroad. Subgrades constructed with low *permeability* soils, such as clay or silt, or with *moisture-sensitive soils* experience soft track problems more often than subgrades of rock or relatively permeable sand and gravel. Subgrades located too close to the bottom of the track, with insufficient ballast and top formation thickness, may become over-stressed and also subject to soft track problems. Subgrade problems often are progressive in nature. They develop over a number of years, and soft track situations may occur at locations that have not experienced problems since they were originally constructed.

4.2.3 Contributors to "Soft Track"

Factors that commonly contribute to subgrade related soft track conditions include:

< Water

— Rainfall
— Water in *ballast pockets*
— Water in ballast
— Water between "rigid slabs" and underlying subgrade soils
— Water in embankment soils and cracks in embankments
— High groundwater and springs
— Embankment erosion

< Weak subgrade soils
— Clay subgrade
— Silt subgrade
— Saturated or wet soils
— Progressive *shear failure* (and buildup of *ballast pockets)*

< Overstressed subgrade soil
— Insufficient ballast and top formation thickness
— Progressive *shear failure* (and buildup of *ballast pockets)*
— Increased train loadings
— Too high or too steep of an embankment

< Poor Construction Practices
— Inadequate foundation preparation –
∗ Constructing new fill over topsoil
∗ Constructing new fill over wet, weak, or soft ground
∗ Not benching into existing ground prior to placing fill

— Inadequate compaction or moisture conditioning of fill
— Fills constructed too steep
— Inadequate drainage systems
— Use of "wrong" type of fill –
∗ Use of oversized rock
∗ Use of *moisture-sensitive soils*

< Poor Maintenance Practices
— Inadequate cess drain and culvert maintenance
— Oversteepening of embankments (by excessive track raising or widening of tops of fills)
— Placing fill on slopes
— *Undercutting* of slopes

< *Fouled ballast*

4.2.4 Typical places where soft track is found

Soft track situations may occur just about anywhere along a line. However, certain areas, even those initially well constructed, may be predisposed to developing soft track conditions. These locations include (but are not limited to):

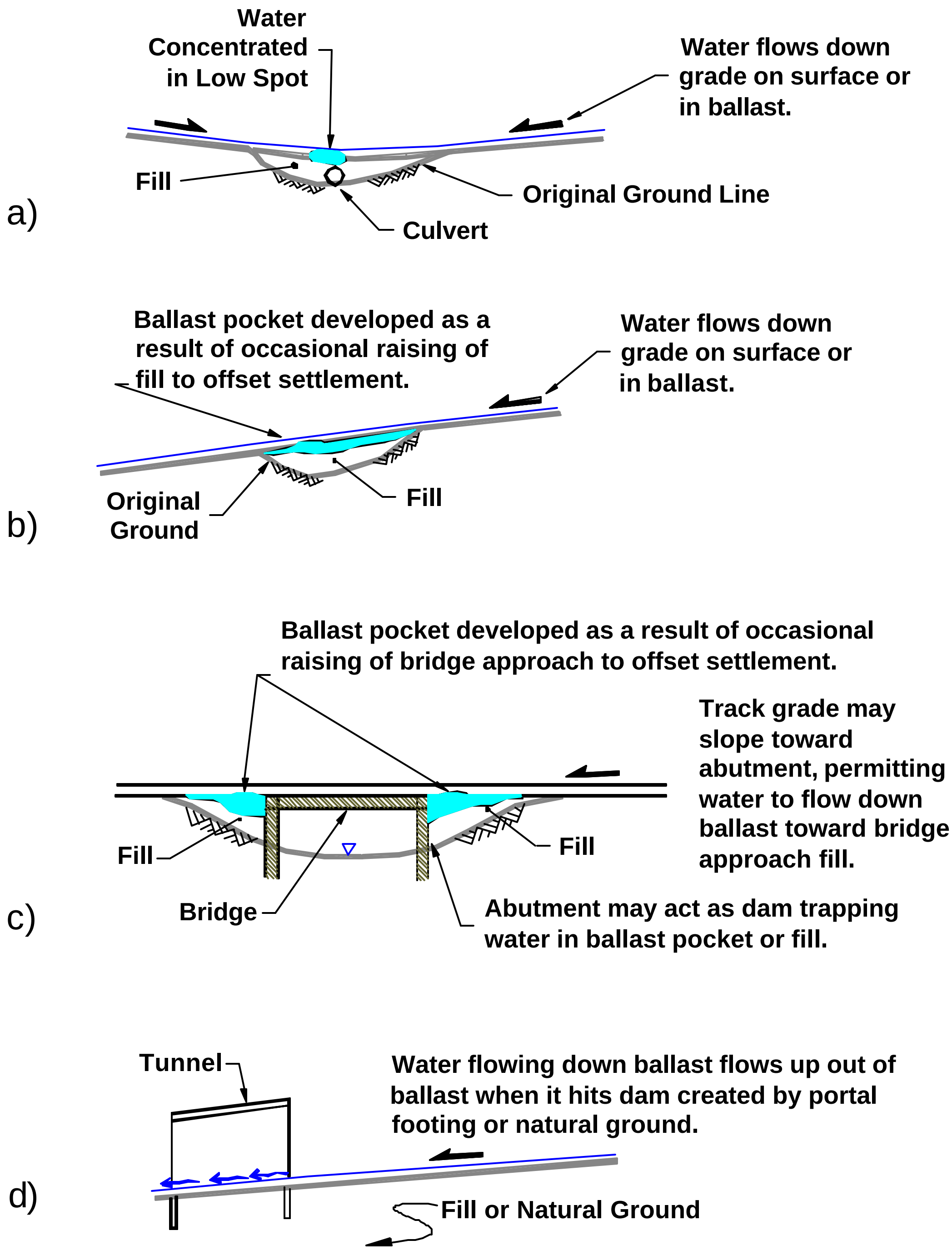


Figure 2. Some typical soft track locations: a) sags in vertical alignment, b) fills, c) bridge approaches, and d) tunnel portals.

< Bottom of sags in vertical alignment (Figure 2a)

< Embankment/fill (progressive "sag" and *ballast pocket* buildup) (Figure 2b)

< Contact of embankment/fill with track in cut (Figure 2b)

< Bridge approaches (Figure 2c)

< Tunnel portals (Figure 2d)

< Over culverts (Figure 2a)

< Embankments without culverts or with plugged culverts (Figure 3)

< Road crossings (Figure 4)

Soft track problems also tend to develop where low quality construction practices were employed, where progressive failures have resulted due to the passage of time or increased train loadings, or where poor drainage practices have been employed. Examples include:

< Low embankments where the track elevation is very near the original grade, a situation that may result in poor drainage, overstressed subgrade soils, or in which low quality soils were used to construct the embankment.

< Older embankments constructed across sloping ground. These embankments were often constructed using uncompacted materials, unsuitable soils, or soil containing organics and were often placed without first removing topsoil from the area beneath the fill (Figure 5).

< Embankments that interrupt natural drainage patterns. In many of these locations culverts have not been installed, culvert capacity is inadequate, or the existing culvert or culvert inlet is plugged (Figure 3).

4.3 The Ballast Pocket

A *ballast pocket* develops when a depression develops in the top formation or subgrade below the tracks (Figures 1b and 1c). This depression may get its start as a result of a number of factors

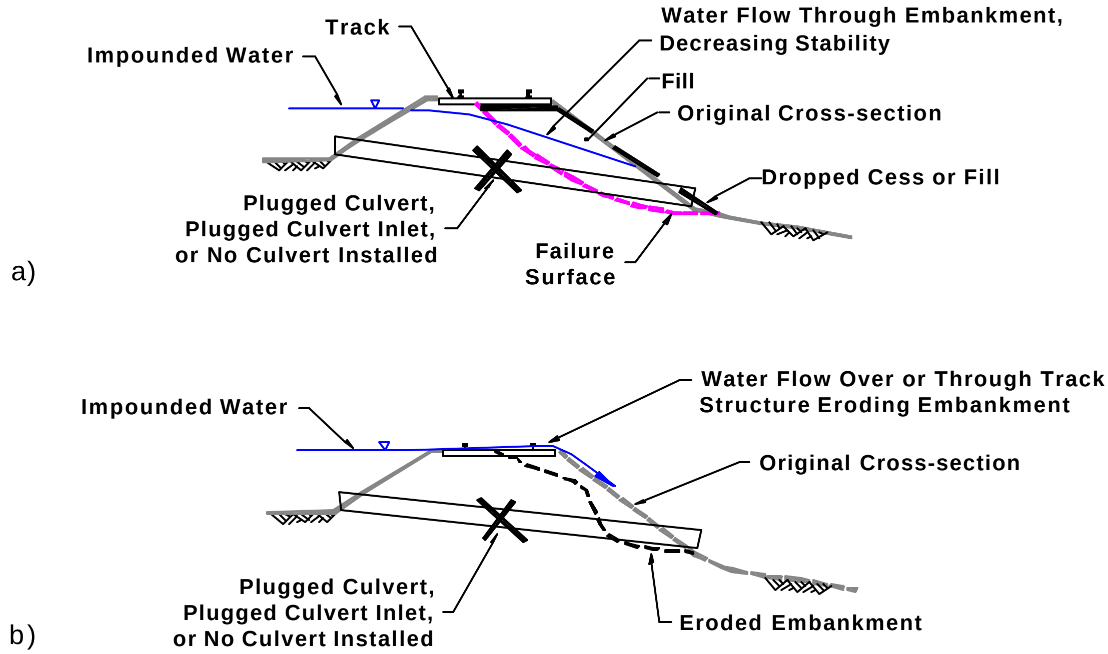


Figure 3. Embankment instability and erosion caused by plugged culverts, plugged culvert inlets, or inadequate culvert capacity.

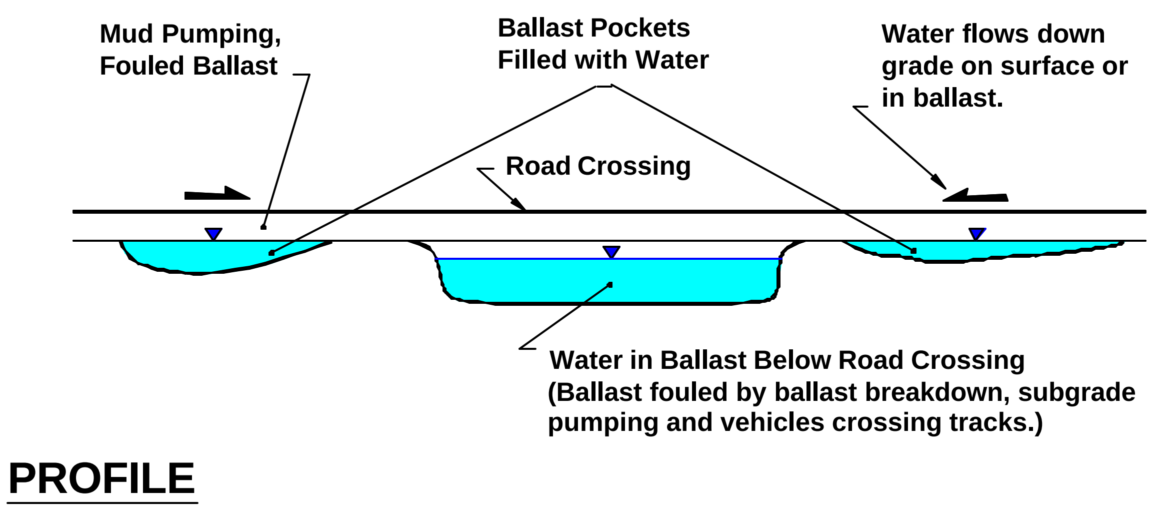


Figure 4. Water trapped in ballast pockets and fouled ballast at a road crossing.

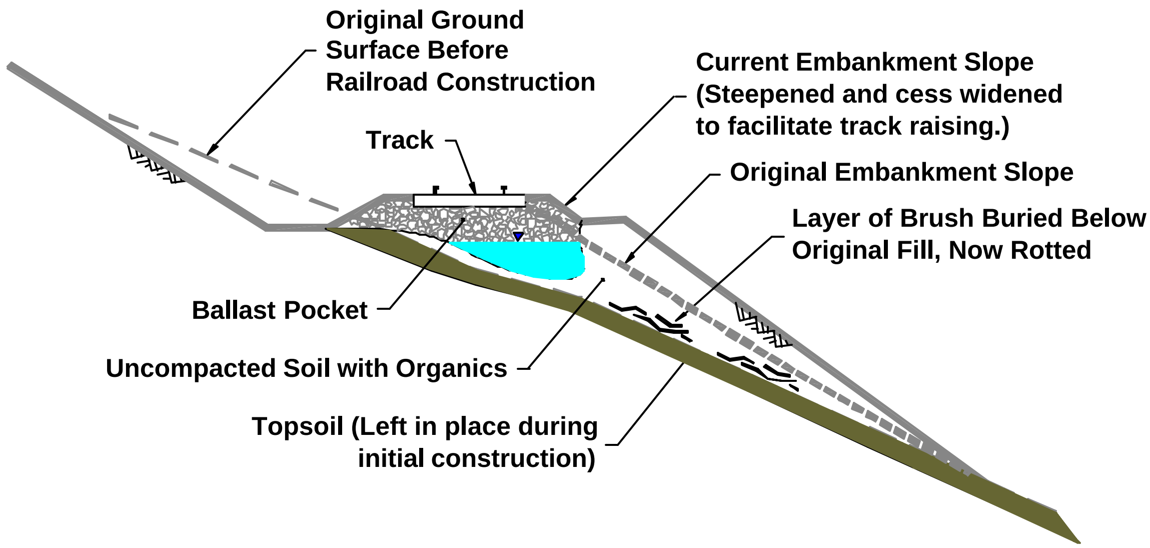


Figure 5. Embankment constructed using poor construction practices.

including settlement of the fill, progressive *shear failure* of soils beneath the track, *consolidation* of subgrade or top formation material, deformation of the subgrade under train loads – including impact loading, and other factors. Poor initial construction practices and construction with or on soft, loose, or weak soil can result in development of *ballast pocket*s. However, *ballast pockets* also develop in locations that were initially properly constructed. Settlement of high fills; settlement of fills adjacent to road crossings, tunnels, and bridge abutments; concentration of water at low points on track profiles; and overcompaction of soils directly beneath the rails may result in the development of relatively large (deep) *ballast pockets* over time as the track is continually regraded and additional ballast is added.

Once a depression develops beneath one or both rails, water falling on the track will flow to and sit in these depressions (see Figures 1, 2, 4, and 5). This water will then infiltrate the ground or flow down the track section until it finds an outlet, a crack to flow into, or a lower elevation pocket in which to sit. Water that infiltrates the ground may weaken underlying soils and thereby increase the rate of *ballast pocket* development. As *ballast pockets* get deeper, water may sit in the pockets for longer periods of time, resulting in the soil remaining in a weakened state for a longer period of time. The *ballast pockets* also are a source of water that may act to destabilize marginally stable embankments. Raising of embankments that have settled deepens existing *ballast pockets* in the fill, and may contribute to future *instability* of the embankment.

