DAMAGE TO RAILROAD EMBANKMENT BY SEEPAGE AND PIPING

By

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ABSTRACT

Seepage and piping is a process long recognized by the dam safety community as a failure mechanism in earth embankment dams. It has been identified as a leading cause of earth dam failures, second only to overtopping. This process and resultant damage is equally applicable to railroad embankments.

Seepage through earth embankments is a natural process. It occurs when water stands against an embankment for any length of time. The extent of seepage penetration is related to the length of time water is present, permeability of the embankment, flow paths and the water pressure head between the entrance (upstream) and exit (downstream).

Seepage can result in damage to earth embankments through the development of seepage “pipes”, slope stability failures, and seepage erosion. There are many signs which indicate an on-going seepage/piping situation such as sand boils, minor slope failures, and sinkholes. Extreme occurrences of piping, or the cumulative effects of decades-long seepage, can result in catastrophic failures.

Prevention of embankment damage due to seepage depends on recognition of the problem and application of appropriate remedial measures. Preventive measures can be as simple as providing adequate drainage and maintaining existing drainage structures. Remedial measures may require grouting, earthwork and installation of new drainage structures.
This paper will explain seepage and piping in embankments, identify signs of seepage and piping damage, and discuss measures to prevent, halt, and repair damage.
INTRODUCTION

Impounded water presents both a significant benefit and a potential hazard to man. Stored water provides irrigation, power generation, recreation and water supply. It also presents a great hazard because of the tremendous amount of potential energy it contains. The destructive energy of stored water released in an uncontrolled manner, as in a dam breach, has been seen many times in the aftermath of dam failures.

Contrary to popular belief, all dams leak. During the design of a dam, leakage is assumed to occur in the foundation and embankment. If the risks associated with leakage are great, appropriate defensive measures are built into the dam to reduce the loss of embankment material. If the leakage represents a significant economic loss, such as a reduction in water supply or irrigation potential, the leakage is minimized.

Water compromises the integrity of a dam in several ways including such direct means as overtopping, and less obvious mechanisms such as seepage and piping. In the early 1980’s, the United States Bureau of Reclamation (USBR) studied the various failure modes for dams in the United States. Overtopping was found to be the leading cause of failure in all earth embankment dams studied. The second leading cause of dam failure was seepage and piping. It was further determined that seepage and piping were the leading cause of failure for dams over 50 feet high in the western US, accounting for 60% of failures (I).
So why are we concerned about failure modes in earth embankment dams? The various failure modes affecting dams can attack any embankment or structure which impounds water – regardless of whether or not the structure was intended to hold water. Of particular interest to railroads is the detrimental effect of impounded water on embankments in the track structure. Specifically, this paper will discuss damage to railroad embankments through seepage and piping.

SEEPAGE

Seepage is the natural process of water flowing through soil. Soils contain interconnected voids between particles through which water will flow from a point of high to low energy. Water is absorbed by soils through capillary action, and flow into and through the intergranular voids begins if sufficient water is present. The extent of seepage penetration into an embankment depends on several factors including the elevation of water on the embankment, the type of material making up the embankment, the width of the embankment and the amount of time water is in contact with the embankment. Seepage through an embankment is illustrated in Figure 1.

Pressure

The driving force causing water to flow is referred to as head (See Figure 1). The total head affecting water in motion is composed of pressure head, velocity head and elevation head. For this discussion, the most important force acting on water in an embankment is the elevation head, which is essentially equivalent to the difference in the elevation at a particular point in the embankment and the elevation of the upstream water surface. In general, seepage penetration will occur more quickly and to a greater extent when the elevation head is high as compared to a condition when the elevation head is low.
Material

Seepage penetration also depends on the soil type and its permeability. Coarse materials such as gravels and sands with high permeability will permit seepage to occur more rapidly than fine grained soils, such as silts and clays which have low permeability. This is due to the size and extent of the intergranular voids within the soils. The size and extent of intergranular voids is also dependent on the density of the soil. A dense and well compacted material is less permeable than the same material in a loose condition.