Water trapped in *ballast pockets* is a very common occurrence, especially below track that has been previously raised, and at chronic problem areas that have been previously repaired. Draining water from *ballast pockets* should be considered in nearly every soft track situation where there is the potential for *ballast pockets* to exist. How to drain the ballast is discussed in other sections of these course notes.

4.4 Drainage

4.4.1 General

Before "soft track" areas can be effectively treated the cause or primary contributors to the track condition should be identified. This is sometimes easier said than done. As stated previously, water is a primary factor in many if not most soft track situations. However, while water may not have been the initial cause of a particular soft track situation, the development of the soft track situation generally leads to the introduction of water, which accelerates the problem.

Before water can be drained, potential sources of water must be identified. In general, there are four principal sources of water to consider:

1. Rainfall directly on the *track structure.*

2. Surface water flowing toward and infiltrating the *track structur*e.

3. Water flowing within the *track structur*e, e.g., within *ballast pockets* or fill used to construct the embankment.

4. Groundwater

4.4.2 Water falling directly on the track structure

Short of constructing a shed over the track or relocating the track through a tunnel, it is unlikely that water could be prevented from falling on the *track structur*e. However, maintenance programs should attempt to drain as much of the water that hits the *track structure* as possible.
Techniques used to reduce infiltration when constructing new track include sloping the upper surface of the subgrade and top formation, placement of clean ballast, construction of cess drains.

below the bottom of the top formation, and shaping embankment shoulders so that water flows away from the track. Periodically regrading the top of the subgrade and top formation is not a practical track maintenance operation. However, ballast and embankment drainage are areas that can be addressed by maintenance programs. Activities that address *fouled ballast* issues are discussed in Section 4.5. Cess drain maintenance and maintenance of well-graded embankment cesses are areas where maintenance personnel can make a difference.

< Maintain cess drain bottoms at least 300 millimeters below the bottom of top formation.

< Keep cess drains clean and properly graded.

< Keep embankment cesses clean and sloped to drain.

4.4.3 Surface Drainage

Collecting and diverting surface water away from the *track structure* may be the most cost-effective portion of any subgrade maintenance program. The more water that is intercepted and diverted, the less water available to infiltrate and potentially weaken the *track structur*e. Recommended maintenance practices include:

< Improve surface drainage – make sure runoff runs off and does not pond.

< Divert surface water prior to it reaching the problem area.

< Keep surface water as surface water – do not let it pond, do not let it infiltrate the embankment or ground upslope of the embankment.

< Deepen cess drains to 300 millimeters below the bottom of top formation (do not deepen cess drains to the point that the track section is undercut).

< Grade cess drain bottoms to improve runoff.

< Clean cess drains and culverts.

< Check culverts and ensure they are in good condition, have not rusted through, and have not pulled apart.

a)

b)

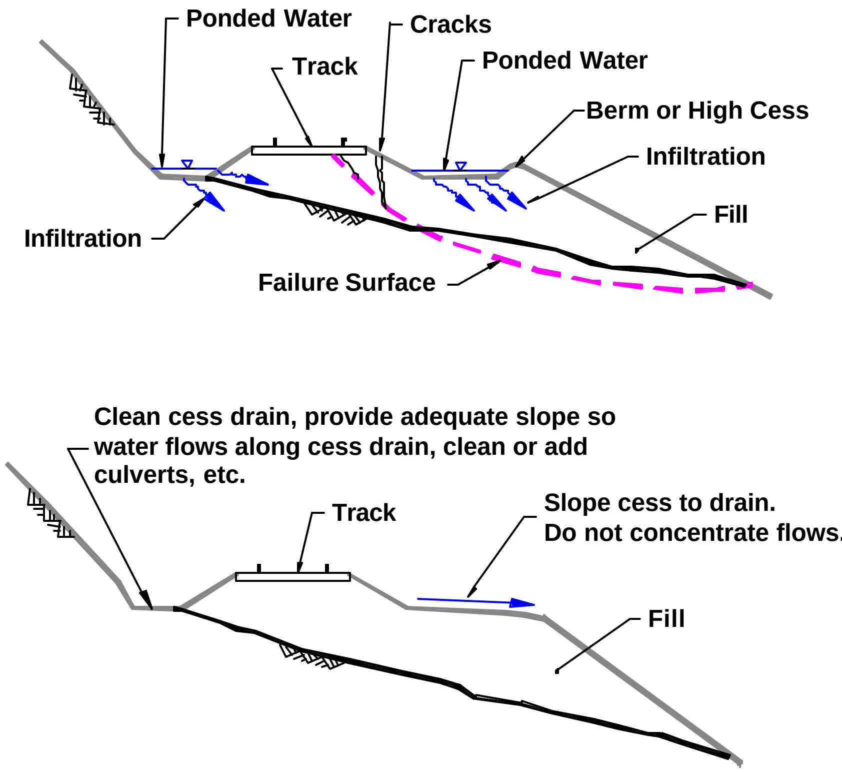


Figure 6. a) Infiltration of water resulting from poor surface drainage; b) recommended surface drainage improvements.

- Replace culverts that are too small with culverts of adequate capacity.

- Maintain culvert inlets and install systems to reduce the potential for the inlet to plug or for debris to wash into the culvert and plug it.

- Clean embankment cesses of undercutter, ballast cleaner, and cess drain cleaning debris. Grade cesses to drain water over side of the embankment without concentrating the flow (Figure 6). Erosion protection measures may be required on the slope of the embankment.

A common misconception with construction of cess drains is that deeper is better. This is not always the case. Digging too close to the track section or embankments and digging too deep can cause undermining of the track or embankment failure. Care should be taken to properly construct the cess drains so that they serve to drain the track area, not adjacent fields. In some cases, installation of near-track subsurface drains is more appropriate (see Section 4.4.5).

4.4.4 Culverts

4.4.4.1 General

Surface drainage systems include culverts. Because this course is oriented toward maintenance issues, design and installation of culverts will not be discussed. However, improperly maintained or inadequate culvert pipes, inlets, and outlets can contribute to soft track situations. Also, culverts are often located in areas particularly susceptible to the development of soft track because of topography, *geology* and *geologic history*, poor original embankment construction practices, and because water is diverted toward the culverts – which provides greater opportunity to introduce water into the adjacent embankment. Many culverts were put in many years ago and may be corroded, damaged, partially or completely plugged, or undersized. Other culverts may have been improperly installed or backfilled or were installed under conditions not conducive to long culvert life (for example, installation during a rainstorm or a short track window).

4.4.4.2 Culvert Pipes

Leaking culverts, whether due to corrosion, poor installation, pulling apart of the culvert (typically at joints), or some other cause may permit water to flow into the embankment soils. This water may then contribute to destabilization of the fill.

Culvert maintenance programs should include:

< Replacement or repair of undersized and damaged culverts.

< Cleaning completely or partially plugged culverts.

< Relining of corroded pipes. Many methods for doing so are available. A qualified engineer should be consulted to evaluate the alternatives and develop recommendations.

< Replacing severely damaged, undersized pipes, and pipes with vertical sags. If the existing damaged pipe is left in place in the embankment and a new pipe installed nearby, the inlet to the existing pipe should be plugged so that water does not continue to flow down it and leak into the embankment. Completely filling the abandoned culvert with soil,

grout, or concrete should be considered if there is a potential for collapse of the culvert and impacts to the *track structure*.

< Installing internal couplers to repair or re-couple corrugated metal pipe joints that have partially pulled apart.

When you see that a culvert joint or the culvert pipe itself has pulled apart, it should warn you that a more serious problem may exist at the site and something other than simply replacing or repairing the culvert may be required. Shifting and settlement of the embankment, progressive failure of the embankment over time, or relatively rapid slope movements (some of which may have happened in the past and the embankment "repaired" at that time) can result in culvert joints pulling apart or stretching and failure of the pipe itself. Often this occurs in chronic soft track locations, in areas predisposed to embankment problems, and where the embankment has been oversteepened due to erosion at its toe or overbuilding of the embankment cess. An embankment already predisposed to *instability* may experience a further decrease in stability by water introduced into the embankment from the damaged culvert.

The potential need for embankment stability improvements should be explored whenever pulled-apart culverts are observed. Implementation of some potential stability improvement alternatives is discussed in this course. Implementation of other measures may require the assistance of a geotechnical engineer.

4.4.4.3 Culvert Inlets

Plugging of culverts and culvert inlets with debris can decrease culvert capacity. Ponding of water upstream of the culvert can result in water flowing over or through the embankment or *track structur*e. Water that infiltrates the embankment can decrease stability (Figure 3a). Water flowing over the embankment can erode the downstream face (Figure 3b). Both situations should be avoided if possible.

Plugging of culverts and culvert inlets can occur slowly or rapidly, e.g., during a heavy runoff storm event.

Figure 7. Culvert inlet trash rack constructed with rail.

Maintenance programs geared toward reducing the possibility for culverts or culvert inlets to plug should include:

< As-needed cleaning of soil and debris that accumulates in culverts and at culvert inlets.

< Removal of brush and trees that may be carried with runoff water toward the inlet from upstream drains and channels.

< Construction of inlet grates and trash/debris racks (Figures 7 and 8). Inlet grates and trash/debris racks should include features that permit access for cleaning debris that accumulates on them. Access for cleaning the culvert should also be provided.

4.4.4.4 Culvert Outlets

Erosion of slopes below culvert outlets by water discharging from culverts is a frequent contributor to embankment failures and loss of track cess (Figure 9). To reduce the potential for this occurrence:

Figure 8. Culvert inlet trash rack designed to permit continued flow if end of culvert becomes plugged with debris.

Figure 9. Erosion of embankment below culvert outlets.

Figure 10. Riprap placed around and below a culvert outlet to reduce erosion.

< New culverts should be installed so that their outlets are located at the toe of the embankment slope.

< New and existing culverts that do not discharge at the toe of the embankment should be extended so that the water discharges at a location that will not erode the slope.

< If culvert pipes are not extended or if anticipated discharge velocities may result in erosion, the slope or channel below the outlet should be lined or otherwise protected. Riprap and concrete are commonly used for lining outlet channels and protecting slopes below culvert outlets (Figure 10). Other systems are also available.

4.4.5 Track Subsurface Drainage

Excluding erosion by surface waters, water generally causes the most problems after it infiltrates railroad embankments and *track structures*. Water in the soil and in cracks that have opened in the ground can destabilize embankments or decrease soil strength. This water is often a major contributor to soft track conditions. Draining this water from the track section and embankment is fundamental to improving track and embankment performance.

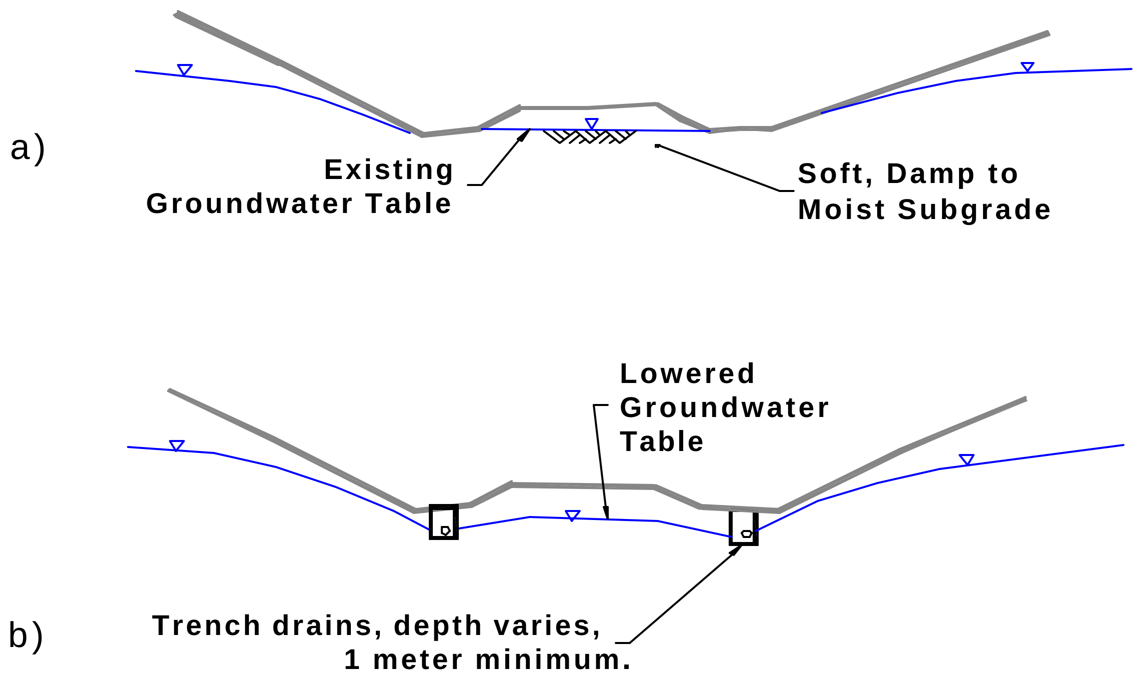


Figure 11. a) High groundwater condition in a cut, b) shallow drains installed parallel to the track to lower the groundwater table.

Typical places within an embankment where water may be expected to accumulate or become trapped, and from which it should be drained, include:

< *Ballast pockets*

< Cracks in embankments

< At the contact between the subgrade and a relatively rigid slab that overlies the subgrade but is below the ballast. (see Section 4.6)

< At the contact of more permeable rock or soil with less permeable materials.

A method commonly employed to drain water from track sections and embankments is to construct gravel-filled *trench drain*s. Because this method is so frequently used and because of its economic benefits and ease of construction, an entire section of this course is dedicated to *trench drain* design, location, and construction (see Section 6).

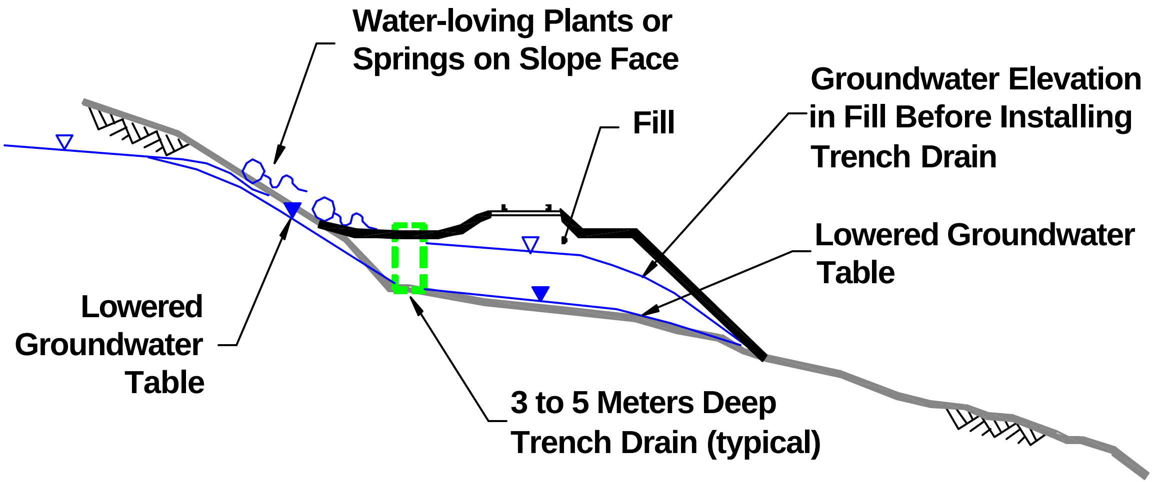


Figure 12. High groundwater condition causing embankment instability. Lowered groundwater condition resulting from trench drain installation also depicted.

In very rare situations where track sections cannot be shut down to permit *trench drain* construction, other drainage systems may be warranted. The assistance of a geotechnical engineer should be retained for these situations.

4.4.6 Non-track Groundwater Interception and Drainage

Groundwater in soils below embankments, flowing toward embankments from upslope areas, or flowing toward track constructed in cuts can lead also to soft track conditions (Figures 11 and 12). Interception and removal of this water and lowering of the water table to a satisfactory distance below the embankment or track substructure may improve the performance of embankments and track sections. Collection and removal of this groundwater may also improve stability of the slope through which the water is flowing, whether located above or below the track.

Some indicators of high groundwater conditions are:

- The presence of springs on slopes above or below the track.
- Ground that is wet even during extended dry periods.
- Vegetation normally associated with wetlands growing on nearby slopes.

< Green vegetation growing in cess drains or on slopes during dry times of the year, especially in regions of the country with dry climates.

Gravel-filled *trench drains* (see Section 6) may be constructed to intercept and drain near-surface (less than 6 meters deep) groundwater flowing toward the track (Figure 12). These drains may be constructed parallel to and relatively near the track or at some distance upslope from the track. Shallow drains with pipes are sometimes installed parallel and near the track to improve subgrade performance (Figure 11b). The most effective and most practical location to install *trench drains* to intercept off-alignment groundwater depends on a number of factors, including the source of the water, depth, site topography, site *geology*, access considerations, property ownership, etc. In the vast majority of situations, a geotechnical engineer should be consulted to assist with siting and installation of these *trench drains*.

Depending on the groundwater depth, topography, and *geolog*y, other drainage systems may be required. *Horizontal drains*, small diameter perforated pipes installed in holes drilled into the cutting batter, are one common alternative. The holes are drilled at a slight upward inclination so that water that infiltrates the pipe will flow to the pipe outlet at the slope face. This technique gained wide acceptance along some railroads for landslide stabilization in some locations of the United States during the 1960's and 1970's. At that time *horizontal drains* were commonly referred to as "hydroaugers." The assistance of a geotechnical engineer is recommended for *horizontal drain* applications.

High groundwater conditions and springs are also common contributors to landslides. In landslide susceptible terrain *trench drain*s, *horizontal drains*, or other subsurface drainage methods may be components of a landslide stabilization program. However, because many factors may affect ground *instability*, the assistance of a geotechnical engineer is recommended.

4.5 Fouled ballast

In many different types of circumstance, localized stretches of *fouled ballast* form in the *track structure* (Figure 13). *Fouled ballast* may be caused by a number of sources, including ballast breakdown, contamination by top formation or subgrade soils, and contamination by soils carried into the ballast by wind, water, vehicles crossing the track, materials dropped from wagons, or

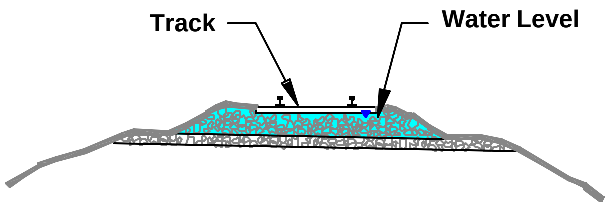
Figure 13. Fouled ballast

other sources. Ballast breakdown has been found to be the greatest contributor to *fouled ballast* conditions.

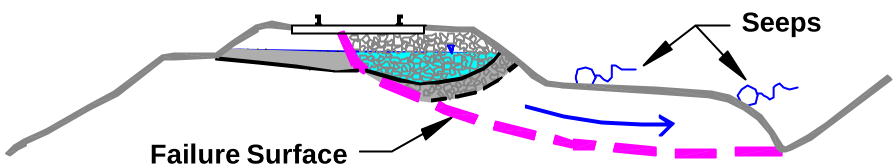
Ballast breakdown often occurs under track locations where impact loading is most intense. Problems with impact loading in switches, particularly at the frog, are common. Railhead imperfections like wheel burns and battered joints may also cause impact loading under traffic. Impact loading can lead to accelerated ballast breakdown and fouling of the ballast. *Fouled ballast* and shoulder fouling lead to water retention in the *track structure* (Figures 14 and 15). As the crushing and grinding of ballast particles under traffic progresses, drainage from the *track structure* is impaired. The water retained in the ballast as a result of this impaired drainage accelerates the ballast breakdown process. Ballast failure and the *mud pumping* associated with it may cause loss of sleeper support.

Traditional maintenance methods such as *undercutting* and shoulder cleaning should generally be employed to clean and replace ballast fouled as a result of ballast breakdown. However, if the fouling is localized, shallow *trench drains* cut perpendicular to the track section and at relatively close spacing may be a cost effective temporary means of improving an otherwise deteriorating situation (see Section 6).

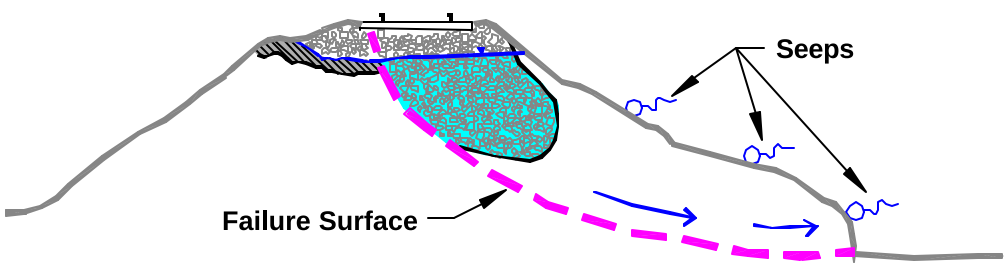
Ballast contamination can also occur as a result of pumping of subgrade soils into the ballast or pushing of ballast into the subgrade. These situations most commonly occur in areas with



Ballast breakdown and shoulder fouling - water trapped in fouled ballast. Top formation may be clean and dry.



Shallow shear failure blocks cess drain.



Deeper shear failure.

Figure 14. Water retained in fouled ballast and development of ballast pockets because of ground movement contributed to by trapped water.

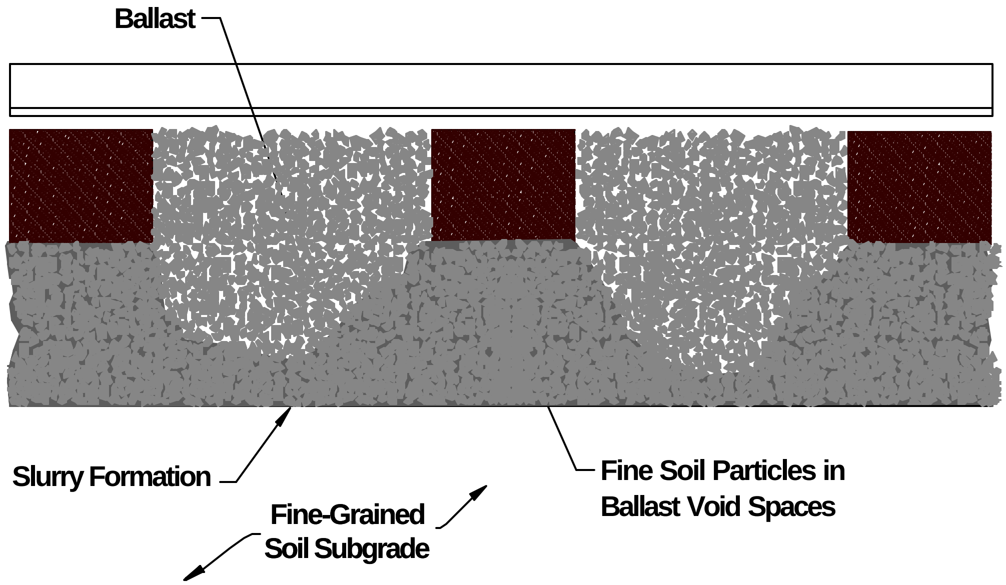
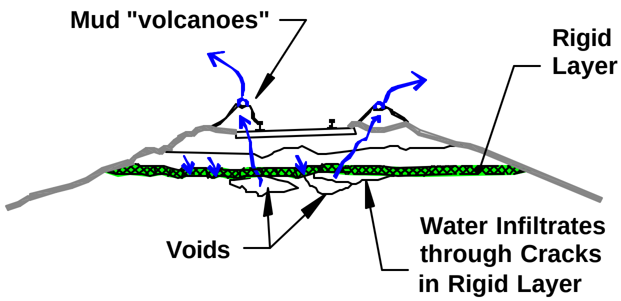


Figure 15. Schematic of fouled ballast.

soft subgrade soils (Figures 1b and 1c). Construction of shallow *trench drains* may provide cost-effective temporary relief (see Section 6). However, treatment of locations underlain by soft soils eventually may be expected to involve decreasing the stresses acting on the subgrade by raising of the track and placing additional ballast or by reconstructing the track section with clean, well compacted top formation and ballast of adequate thickness to spread the loads.

Many grade crossings are located at the low point of a track profile. Severe ballast fouling often occurs on the upgrade side of the crossing, partially as a result of water flowing down the *track structure* toward the crossing where it accumulates on the approaches or in the crossing itself (Figure 4). Other crossings, though on flat profiles, also develop muddy approaches. The water in the ballast accelerates ballast breakdown and often results in *mud pumpin*g. The water may soften low *permeability* subgrade soils, resulting in loss of support for the track and the buildup of *ballast pocket*s. While reconstruction of the affected approaches may be the ideal solution, installation of *trench drains* within and upgrade of the affected areas may be a sufficient maintenance remedy. These drains would intercept and drain water flowing down the track section (see Section 6), which may substantially lengthen the service life of the crossing.



Rigid layer pumping failure caused by breakup of rigid layer and erosion of underlying subgrade.

Figure 16. Formation of mud volcanoes as a result of rigid slab mud pumping.

4.6 Rigid Slab Mud Pumping

Mud pumping, and subsequent fouling of the ballast can also occur at track locations that are underlain by “rigid slabs.” A rigid layer may be caused by compacted fouled limestone ballast, densified or desiccated clay-rich soils, *lime treatment* of subgrade soils, injected materials, asphalt layers, and more. Repetitive train loading can cause cracks to develop in “rigid” slabs overlying relatively weak soil or in slabs with inadequate burial depth below the track.

Water that finds its way into the cracks can accumulate on top of the subgrade soils beneath the rigid slab. In addition to softening the subgrade soils, each train wheel that passes forces water out of the crack. Because the loading is relatively rapid and the pressures high, the water is squeezed out at a relatively high velocity and may carry soil particles with it. Mud volcanoes may be created in and above the ballast as a result of this process (Figure 16). As soil particles are eroded from below the slab, a void may develop. The presence of voids created in this manner can further decrease track performance.

The long-term treatment generally recommended for this situation is to remove the track, excavate the rigid slab, repair or replace the weakened subgrade soil, and place a properly constructed track section with adequate thickness of top formation and ballast. However, this is not practical in all locations. Alternative solutions that can be rapidly implemented by maintenance personnel may be more appropriate.

An alternative is for maintenance crews to install shallow *trench drains* oriented perpendicular to the tracks to drain water that collects below the rigid slabs (see Section 6 for *trench drain* construction information). The *trench drains* should be positioned along cracks in the slabs (i.e., where mud volcanoes form), should penetrate the slab, and should extend across both rails. Relatively close spacing of the *trench drains* may be required, although their total depth may be relatively shallow. Special excavator buckets that fit between sleepers may simplify construction of these shallow drains as the need to remove ties may be eliminated and track restoration simplified.

4.7 Embankment Construction, Configuration, and Repair

4.7.1 Embankment Construction

While new embankment construction may not generally be considered a maintenance function, improper construction of new embankments often leads to maintenance headaches. For the purposes of this discussion, new embankment construction also includes widening of existing embankments. In general, embankment construction should be performed with the assistance of a geotechnical engineer. However, some key factors to consider when constructing fills are discussed here to aid personnel in recognizing potential contributors to maintenance problems.

Prior to placing fill for new embankments, a solid foundation should be prepared. Unsuitable soils (topsoil, soft, loose, weak, or saturated soil) that lie beneath the footprint of the fill should be removed so that the fill soils are keyed into firm ground. Quality fill material should be used and it should be compacted as it is placed to minimize post-construction settlement. Reduction in post-construction settlement should reduce the rate at which *ballast pockets* develop (but not prevent them). Implementing quality construction practices for fill construction is a proven method for reducing long-term fill maintenance.

Unfortunately, removal of unsuitable material, use of quality fill materials, and proper moisture conditioning and compaction of the fill were (and in some instances still are) not common practices of railroads and their contractors (Figure 5). A relatively common modern practice has been to replace old timber bridges with fills. This replacement is often performed by dumping fill between the existing bridge piles and piers. The bridge and its piles may or may not be removed prior to placing the fill, unsuitable soils are rarely removed prior to fill placement, and the fill is rarely compacted. Embankments constructed in this manner are susceptible to deep-seated failures, settlement, and

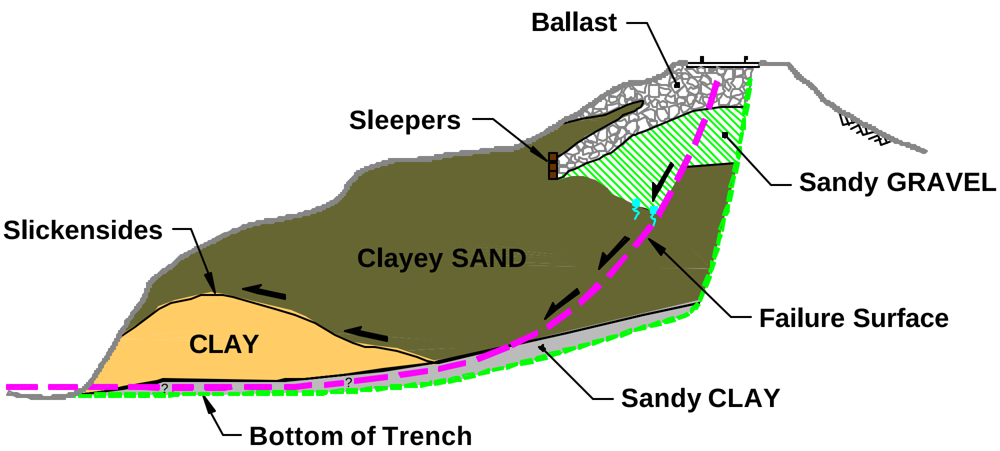


Figure 17. Cross section through embankment constructed to replace timber bridge.

development of *ballast pockets*. "Soft track" frequently occurs at these locations and they generally require frequent maintenance. A generalized cross section of one eight-year-old embankment constructed under these conditions and subsequently repaired is presented in Figure 17. Photographs of excavations into the embankment are presented in Figures 18 and 19.