Flow Length

The distance that seepage must travel through an embankment is directly related to the severity of the seepage condition. As water seeps through soil, some of the driving force, or head, is lost to frictional resistance moving through the soil voids. This process is referred to as head loss. If water moves through a soil and the head loss is great, it will result in a condition where there is no flow. Head and head losses are related through the principle of hydraulic gradient. Hydraulic gradient is the ratio of head loss to a distance over which head loss occurs. For a given amount of head loss, a greater distance results in a lower gradient. Conversely, the same head loss over a shorter distance yields a higher hydraulic gradient.

Seepage is also aided or enhanced by any natural pathways encountered within the embankment. Water will seek, find and utilize paths of least resistance. These paths may be naturally occurring geologic features such as joints and seams within the foundation of an embankment. Other pathways which contribute to rapid seepage penetration may be voids from rodent activity (gopher holes) or root growth.
Construction techniques that result in poor placement and compaction of fill next to structures such as culverts is another area of concern.

**Time**

The depth or length of seepage penetration is also dependent on the amount of time that a source of water is present. This water must not only be present, but acting under a driving head. The effects of seepage on an embankment can be cumulative, taking place over decades. Damage caused by minor episodes of seepage will remain and become the starting point for additional damage during subsequent events.

**EXTENT AND LOCATION**

Seepage penetration will be minimal when water is present for only a short period of time, there is minimal head, or the soils are fine-grained and dense. However, given the proper combination of time, head, and material, an embankment can become completely saturated due to seepage. If the water has sufficient head to cause continuous flow, a condition of “through” or “steady state” seepage exists. It is important to note that the foundation of an earth embankment is just as susceptible to seepage as the embankment itself. Seepage moving through the foundation of an embankment is called underseepage. The risks associated with foundation seepage are just as critical as seepage within the embankment itself.

**DAMAGE DUE TO SEEPAGE**

Damage to an earth embankment and/or it’s foundation as a result of seepage is manifested in several ways: erosion, piping and loss of soil strength.
**Erosion**

Seepage erosion is the loss of embankment materials due to the movement of water through the embankment, which carries soil particles away. This occurs through established internal voids such as transverse cracks and rodent dens, or along surfaces such as the outside of culverts or bridge abutments. This type of damage is characterized by the continual collapse of overlying soils as seepage enlarges the internal void. The overlying soils collapse and are quickly carried away. This process continues and appears as a visible cut or gully in the top and side slopes of the embankment.

**Piping**

Piping is a process whereby internal voids are created by seepage flow. The seepage water has a velocity and force such that it is able to remove soil particles from the ground surface at the point of exit. As soil particles are removed, the length of the seepage path decreases resulting in a higher hydraulic gradient. The increased hydraulic gradient induces higher seepage velocity and force, which in turn moves ever larger soil particles. This process of “backward erosion”, or “piping”, proceeds upstream forming a soil “pipe”. The pipe will continue to enlarge and progress closer to the source of water until it breaks through the embankment. The development of piping from seepage is shown in Figure 2.

The extent and severity of piping is dependent on the embankment soil type. A soil which allows bridging, or a “roof” to form over the void, will allow piping to develop to a great extent and remain unnoticed from above. Piping often causes sinkholes to form in isolated points along its path through the embankment. If the soil mass over the pipe is
unable to bridge, or the pipe enlarges to such an extent that the overlying soil mass collapses, a sinkhole will be created.

Seepage may exit the downstream face of an embankment or its foundation at any point. Therefore, piping may develop on the embankment slope, along the toe in the foundation or at some distance beyond the toe. Generally, underseepage which exits closer to the toe of the embankment is potentially more critical than seepage which initially exits at some distance away.