The unsuitable soils located beneath embankments contribute to embankment *instability*. In these situations, simply draining water that finds its way into *ballast pockets* that develop in the fills may not be enough to stabilize them. Additional measures may be required, including flattening the slope, *buttressing* the toe of the slope, constructing *shear keys*, constructing *retaining walls,* embankment removal and replacement, or other measures. In general, a geotechnical engineer should be retained to assist with the design and construction of these additional measures, especially at chronic soft track locations.

When existing fills are widened, quality construction practices should be employed to avoid creating potential maintenance problems. Quality construction includes:

- Removal of topsoil and other unsuitable soils from beneath the footprint of the new fill, including the slope of the existing fill.
- Compaction of fill materials.

Figure 18. Photo of excavation into embankment constructed to replace timber bridge. Notice bridge bent buried in fill.

Figure 19. Photo of excavation into embankment constructed to replace timber bridge. Notice timber piles buried in fill and now leaning as a result of embankment movement.

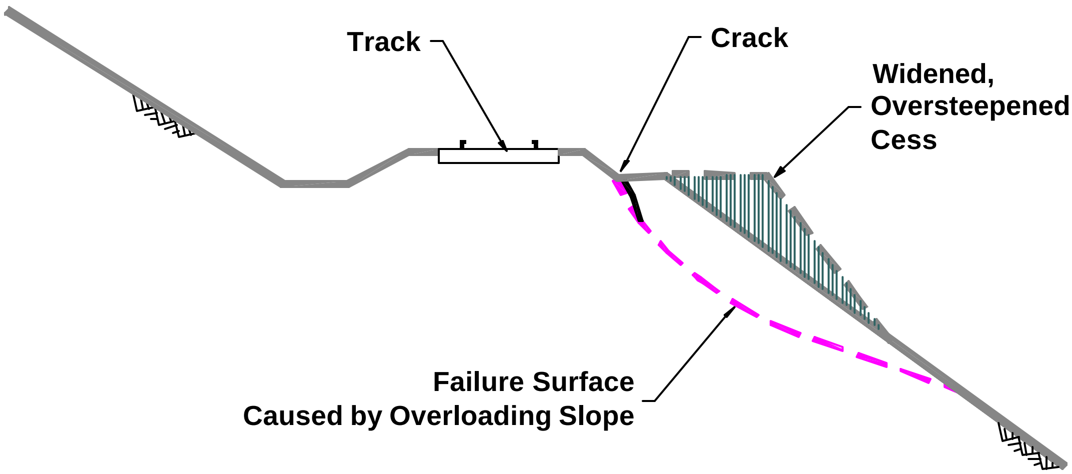


Figure 20. Embankment instability caused by oversteepening and placing fill on top of slope.

< Benching existing slopes to key the new fill material into it.

< Constructing the new slope as flat as or flatter than the existing slope.

< Installing a drainage system between the new and old fill if clayey or silty soils make up the existing fill or will be used for the new fill.

< Installing drains through *ballast pockets* beneath the tracks on the existing fill.

4.7.2 Embankment Slopes

In general, the flatter the embankment slope, the more stable the embankment. Increasing the steepness of existing slopes tends to decrease stability and may cause or contribute to embankment failures. Railroad embankments may be especially susceptible to becoming oversteepened because many of them were initially constructed with slopes nearly as steep as they could stand (to minimize material requirements) or have been steepened as a result of raising the track.

The most common situations observed on railroads that result in steepening of existing embankments include:

< Raising the track grade without widening the fill.

< "*Bank widening*," i.e., adding material at the top of an embankment to increase the width of the cess (Figure 20). *Bank widening* is mistakenly believed by some

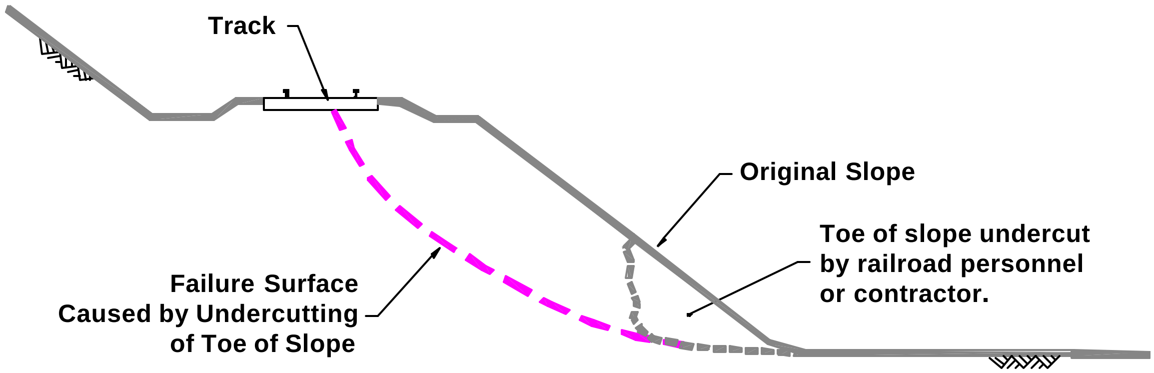


Figure 21. Embankment instability caused by undercutting the toe of the slope.

railroaders to increase embankment stability because it provides them with a wider cess to work on, so they "feel" safer.

< Disposing of material from cess drain cleaning, *undercutting*, or ballast plowing operations on the side of the embankment. This material tends to end up near the top of the slope (Figure 20).

< *Undercutting* of the embankment toe by railroad personnel or contractors (Figure 21). This situation commonly occurs when repairs are being undertaken on an embankment that has experienced a *slope failure* and material at the toe of the slope is being replaced, or by the construction of access roads.

< *Undercutting* of the embankment toe as a result of erosion by water flowing along the base of the embankment or water flowing down the side of the embankment (Figure 22). Water discharging from culvert outlets is also a common contributor to *undercutting* of embankment slopes (see Section 4.4.4.4).

These situations should be avoided as they effectively steepen the embankment, decreasing stability. Maintenance programs should be planned and undertaken so that materials are not placed near the top of embankment slopes and slopes are protected from erosion. Replacing material at the toe of the slope should be performed under the direction of a geotechnical engineer.

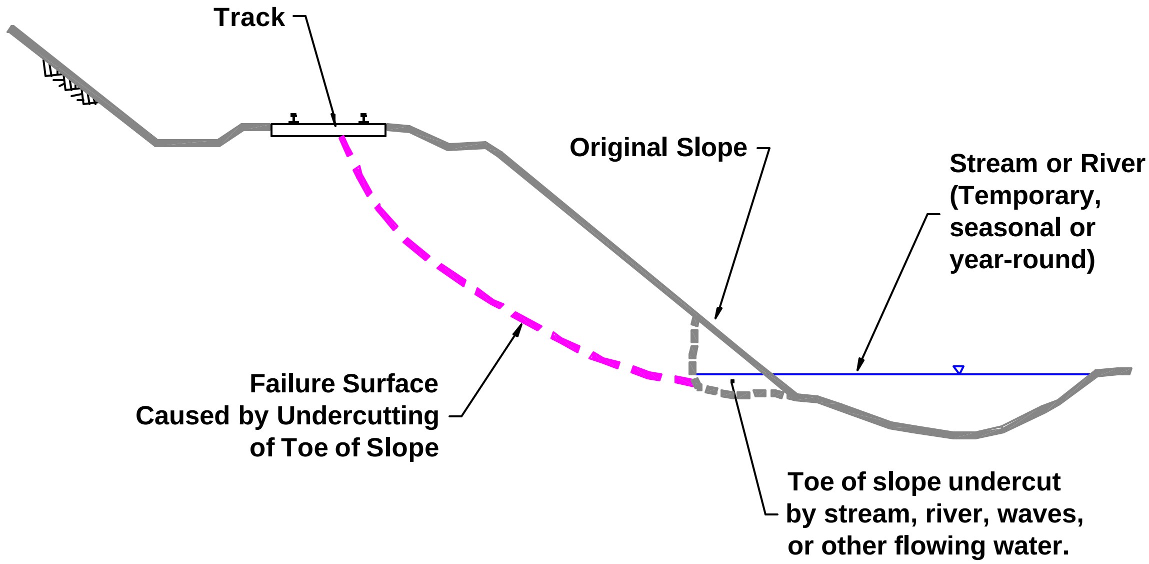


Figure 22. Embankment instability caused by erosion at the toe of the slope.

4.7.3 Embankment Repair

4.7.3.1 General

Embankment repair and other stability improvement measures may be required when slumping, shifting, or cracking of an embankment occurs. In general terms, there are three basic actions that can be taken to improve the stability of existing embankments:

1. Decrease the destabilizing forces. This includes decreasing water pressure in the soil and in cracks in the embankment and removal of weight from the top of the embankment. Drainage related considerations have been previously discussed. Weight removal from the top of the slope may include trimming the slope to create an embankment with a minimal shoulder width or lowering the elevation of access roads constructed along the top of the embankment adjacent to the track. These actions can normally be undertaken on relatively short notice by railroad or railroad contractor personnel.

2. Increase the resisting forces. This includes adding weight at the toe of the embankment such as

through construction of a *buttress* fill, flattening of the slope, and construction of a retaining structure.

3. Increase the strength of soils within the embankment and along (potential) sliding surfaces. This may be accomplished by removing and replacing weak soils with more competent soils or by improving the *shear strength* of soils using special techniques. Assistance from a geotechnical engineer is recommended for implementation of these alternatives.

A common mistake made when repairs are made to embankments that have settled is for the embankment to be raised back to its original grade without addressing the cause for the settlement. In general, settlement tends to occur following a wet period or as a result of water in the fill. Consequently, drainage improvements should be a part of track raising or reconstruction of a fill that has experienced a blowout at its toe. If erosion of the embankment slope was the primary cause of the embankment *instability*, reconstructing the slope to a stable configuration should be performed as part of track restoration. Other stability improvement measures, such as removing material from the top of the slope, slope flattening, toe *buttressing*, constructing retaining structures, or other measures may follow.

The assistance of a geotechnical engineer is advised when soft track conditions occur or persist during or following relatively dry periods.

4.7.3.2 Cess Heave

These are shallow *shear failures* in *track structures* resting on soft subgrade soils. These failures are driven by repetitive and dynamic loading of the soil by trains. With the passage of time and additional train loading the failure progressively increases in size. These failures are characterized by track deformation adjacent to heaved soil on the toe path or heaved ground immediately adjacent to the track. They are sometimes referred to as “track squeezes.”

Cess heave can be found anywhere along a track with soft subgrade, even on the top of a high fill. It develops as a result of *shear failure* of subgrade soils or remolding and displacement of soft soil from beneath the track section

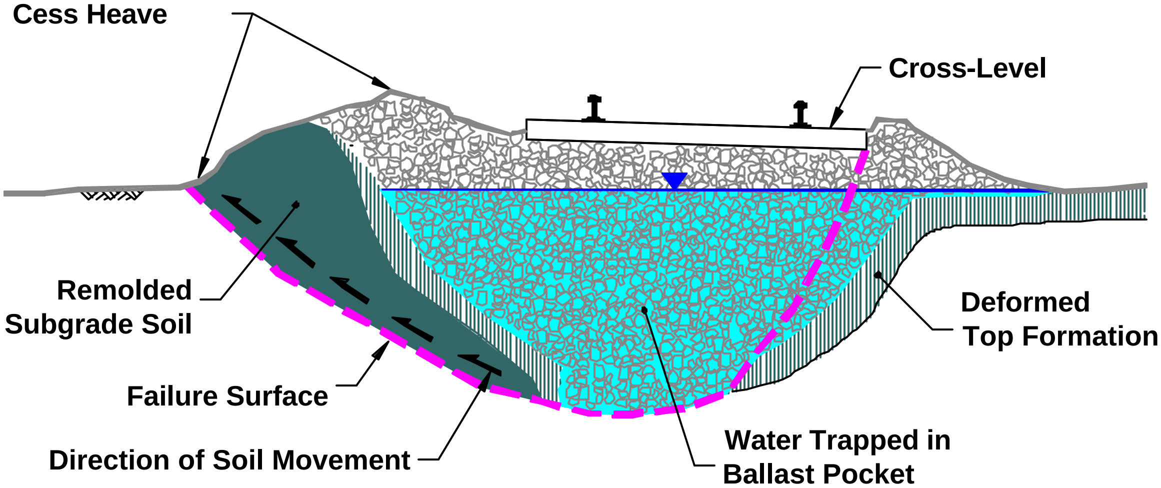


Figure 23. Heave of track shoulder due to overstressing of subgrade soil.

(Figures 1c and 23). The use of poor materials for top formation, or the lack of a top formation layer, may result in lateral displacement (squeezing) of soils relatively close to the bottom of the ballast (Figure 1d). The progressive nature of this type of failure frequently results in the development of a *ballast pocket* below the track. Water trapped in this ballast exacerbates stability problems, because the presence of water tends to keep the soft soil “soft” and applies lateral pressures to the soils on either side of the water pocket.

Closely spaced *trench drains* combined with construction of a “*shear key*” (replacement of weak materials with better materials, Figure 24) can be very effective at controlling these failures. The drains allow water to drain from the failure and, if installed correctly, also replace portions of the shear plane with stronger granular materials. The *shear key* constructed adjacent to the track replaces weak soils with stronger granular soils. If water is permitted to drain from the *shear key* backfill, the *shear key* also acts as a shallow subsurface drain.

Trench drain design and construction is discussed in Section 6. To construct a *shear key*, the heaved zone adjacent to the track is removed and replaced with compacted, angular, granular materials. Ballast is commonly used for backfill because it is readily available, easy to work with, and drains well. One edge of the *shear key* is commonly located along the edge of sleepers on the side of the track experiencing the heave. If both sides are

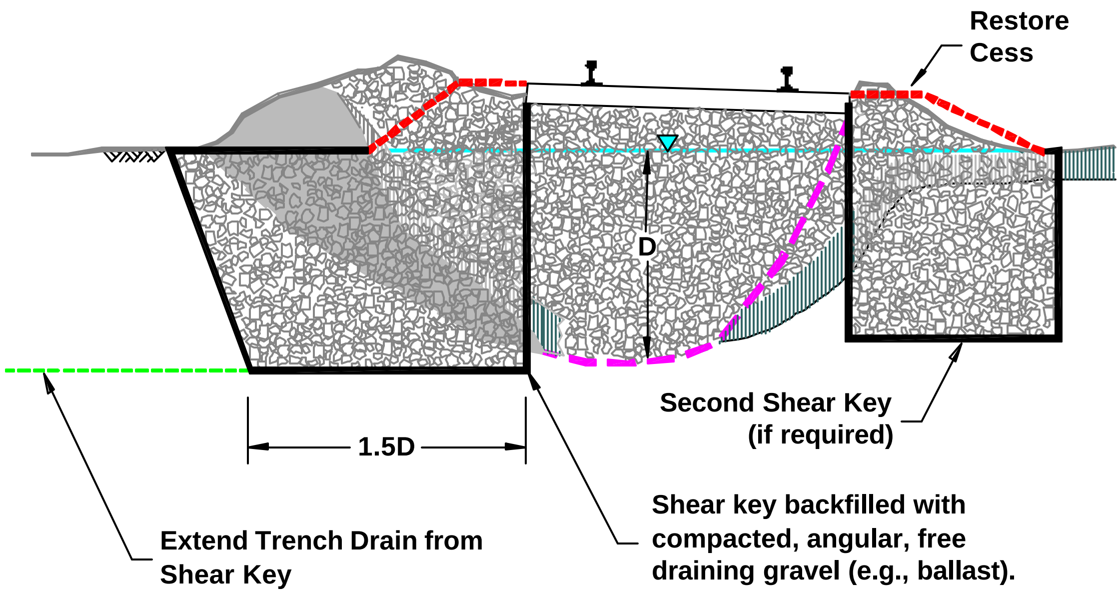


Figure 24. Gravel filled shear key.

heaving, construction of a key on both sides of the track may be required. The width of the *shear key* is a function of the height of the embankment, underlying soils, and size of the failure. Typical widths are about 2 to 4 meters. The bottom of the *shear key* must be located below the *slide plane* and founded in firm materials.