**Stability**

Seepage may also adversely affect the stability of an embankment. A soil slope is stable when the resistive forces developed by the soil's shear strength along a potential failure surface are greater than the driving forces tending to cause slope failure. The primary driving force which causes slope failure is the weight of overlying material. Resistance to slope failure is developed by frictional and cohesive forces present between soil particles in the embankment. Seepage affects this balance by reducing the cohesive and frictional forces between soil particles, by increasing the weight of the soil, and by exerting force on the soil.

*Shear Strength of the Soil*

The frictional component of a soil’s shear strength is dependent on the shear stress in the soil. In moist soil (unsaturated), the shear stress is carried by particle to particle contact within the soil mass. In a saturated soil, some of this stress is removed from the particle to particle contacts due to the development of pore water pressures within the intergranular voids. The shear stress supported by pore water pressure does not contribute to the shearing strength of the soil. The resultant stress which contributes to
the soil’s shear strength is referred to as “effective stress”. Effective stress is the resultant of total stress reduced by the pore water pressure.

It has been shown that frictional resistance within a soil is reduced by saturation. This is believed to be due to the lubricating effect of water acting to reduce the frictional resistance to sliding between soil particles. The frictional component of a soil’s strength is thereby reduced.

*Soil Weight*

One of the forces contributing to slope instability is the gravitational influence, or weight, of the soil itself. In a saturated condition, all voids within a soil are filled with water instead of air. The saturated soil weighs more than an equal volume of the same soil in either a dry or moist condition. This additional water weight contributes to the forces tending to cause instability.

*Seepage Force*

In a condition of steady state seepage, water moving through soil exerts a force on soil particles. The effect of this seepage force is an increase or decrease in the effective stress within a soil. The seepage force per unit volume of soil acts in the same direction as the direction of flow. In the case of seepage exiting the downstream face of an embankment or the toe, the seepage force will cause further destabilization.

**IDENTIFICATION**

It is important to recognize the signs of on-going seepage. If seepage is identified and determined to be adversely affecting the embankment, preventive measures can be taken. Investigation of embankment failures for evidence of seepage is also important so that remedial measures can be implemented in other portions of the embankment.
Locations Where Seepage May Occur

Essentially, any location where water collects and stands against an embankment will subject the embankment to some degree of seepage. Most obvious is where embankments cross water-conveying channels such as canyons, streams, and ditches. Embankments which may impound water can also be found in other locations, such as along hillsides. An embankment which crosses a hill perpendicular to the natural downhill direction of drainage may impound surface runoff.

Railroads traditionally provide some means for water to pass safely through an embankment such as bridges or culverts. However, conditions may develop which hinder or prevent the structure to pass water as designed. These may include culvert collapse, blockage by drift, trash or vegetation, and siltation. Activities directly related to railroad maintenance may also contribute to culvert blockage. Raises in grade may provide a source of material that sloughs into a culvert unless adequate headwalls are provided. Wasted material from undercutting operations may also contribute to culvert blockage if disposed of carelessly. Bridges may be blocked or restricted by excessive drift and trash or channel aggradation. Construction activities may also restrict bridge openings where temporary berms or access roads are built next to a bridge.

Slight depressions adjacent to the uphill side of an embankment can collect and hold water. Many times, railroad embankments are utilized as dikes to capture, collect and redirect overland flows to the nearest culvert or bridge. These areas should be monitored to ensure localized depressions do not develop. These depressions may be due to a lack of ditch maintenance, recent excavations, or long-term cycles of plant growth.
and sedimentation. Over time, this cycle of sedimentation and plant growth may result in the formation of isolated depressions.

Very few railroad embankments are constructed with the intent to store water, however some do exist. In the days of steam locomotives, water was often obtained using the railroad embankment to dam up a river or stream. The impounded water was then pumped into water tanks and stored for use in steam locomotives. These types of embankments, or railroad dams, still exist even though the original need for the water no longer applies.