Because excavating a continuous trench along the end of the sleepers may undermine the track, extreme caution is required during construction. Generally, to improve embankment stability, the *trench drains* should be installed prior to excavating the *shear key*. *Shear key* installation on embankments greater than 1.82 meters in height should be performed with the assistance of a geotechnical engineer.

4.7.3.3 Embankment Buttressing

It is a common misconception that big rock provides more support than small rock. As a result, big rock is routinely used for construction of *buttresses* and reconstruction of failed embankment slopes. Although big rock may be necessary in special cases, such as where fast moving water is present where the fill needs to be placed, in most other cases, big rock is a poor material for stabilization work. This is because fill constructed primarily of big rock particles also has a lot of void space between the particles (Figure 25), and thus, although the individual particles may be heavy, the large volume of voids results in a low average mass of the overall fill.

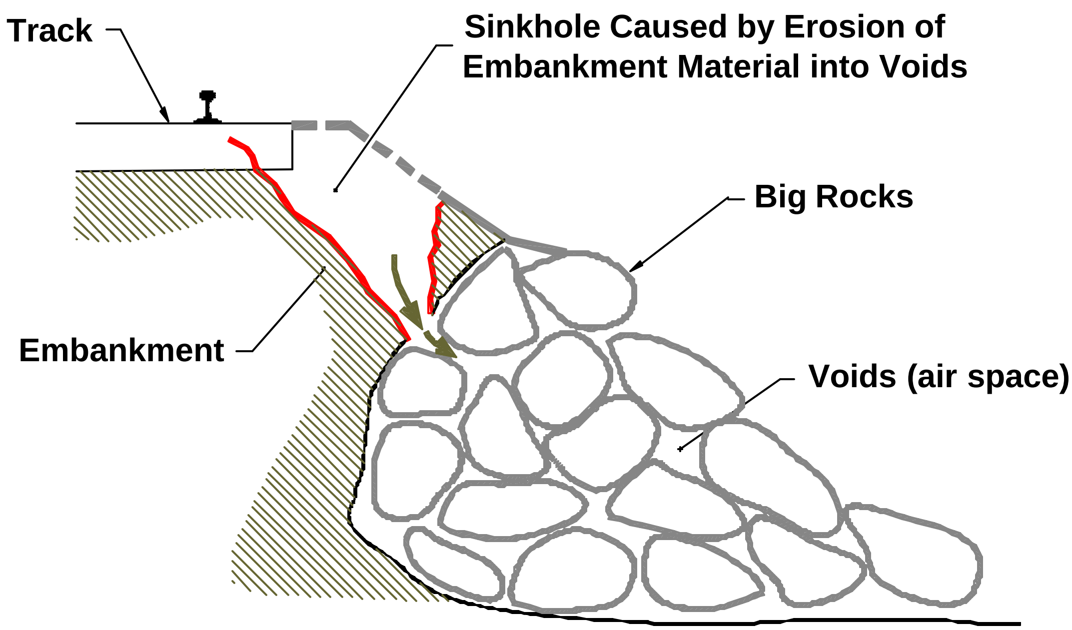


Figure 25. Big rocks used for embankment construction and buttressing.

An additional potential problem created by using big rock for fill is that the soils that are placed above or are located below the big rock may migrate into the voids. This process could result in ground loss, settlement or the development of sinkholes (Figure 25).

A better material choice than big rock is a well-graded material where smaller particles fill the voids between larger particles (Figure 26). Fills with lower void volumes are generally heavier, and thus, more stable. In many situations, if the material can be placed near its optimum moisture content and protected from future saturation, site available soil or other soil without special *gradation* requirements may suffice. Additionally, because the voids are relatively small or have been filled, the potential for migration of adjacent soils into voids into the fill is eliminated.

Although unsuitable material should, in general, be removed prior to construction of a fill, excavating at the toe of an existing embankment to "key" new fill into the existing ground may cause an embankment failure. Excavation for the key may create a situation similar to *undercutting* of the embankment toe (Figure 21). Excavations at the toes of existing embankments, especially those that have experienced prior movement, should be performed with care. The assistance of a geotechnical engineer is generally advised.

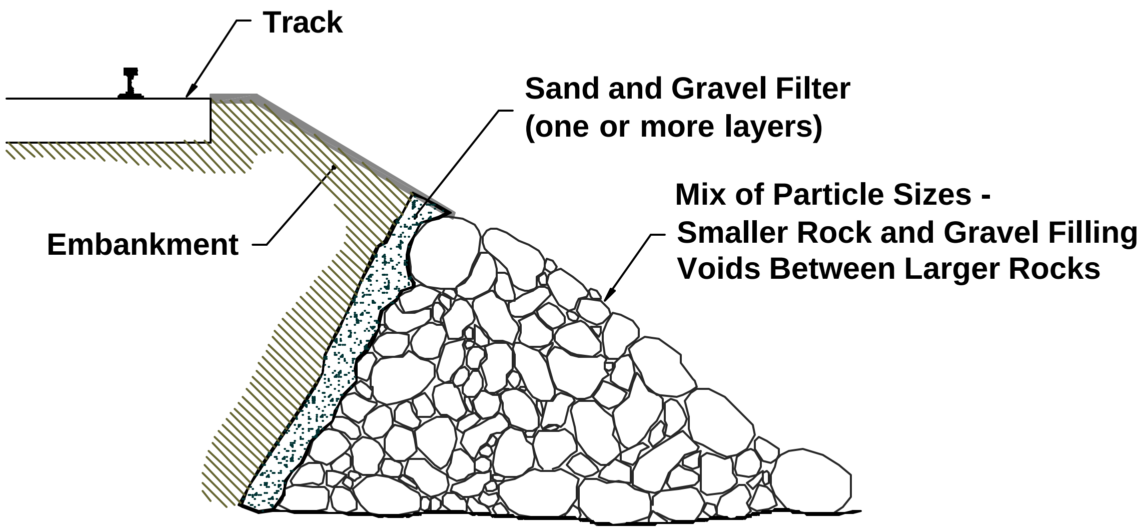


Figure 26. Well graded rock fill used for embankment construction and buttressing.

4.8 Riprap Erosion Protection

Erosion protection may be required when the source of water that is eroding or may erode an embankment cannot be directed away from the embankment or routed through a conduit. Installation of erosion protection on new and existing slopes can reduce the potential for oversteepening of slopes due to erosion at their toe, water flowing down the side of the embankment, or uncontrolled discharge from culvert outlets (Figures 10 and 27). Although other erosion protection systems are available, rock riprap is the most common material employed in railroad applications.

In general, the assistance of a geotechnical or hydraulic engineer should be obtained for the proper design of riprap erosion protection. The cost effectiveness and importance of employing an engineer increases with increasing size of the area to be treated, with increasing construction cost, and with increasing risk associated with potential failure of an area subject to erosive forces. When riprap is to be placed in or near a stream, river, or wetland, permits may be required from the controlling government agencies.

Riprap should be properly sized for the location where it is to be installed. Larger rock may be required when the riprap is to be placed on steep slopes or where it will be subject to high water volumes or velocities. Smaller rock may be used on flatter surfaces and where flow volumes and velocities are moderate. The riprap rock should not be all one size, but should be a mix of sizes

Figure 27. Riprap erosion protection.

so that voids between larger rocks are filled with smaller rocks. This grading of the rock helps to interlock the particles, increasing their erosion resistance. It also decreases the velocity of water flowing between the rocks, which might otherwise potentially erode materials beneath the riprap. The appropriate riprap *gradation* to use is a function of the slope angle and the anticipated water velocities. In many areas, riprap selection is based on experience and a knowledge of what has worked in the past.

At many locations, one or more finer-grained *filter layers* may be required between the riprap and the underlying soil being protected (Figure 26). These *filter layers* protect underlying soils from being eroded by water flowing through the riprap.

As with embankment construction, riprap and riprap *filter layer* construction requires good construction practices. The riprap should be constructed so that water cannot erode behind it. This may require keying the riprap into the bottom of a stream or into the slope of a channel (Figure 28). Along streams and rivers, the three most common reasons for failure of riprap slope protection, in decreasing order of importance, are undermining of the toe, erosion at the upstream or downstream end, and overtopping.

Figure 28 Keying riprap into stream bottom.

Riprap slopes should be constructed from the bottom up. Riprap should be placed using equipment and compacted so that the rocks interlock. To properly construct a riprap slope, the rock should not simply be dumped down slopes as this results in segregation of the material. The larger stones roll to the bottom of the slope, while the smaller stones remain closer to the top of the slope (Figure 29). Even if the original riprap *gradation* delivered to the site would have been sufficient to provide the desired erosion protection, segregated riprap may not adequately protect the slope.
Also, because the rocks have not been compacted or interlocked, the dumped rock is only marginally stable.

Dumping of riprap may be necessary in emergency situations when an embankment has been damaged, for example, during or following storms or floods. Dumping may also be the practical solution when access is difficult. Even during emergency repairs, if time permits, the bottommost rock should be keyed into the streambed and the rock interlocked. This will provide a less erodible foundation for the rock that is later added.
The stability of dumped riprap should be improved after the emergency has passed, if practical and cost effective. Doing so may decrease the potential for the riprap to fail in a future storm or flood. Stability may be improved by rehandling the rock so that it interlocks, placing additional rock to flatten the slope, or filling voids in the rock with concrete.

Riprap slope erosion protection should encroach on adjacent channels as little as possible. Encroachment may increase water surface elevations upstream from the project, which might affect either the railroad or other property owners. It may increase water velocity as the water is forced through a tighter stream channel. And, encroachment may increase erosion on the opposite side of the channel, potentially affecting other property owners.

Figure 29. Improperly placed riprap. Rock has been dumped down the slope. Note that the material has segregated: larger rocks (with large void spaces) are located at the bottom of the slope and smaller rocks near the top of the slope.

5.0 RECORD KEEPING

The history of the performance of track that has experienced or continues to experience occasional or frequent settlement or track geometry defects is important in determining the probable cause(s) of the problem and in selecting an appropriate repair method. The frequency of repairs, type of repairs undertaken, and their cost are important factors to consider when assessing the next move to be taken to treat a chronic soft spot. Records of maintenance activities can provide this information.

The Track Supervisor and Track Inspector should maintain a joint written record of repairs, settlement, or track shifts. Information recorded should include:

< Exact location.

< Date and time of observation of condition.

< Length of track affected.

< Measurements of track settlement, cross-level rotation, or horizontal movement, (e.g., number of centimeters of settlement or horizontal shift).

< Notes describing ground disruption (cracking, plowing, heave, etc.).

< Notes on drainage (e.g., standing water in cess drains, springs, wet spots, etc.).

< Weather during the two-week period preceding observation of the settlement (take particular note of rain including amount of moisture and intensity of storms).

< Last date of repairs at this location.

< Description of repairs undertaken.

There are many possible ways to record this information. One method may be to record the information on loose-leaf paper in a small field notebook – one location per page – with pages numbered by kilometer marker. Use of a small field notebook permits the book to be kept with the track supervisor or track inspector in their vehicle so that it can be easily referenced and readily updated. The notebook, which references a particular section of track, can also be passed along to the new track supervisor or track inspector when personnel are reassigned. The benefits of loose leaf paper include the ability to add sheets in the notebook so that the records can be maintained in order by kilometer marker, additional pages can be added for to continue the record for a particular location, and so that pages can be easily copied. A copy of the sheets in the record book should be maintained at the track supervisor's office. A sample record is presented in Figure 30.

	K Marker 7.55
1/12/99	- Tamp + Raise Track
2/13/99	- Tamp + Raise Track 1.25 centimeters
3/10/99	- High Rail 2 centimers low. Tamped
3/16/99	- Tamp + Raise. High Rail Low 1.25 centimeters
	Wetter than normal
	last 2 months.
5/20/99	High Rail Settle 2.5 centimeters
	- Tamped
	- Last Rain Appx. 4/10 -
	Rec'd 5 centimeters
6/10/99	High Rail 2 centimeters low.
	Tamped, No Rain.
7/21/99	Track Settle - Add Ballast,
	Tamp, Raining Past Week
8/13/99	Track Settle 5 centimeters - Raise

Figure 30. Sample record of track performance and repairs.

6.0 TRENCH DRAINS

6.1 General

Trench drains consist of an excavated trench backfilled with clean, well-graded, gravel products that provide a high *permeability* path for water to escape from the embankment or subsoils. Ballast is usually selected as the backfill material for *trench drains* because it can often be acquired conveniently and at a relatively low cost compared to other drainage materials.

While water may not be the cause of all of the problems previously described, their occurrence generally leads to the introduction of water, which accelerates the problem. Removal of the water from the ballast, *ballast pocket*s, and subgrade soils is frequently an important first step in improving stability.

In embankments where *fouled ballast* and pumping mud problems occur, closely spaced *trench drains* oriented perpendicular to and extending under the track provide a dramatic increase in the overall *permeability* of the track substructure and help to slow the rate of ballast d*egradation* (Figures 31 and 32). If the *mud pumping* is associated with a rigid-layer below the track *trench drains* that cut through the rigid layer and drain water trapped below it may decrease the magnitude of the *mud pumping* problem. If *mud pumping* continues the rigid layer may have to be removed, the subgrade repaired, and a compacted top formation placed. This

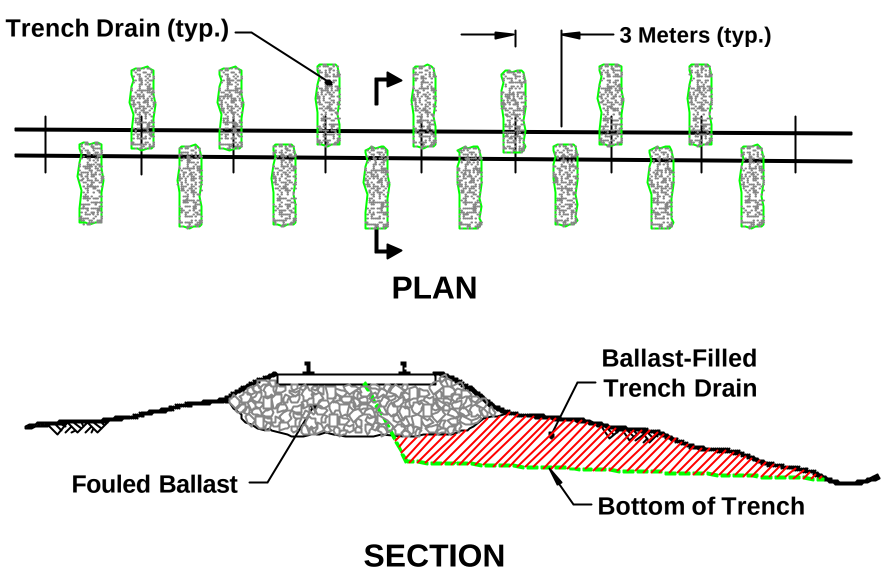
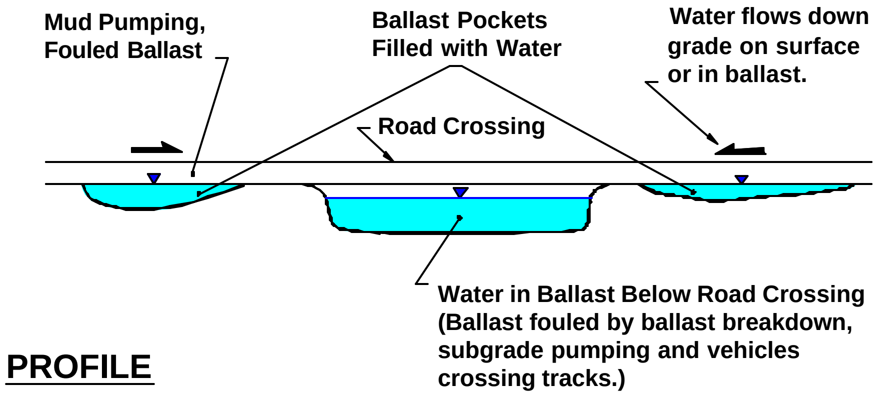


Figure 31. Trench drains for fouled ballast.



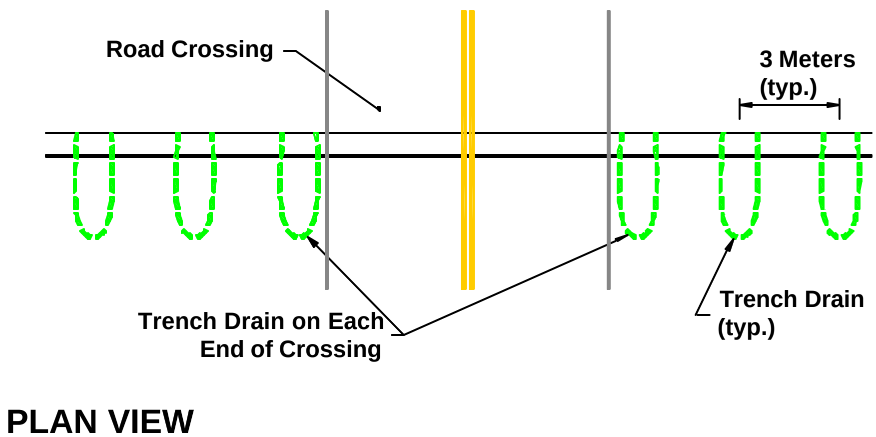


Figure 32. Trench drains at road crossings.

generalization applies whether the rigid layer consists of compacted clayey or silty soil, or a lime or asphalt treated base.

In progressive *shear failure* applications, *trench drains* oriented perpendicular to the track extend into the *ballast pocket*. The depth of the drain is controlled by the depth of the *failure surface* or by the embankment height. When possible, *trench drains* are installed so that they extend deeper than the *failure surface* (Figures 33, 34, 35, and 36).

In this way, the drains not only provide *ballast pocket* drainage, but have the added benefit of increasing shearing resistance along the *failure surface* since the ballast backfill has a higher *shear strength* than the subgrade soil. *Shear keys* oriented parallel to the track are sometimes combined with *trench drains* to provide increased shear resistance along the entire length of the heaved cess (Figure 24).

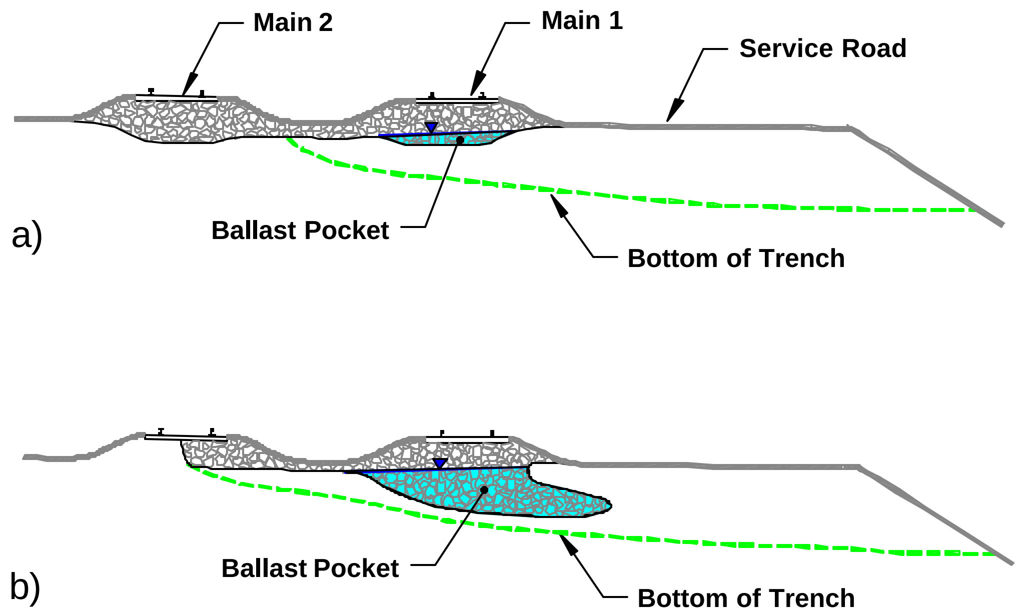


Figure 33. Typical cross sections of ballast pockets in areas that have (a) experienced little ground movement, and have (b) experienced significant ground movement.

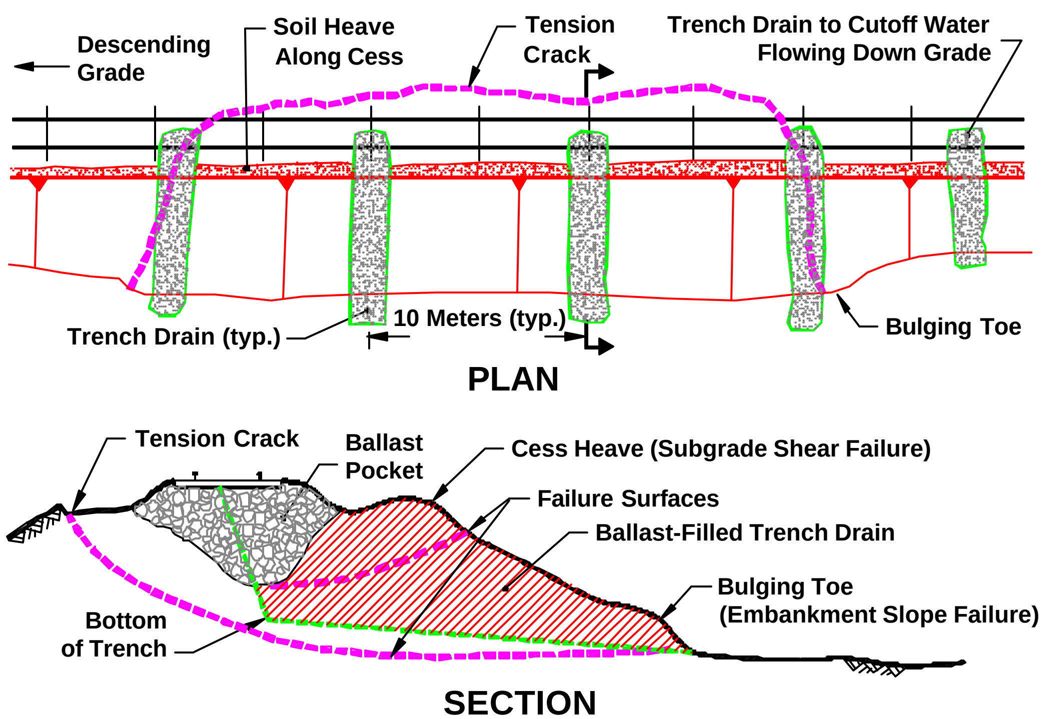


Figure 34. Trench drains for embankment failure, a) plan view, b) typical cross section. Note: heaved shoulder and bulging embankment may not occur at same location, and may be difficult to identify.

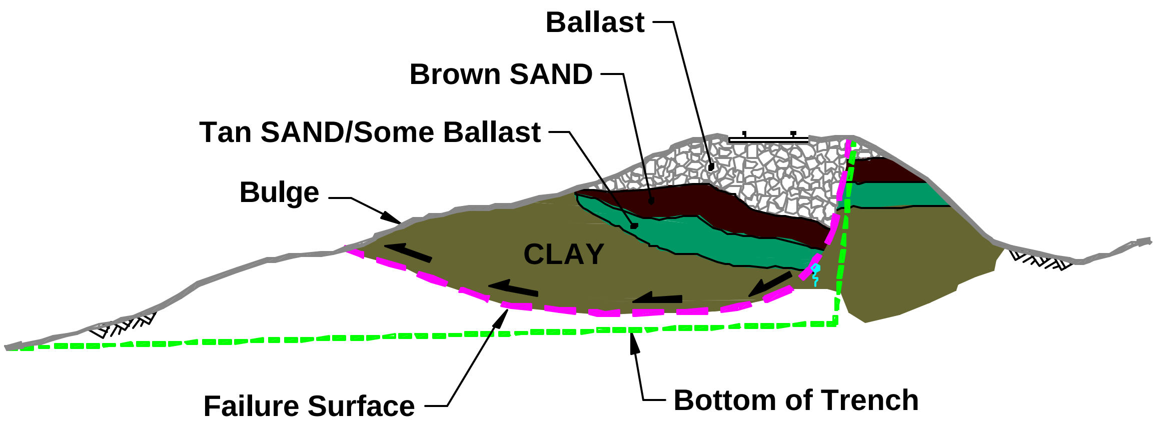


Figure 35. Generalized cross section of trench drain in 3.7 meter high embankment. Note different soil layers and offset of those layers along the failure surface.

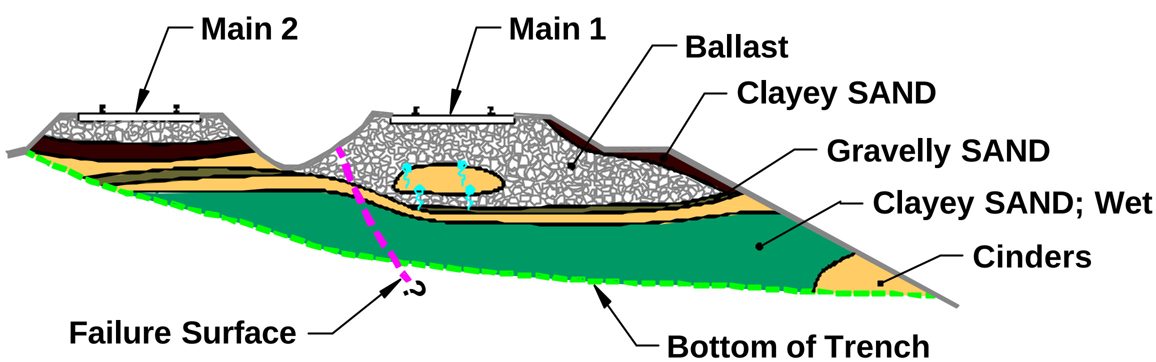


Figure 36. Cross section through a trench drain where the embankment has been periodically raised using a variety of materials. Main one crosses a landslide that has a deep-seated failure surface.

In embankment *slope failures* and landslides, *trench drains* can be very effective in reducing water pressures in cracks and along *failure surfaces*. *Trench drains* are appropriate for rotational and translational landslides that are generally less than 9 meters deep, where the critical groundwater level is not deeper than 6 meters, and where slope angles are flatter than 1.5H:1V (horizontal:vertical).

Trench drains are commonly installed in landslides in conjunction with other stabilization techniques. For example, following mass excavation of material in the head of a slide, *trench drains* can be installed around its perimeter. The excavation reduces *driving forces* on the slide mass and enables the *trench drains* to extend to deeper elevations. Spoils from the trench excavations are often used to construct a *buttress* at the toe of the slide, which increases the forces that resist sliding. Slope stability analyses should be performed to evaluate the effectiveness of *trench drains* proposed to stabilize landslides. The assistance of a geotechnical engineer should be obtained prior to attempting to stabilize a landslide.

6.2 Advantages of Trench Drains

Trench drains have several advantages over other stabilization methods:

1. The number one benefit of *trench drains* is removal of water from the embankment and subsurface soils.

2. The process of excavating each drain provides an opportunity to observe the subsurface conditions. Before backfilling a *trench drain* with ballast, sketches should be made of the trench with descriptions of the subsurface materials, dimensions, location and description of the *failure surfac*e, seepage, etc. Samples of the materials can be obtained if desired. By visually monitoring conditions in each trench, the *failure mechanism* can be evaluated and drain design parameters, such as spacing and depth, can be modified as needed to obtain acceptable improvement in stability.

3. *Trench drains* can be installed while the track is in service. Drains that extend under the track in low embankments can be installed quickly. Longer work windows are sometimes needed for deeper drains in landslides.

   Only in rare cases does a track need to be removed from service in order to construct the drains.

4. *Trench drain* construction requires no special equipment. Conventional earthwork equipment such as readily available excavators, loaders, and bulldozers are used and can be operated by railroad or contractor personnel. The equipment is adequate for grading the ground surface and therefore, surface drainage improvements are routinely performed as part of the *trench drain* work.

5. Finally, the simplicity of *trench drains* has to be considered among their advantages. Pipes and geosynthetic materials are occasionally used, but in most applications, ballast is the only material needed for a project.

6.3 Planning and Design

This section describes the typical steps involved in developing and constructing an embankment stabilization project that requires the construction of *trench drain*s. The description is presented in its most general form, assuming the involvement of a geotechnical engineer or geologist. However, qualified railroad personnel experienced in recognizing and treating soft track conditions may be able to assess the situation and properly define and implement repairs at some locations. The steps to follow are:

1. The railroad determines the need to correct unstable sites based on speed restrictions, frequency of maintenance and severity of the problems.

2. The site or sites are visited by a geotechnical engineer who is accompanied by railroad personnel who have detailed knowledge of the unstable locations. The railroad personnel should also bring the maintenance records for the site.

3. The geotechnical engineer records data for each problem area, including kilometer marker location, length of *instability*, track deflections, and embankment dimensions. Some stability problems and landslides may require more detailed site reconnaissance and subsurface explorations before remedial measures can be designed. If it is determined that *trench drains* are feasible, an initial estimate of the number of drains and ballas quantity required is recorded.

4. The geotechnical engineer prepares a report presenting the data collected in the field, recommended course of action

(which may not always include *trench drain*s), and an estimated cost.

5. The railroad approves funding to perform the remedial work.

6. If *trench drains* are part of the remediation, the railroad delivers ballast to the site and stockpiles it at appropriate locations.

7. Construction equipment is mobilized.

8. *Trench drains* are constructed with the assistance of an on-site geotechnical engineer or geologist.

9. The geotechnical engineer prepares a report summarizing the construction work. This report provides a record for the railroad of work at the site and may be a useful reference if additional work is required at the site or nearby.

The probable *failure mechanisms* and locations of water pockets or sources of water should be considered when planning where to put the *trench drain*s. Water trapped in *ballast pockets* or draining down the railroad grade toward the site in the ballast are two of the most common sources of water that contribute to railroad fill settlement, softening of the subgrade, and embankment failures. Water also tends to collect in *ballast pockets* on the low side of superelevated track, particularly when the track has been undercut. When planning for *trench drain* installation it is useful to keep in mind that the *trench drains* are being installed to intercept and drain this water. How the drains will be oriented, their depth, and where they will be located are primary factors to consider in laying out the *trench drain* design:

< *Trench drains* should be oriented perpendicular to the track.

< The bottom of the trench should be 300 to 450 millimeters below the deepest point in the *ballast pocket*. (Note that where progressive failure of the fill has occurred over a number of years and where the fill has been raised numerous times, relatively deep *ballast pockets* may have developed. If the depth of *ballast pockets* is greater than 1.2 meters, or greater than half the height of the fill, a geotechnical engineer should be consulted).

< In general the outlet for water discharging from the *trench drain* should be at the toe of the slope. For low embankments or deep *failure surface*s, drainage pipes may be needed to carry water from the *trench drain* to a discharge location; however, the need for drainpipes is relatively infrequent.

< Whenever practical, each *trench drain* should extend beneath both rails.

< *Trench drains* should be installed at each end of the affected area and at 12 to 30 meter intervals throughout the affected area. Closer spacing is sometimes required for shallow embankments and *mud pumping* situations.

< If the site is located in a vertical curve, a *trench drain* should be installed at the lowest point in the curve, on both ends of the affected area - upgrade of the area experiencing settlement, and at both ends of the embankment at the transition from cut to fill. Installing *trench drains* at each end of the fill is often advisable even if the affected area is rather limited relative to the overall length of the fill (Figure 37).

< If the track is on a grade, a *trench drain* should be installed upgrade of the affected area to intercept water traveling down the ballast before it reaches the site (Figure 38).

< If the location experiencing settlement is near a bridge or tunnel, a *trench drain* should be installed as close to the bridge abutment or tunnel portal as practical and upgrade of the affected area (Figures 39 and 40).

< If the track is superelevated, the *trench drain* should extend below the low side of the track (Figure 41), although it need not necessarily drain in that direction.

< *Shear keys* should be constructed on the side of the track experiencing the most heave (Figure 23). *Trench drains* should extend from the *shear keys* to drain water.

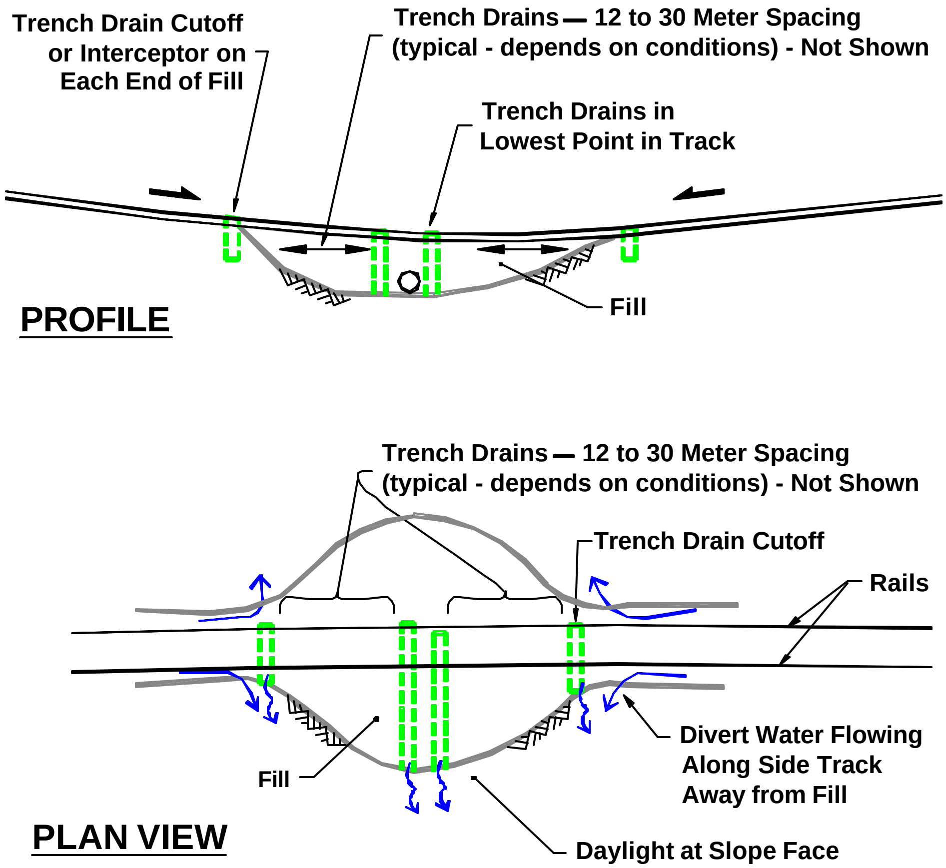


Figure 37. Typical trench drain locations at the bottom of a vertical curve.

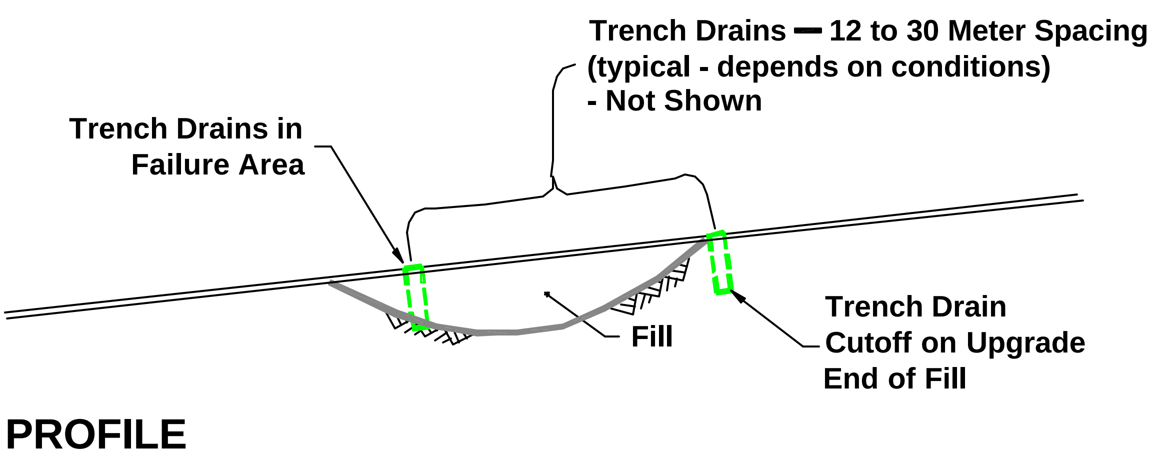


Figure 38. Typical trench drain locations for embankments on a grade.

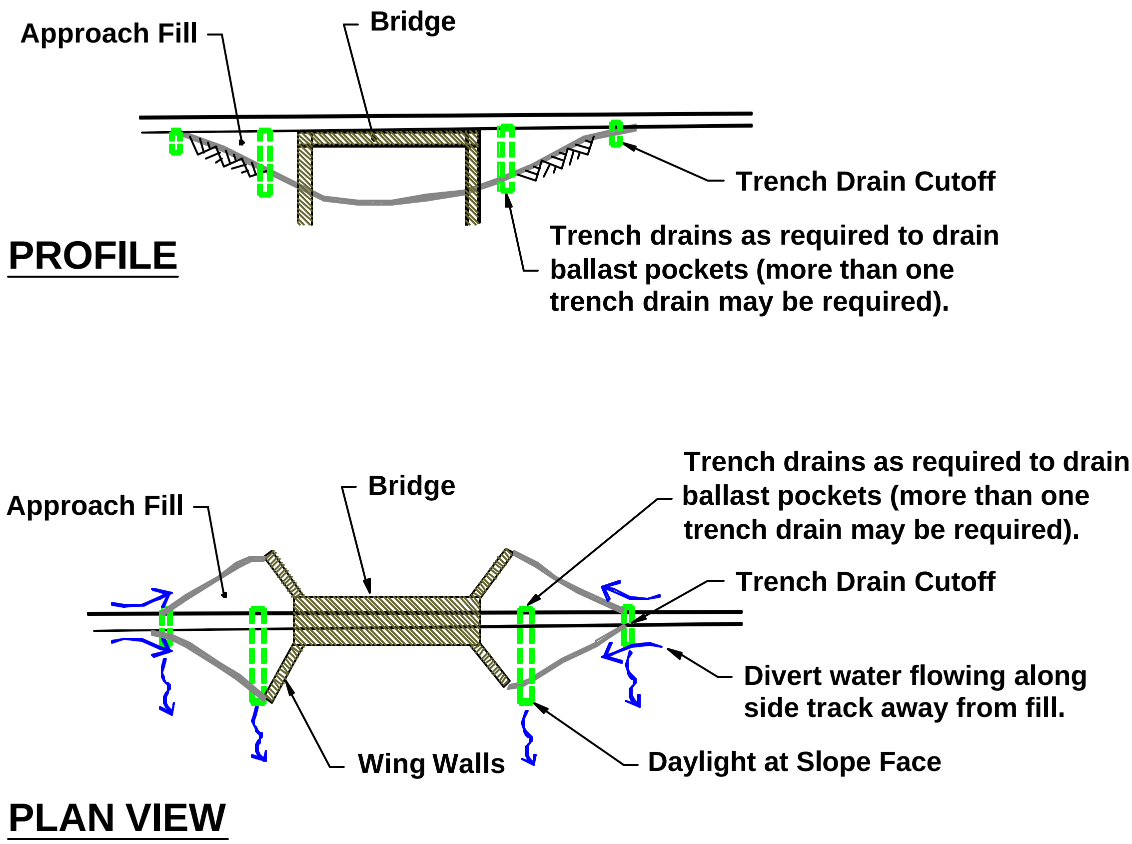


Figure 39. Typical trench drain locations in bridge approach fills.

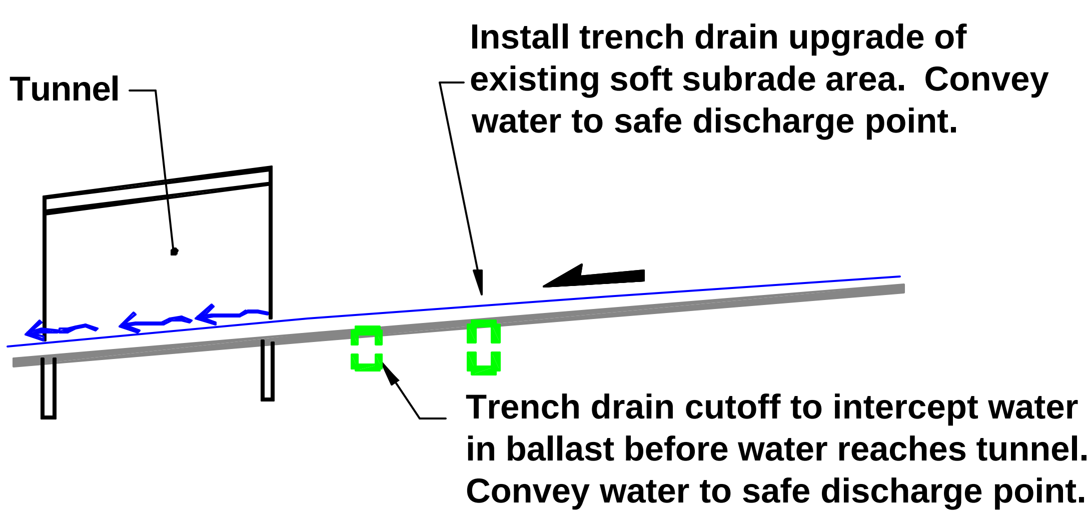
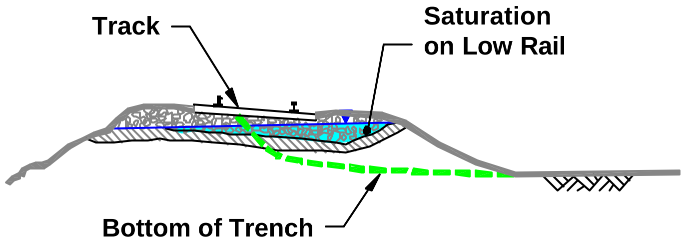


Figure 40. Typical trench drain locations at tunnel portals.



Superelevated track.
High loading on low rail.
Water trapped below low rail.
Track gains superelevation
with continued loading.

Figure 41. Trench drain installation on superelevated track.

6.4 Trench Drain Installation

6.4.1 Material Delivery

The most common method of delivering ballast to project sites is by side dump wagons. These wagons typically have capacities of 26 to 37 cubic meters.

Hopper ballast wagons can carry up to 60 cubic meters of ballast. Doors on the bottom of the wagon can be opened to discharge ballast on either side of the track or in the center. On some projects, trenches that extend beneath the track may be backfilled by discharging ballast directly from the hopper wagons that had been pulled over the open excavations. Finally, material can be delivered by truck if the site is accessible.

Whenever possible, ballast should be stockpiled on site prior to beginning *trench drain* installation so that the material is readily available (Figure 42).

6.4.2 Installation Equipment

Equipment needs will vary depending on specific site conditions. A rubber-tired backhoe is often adequate for low embankments. For most embankment and landslide projects, a track-mounted hydraulic excavator is required. A narrow 600 to 750 millimeter sand bucket (without teeth) is recommended. Installation of drains in steep slopes or limited access areas may require a long-reach hydraulic excavator. These are available with booms that can reach 18 to 24 meters.

The backhoe or excavator used to dig the trench or a small tilt-blade dozer is generally used to backfill the drains, grade the

Figure 42. Ballast stockpiled on site for use in trench drains.

excavation spoils, and improve surface drainage. A dozer with a slopeboard attachment is useful for grading slopes.

Front-end loaders are necessary when the ballast needs to be hauled from the stockpile area to the drain locations.

Depending on site accessibility and haul road conditions, highway dump trucks or off-road dump trucks may also be used to deliver and transport ballast. Track-mounted all-terrain dump trucks may be useful on very steep or wet terrain.

6.4.3 Preparing the Track

Before beginning excavation, the sleepers over the top of the drain location should be secured to the rails so that they do not fall into the trench. Generally, double spiking timber sleepers to each rail is effective. Sleepers may need to be removed in those situations where excavation beneath the track must be performed by the excavator digging between the rails.

6.4.4 Constructing the Trench Drain

Trench drain construction is depicted in a series of photos presented in Figures 43 through 46. Typical *trench drain* layouts and cross sections are presented in a number of Figures included with this text.

Figure 43. Excavator reaching over track to start trench drain excavation in low embankment.

Figure 44. Excavator starting trench drain in higher embankment.

Figure 45. Trench Extended to toe of slope

Figure 46. Backfilling trench.

Generally, *trench drains* should be excavated starting on the side of the embankment with the greatest vertical distance from the track to the toe of the slope. For shallow embankments or embankments with slopes of equal height, the excavation should start on the side of the slope that has experienced the greatest distress (i.e., cracking, bulging, heave, etc.). Because the depth of the *ballast pocket* under each rail may not be equal, because there is often a hump of less permeable soil between the *ballast pockets* under each rail and water may be confined to each *ballast pocket,* and because the *failure surface* may extend beneath both rails, the trench should extend beneath both rails, whenever practical. The bottom of the trench should be excavated to 300 to 450 millimeters below the bottom of the *ballast pocket* or *failure surface,* if practical, and subject to the following constraint: The bottom of the trench should not extend deeper than the toe of the slope of the embankment or the lowest point in an extended gravity-flow drain, if such a drain is to be extended from the end of the *trench drain*.

The bottom of the *trench drain* should be relatively smooth and sloped so that water that enters the drain will freely flow toward the drain outlet. Generally, if the trench walls will stand, the entire trench should be excavated before placing any backfill in the trench. The ballast should be compacted beneath the track whenever practical (this is not often the case due to equipment availability and track-outage limitations). The excavator bucket may be used to compact the ballast.

Spoil material from *trench drain* excavation should be placed on the slope so that the slope angle is flattened from its pre-*trench drain* construction state. Flattening the slope by placing material along the toe of the slope also tends to increase embankment stability. Spoil should not be placed near the top of the slope or in any manner that would decrease slope stability. Spoil material should not be placed over the ends of the gravel-filled *trench drains* because it may block the end of the *trench drain*, reducing discharge.

6.4.5 Safety

Safety of railroad and contractor personnel is paramount during *trench drain* (and all) construction activities. In addition to other railroad safety considerations, personnel working around *trench drains* should practice the following:

- In general, *trench drains* should be excavated and constructed so that worker entry is not necessary.

Personnel should not enter *trench drains* except under *very rare* circumstances and then only when the excavation is properly sloped or shored. Determination as to whether a trench is properly sloped or shored should be made by qualified personnel.

< Personnel should not stand on or walk across the rails that span the trench or the sleepers that are hanging from the rails that span the trench – walk around the excavation.

< Because of the potential for trench walls to suddenly collapse, personnel should not stand too close to the edge of a trench. They should watch from a safe vantage point for ground cracking, sloughing of the trench walls, or other indications that the trench wall(s) may collapse.

6.4.6 Post Construction

Trench drain backfill will settle under train loads for a short time after backfill of the trench and resumption of train traffic. Speed restrictions and tamping once a day or once every few days may be required for the first week or two after completion of the drains. Inspect repairs at least once daily until they are stable and a slow order is no longer required.

6.5 Economics of Trench Drains

The application of *trench drains* offers economical solutions to the stability problems discussed above. *Trench drains* can be constructed under the *track structure* with minimal impacts to train traffic. Engineered *trench drain* solutions are typically 5 to 10 times less costly than removal and replacement methods or retaining structures for solving embankment and *slope failures*. This cost difference does not include the cost benefit of keeping the track in service during the work.

The cost of installing *trench drains* in chronic unstable areas can frequently be less than the annual maintenance costs required to keep the track in service. When the operational cost impact of speed restrictions and reduced efficiency is considered, the return on investments in *trench drain* solutions is even shorter.

6.6 Summary

Trench drains provide an excellent means of improving drainage from chronically unstable embankments. They are extremely adaptable to various site and subsurface conditions. *Trench drains* provide several advantages over other stabilization methods. They are simple to understand, economical to construct, and have proven effective on thousands of sites around the country. They are not, however, a cure-all and must be appropriately applied and constructed and may be only one part of a broader soft track treatment program.

7.0 PERMITS

Increasingly, it has become necessary to obtain permits before repairing embankments, constructing *trench drain*s, or placing fill or riprap. Right-of-entry or temporary or permanent easements may also be required. The need to obtain these items varies by site conditions, location, and applicable regulations, and should be evaluated prior to beginning work at a given location.

8.0 WHAT TO DO AND DON'T DO

The advice discussed in this course is summarized in the following list. The reality of particular site constraints is not addressed. Refer to the appropriate section of the course notes for more detailed discussion.

8.1 DO

< Remember that construction and maintenance of adequate DRAINAGE is the most cost-effective component of a subgrade maintenance program.

< Recognize that WATER is a contributor to most soft track situations.

< Treat an area as soon as practical. Delaying treatment increases the potential for a more severe condition to develop, may increase operating costs through extended application of speed restrictions, and may increase repair and restoration costs.

< Intercept and redirect surface water away from the track and *track structures*.

< Keep surface water on the surface - keep it flowing so that it runs off.

< Maintain clean cesses that are sloped to drain.

< Maintain clean and open cess drains and culverts.

< Maintain cess drains 300 millimeters (minimum) below the bottom of the top formation.

< Grade cess drain bottoms to improve runoff.

< Replace undersized culverts.

< Repair or replace damaged culverts.

< Keep culvert inlets clean of debris.

< Extend culvert outlets so that water is discharged beyond the toe of embankment slopes and install erosion reduction and channelization systems below culvert outlets.

< Drain *ballast pockets* by installing *trench drains*.

< Construct cutoff drains upgrade of soft track areas.

< Intercept groundwater before it reaches the *track structure*.

< Remove topsoil and other unsuitable soils from beneath the footprint of new fills (unless directed otherwise by a geotechnical engineer.

< Compact fill materials.

< Construct new slopes as flat as practical.

< Use well graded, free draining materials to *buttress* or flatten a slope.

< Protect embankment slopes from being eroded or undercut.

< Keep a record of soft track incidences and repairs.

< Get professional assistance for embankments over 3 meters high, potentially tricky situations, retaining structure design, landslide stabilization, or if in doubt.

Fouled ballast

< Use ballast that meets ARTC standards – substandard ballast breaks down faster.

< Replace ballast as required.

< Place adequate thicknesses of top formation and ballast under tracks.

8.2 DO NOT DO

< Do not let water pond adjacent to an embankment – install additional culverts or improve surface drainage.

< Do not over-deepen cess drains close to the track.

< Do not let debris accumulate within culverts or upstream of culvert inlets.

< Do not let water from culvert outlets discharge onto embankment slopes.

< Do not steepen existing embankments.

< Do not place soils and rock on the embankment slopes or perform *“bank widening.”*

< Do not undercut the toe of an embankment.

< Do not raise the embankment without installing internal drainage.

< Do not raise the embankment without also widening the base of the embankment.

< Do not push material back into a “blow-out” – install drainage improvements first, and use free-draining compactable material.

< Do not use large rock to construct toe *buttresses* or to widen fills – bigger is not always better.

< Do not do tunnel drainage improvements without professional assistance.

< Do not design or construct retaining structures without professional assistance.

< Do not place riprap or fill in a stream or river without proper design and permits.

9.0 GLOSSARY OF TERMS

Ballast pocket – A depression in the ballast beneath the railroad track. Ballast pockets may form under each rail as a result of repeated loading by passing trains. Track raising to offset subgrade settlement causes the ballast depth to increase.

Bank Widening – Widening the top of an existing embankment, typically to increase the width of the embankment cess.

Buttress – A berm of soil or rock constructed along the toe of a slope to improve stability of the slope by counteracting *driving forces*. Depending on the site geometry and geology, buttresses may also improve slope stability by increasing the friction along a *slide plane* or *failure surface*.

Cement treatment – A method of improving the strength of a soil by mixing it with cement. In railroad applications this process typically involves stripping the site of overlying materials and then tilling the cement into the soils to be treated. A chemical reaction between the cement and soil absorbs excess water, improves the soil's compaction characteristics, and increases its *shear strengt*h. This method is similar to *lime treatment*.

Consolidation – The process by which fine-grained soils compress under load. For consolidation to occur, water must be squeezed out from between soil particles. Because fine-grained soils may have a relatively low *permeabilit*y, consolidation can take years to complete. The process of consolidation results in settlement of the soil, increases the soil density, and, generally, increases the soil *shear strength*.

Driving Forces – Forces in an embankment that tend to destabilize the slope. Examples of driving forces include surcharge loads (e.g., equipment or material stockpiles) at the top of an embankment, the weight of the upper portions of the embankment itself, and water pressure in cracks in the embankment.

Failure Mechanism – The combination of conditions that results in an embankment or slope failure. Failure mechanisms include, but are not limited to, excess water pressure, excess weight at the top of the slope, and over-steepening of a slope. It is common for one or more failure mechanisms to act simultaneously to cause an embankment or slope failure.

Failure surface – The surface(s) along which a mass of soil or rock moves during periods of *instability* or *slope failure*.

Filter Layer – An engineered layer of free-draining granular soil that is placed in an embankment to prevent erosion of finer grained soils while simultaneously permitting water to drain through the filter layer. An example of a filter layer that is applicable to this course is a layer of granular soil placed between coarse riprap and fine-grained embankment soil to prevent erosion of the fine grained soil out through the riprap. The gradation (mix of particle sizes) of the soil used for the filter layer must be selected so that it is compatible with the materials on either side of it. To meet this criteria, more than one filter layer may be required and the size and gradation of the riprap rock may need to be controlled (See Figure 26).

Fouled ballast – Ballast that has become sufficiently contaminated with fines that it ceases to perform its intended function. Fouled ballast is typically of much lower *permeability* than new ballast.

Geologic history – The history of soil and rock at a particular location, including physical and chemical changes that they have undergone, such as folding and weathering.

Geology – The science of the earth and the rocks and other materials that compose it and the changes they have undergone or are undergoing. As used in this document, site geology refers to the particular arrangement of soil and rock at a site and the changes that this soil and rock have undergone.

Geotechnical Engineer – A person that applies engineering principles, and interpretation of naturally occurring materials so that engineering and geologic factors are properly recognized and accounted for in engineering projects. Depending on the individuals' training and experience, they are typically most knowledgeable about the behavior of naturally occurring rock masses or rock slopes.

Gradation (well-graded vs. poorly-graded) **–** The distribution of sizes of soil particles in a sample or mass of soil or aggregate. A **well-graded** material is a material in which a wide range of particle sizes are present so that smaller particles tend to fill the voids between larger materials. A **poorly-graded** material is one in which the particle sizes tend to be approximately the same.

Horizontal drains – Perforated pipes installed in holes that are drilled into a slope at a nearly horizontal orientation for the purpose of draining water from the slope to improve stability. Typically, the holes are drilled at an angle that allows water that finds its way into the pipes to drain out of the slope by gravity. Horizontal drains are typically installed where the water depth is too great for the water to be drained using open-cut *trench drains*.

Hydrologic Engineer – An engineer that specializes in estimating the volumes and rates of surface water runoff and its effects on natural and manmade rivers, channels, and structures. Hydrologic engineers also design structures to mitigate the adverse effects of surface water (e.g., determine the size of culverts and the size of rock to be used in riprap).

Instability – A natural slope, cut slope, or embankment that has experienced a *slope failure* or is only marginally stable under certain conditions and may experience a *slope failure* if measures are not taken to mitigate the conditions that may cause a failure. Instability may be caused by a variety of *failure mechanisms*.

Jet grouting – A technique for increasing a soil's resistance to *shear failure* or *consolidation* by jetting a pipe into the ground using high-pressure water. After reaching the desired depth, cement grout is pumped through the pipe so that it mixes with or displaces soil as the pipe is gradually withdrawn.

Lime treatment – A method of improving the strength of a soil (typically clay) by mixing it with lime. In railroad applications this process typically involves stripping the site of overlying materials and then tilling the lime into the soils to be treated. A chemical reaction between the lime and soil can absorb water, improve the soil's compaction characteristics, and increase its *shear strengt*h. This method is similar to *cement treatment* but is generally limited to use with clay soils. Because of their chemistry, some clay soils do not respond to this treatment.

Moisture-sensitive soil – A soil that undergoes significant changes in volume depending on the moisture content. These soils swell when wet and shrink and crack when dried. In general, soils with high clay contents are the most moisture-sensitive.

Mud Pumping – The process by which soil particles are carried to the ground surface by water when water pressure is suddenly increased, usually by a passing train.

Permeability – The capacity of soil or rock to transmit water. Water does not readily flow through low permeability soils such as clays and silts. In contrast, water more easily flows through high permeability soils such as clean sand and gravel.

Retaining wall – A wall that is designed to support or improve the stability of an embankment or slope by resisting *driving forces*.

Shear Failure – The failure of a mass of soil along a *failure surface* (a.k.a., *slide plane*) in which the soil or rock on the upper side of the surface moves excessively relative to the soil or rock below the failure surface.

Shear key – A zone of relatively high shear strength material constructed to replace soil that has experienced a *shear failure*. The shear key interrupts the *slide plane* and replaces weak material with stronger material. Relatively high *permeability* granular soil or rock, concrete, and timber or steel piles are commonly used to construct shear keys.

Shear Strength – A property that indicates a soil's resistance (strength) to a *shear failure*. Higher shear strength soils can resist greater shearing forces than can lower shear strength soils. In general, sand and gravel have a higher shear strength than clay or silt.

Slide plane – (see *failure surface*)

Slope failure – Excessive movement of a portion of a natural slope, cut slope, or embankment. Slope failure includes slope movements that occur relatively rapidly and movements that accumulate over time. Slope failures may be caused by a variety of *failure mechanisms*.

Track structure – For the purposes of this course, the track structure refers to the rail, sleepers, ballast, top formation, and subgrade, including the railroad embankment.

Trench drain – A trench backfilled with high- *permeability* gravel that is used to intercept and drain subsurface water. For railroad applications the gravel used to backfill the trench is usually track ballast. Trench drains may cross the track structure to drain water from ballast pockets or cracks in the ground, or be installed parallel to or away from the track to intercept and drain groundwater or water in landslides. Practical and equipment constraints generally limit trench drain depth to less than 6 meters below the ground surface. Pipes may be buried in the gravel backfill to increase the volume of water that can be transported by the drain.

Undercutting – A process in which soil and ballast materials are removed from beneath the sleepers. Typical objectives of undercutting include cleaning or replacing fouled ballast, and occasionally lowering the track grade.

AUSTRALIAN RAIL TRACK CORPORATION, LTD.
TRACK GEOMETRY REPAIR RECORD

Kilometer Marker: __________

Division: __________

Date: __________

Time: __________

PERSON COMPLETING FORM:____

DESCRIPTION OF PROBLEM: ____

____

____

____

LENGTH OF TRACK AFFECTED: _____________________________________

RAIL GEOMETRY: ____

RECENT WEATHER: ____

____

REPAIRS UNDERTAKEN: ____

____

____

DESCRIPTION OF SITE: ____

____

____

OTHER COMMENTS: ____

____