With the exception of railroad dams, it is important to maintain open waterways through bridges and culverts. The risk of a complete blockage is obvious; however a partially blocked waterway may also cause water to stand against an embankment for an extended period of time. Even a few feet of water standing against an embankment will initiate seepage.

Other factors will affect the susceptibility of an embankment to seepage. Surface erosion can reduce the cross section of an embankment decreasing the distance that seepage must travel. Similarly, excavation of a portion of the embankment, or excavation along the toe of an embankment, also decreases this distance. Rodent dens and tunneling allow water to flow freely to great depths within an embankment. The decaying root systems of dead trees will leave voids and pathways that water will use as a flow path. Decaying timber from structures abandoned in place (such as culverts, bridges filled in place, etc.) can provide ready made seepage paths.

The pioneer railroad locating engineers were very diligent in identifying areas which needed some form of drainage structure. In those instances where an inadequate
structure (or no structure at all) was provided, Mother Nature has usually been quick to point out the oversight to subsequent generations. However, to this day, you may encounter a location which appears to need a drainage structure. Old right of way maps, bridge records, etc. should be consulted to determine if a drainage structure was originally provided at the location. It will often be found that a structure indeed exists, but was long ago silted in, abandoned and forgotten. If it cannot be determined that a structure exists, the location should be evaluated for installation of an appropriately sized drainage structure.

**Identifying Active Seepage**

Seepage may emerge at any point on the downstream face of an embankment, along the toe, or at some distance from the toe. The most obvious sign of seepage is moisture. It may appear as a soft, wet area, or a flowing spring. Unusually green or lush vegetation, relative to the surrounding vegetation, is a sign of active seepage. Areas subject to long-term seepage will support marshy vegetation and aquatic life. These areas may range in size from a few square feet to several acres. Minor slides or slips on the face of an embankment may also occur because of seepage and saturation.

An easily recognizable sign of through seepage is the appearance of sand boils. A sand boil is formed when the force of upward seepage flow dislodges and moves surface soil particles. An active sand boil looks like a mixture of simmering water and soil. The sand boil deposits the soil particles in the shape of a small cone very similar to a volcano. The sand boil will initially include only very fine grained soil particles easily displaced by the seepage force. However, as the underlying pipe develops and seepage flow increases, larger soil particles are affected. Figure 3 illustrates the development of a sand
boil due to seepage. Sand boils typically appear along the toe of an embankment, but they may also be seen on the slope of the embankment.

Seepage problems may be more difficult to identify in arid regions. Moisture typically comes in monsoon storms of short duration with long intervening dry periods. Storm water will run off and evaporate quickly. Vegetation or soil moisture may not always be relied upon as clues to the presence of seepage. Even though the total time that seepage occurs may be short, seepage erosion and piping can still take place. Seepage from subsequent storm events will seek out these previously established pipes and voids. It may take decades for the cumulative effect to result in a sinkhole or washout.

Other signs of seepage to look for in arid regions include small exit holes, sharp cuts or gullies and sinkholes in the top or downstream side of the embankment. If through seepage is well established, sediment plumes will be seen leading away from these features. The size and extent of the sediment plume may appear all out of proportion to any adjacent surface erosion features, indicating a source of sediment from within the embankment. Occasionally, a small hole or crack can be identified on the upstream side of the embankment.

It is sometimes difficult to distinguish between active seepage and naturally occurring springs. A naturally occurring spring may exist regardless of the presence of water upstream of the embankment, whereas seepage is often noticed to appear and disappear quickly in response to the presence of impounded water. Note however, that seepage may continue to appear for weeks after the pool of water has drained due to saturation of the surrounding soils. The volume of seepage flow may also be observed to increase and decrease directly in relation to the level of water behind the embankment.
Ranchers, farmers and other locals, as well as senior employees are often very helpful in answering questions about the nature and appearance of springs and seeps. Even when it is determined that suspected seepage may actually be a natural spring, it should be monitored for changes in condition relative to the presence of water behind the embankment.

The ends of culverts and abutments should also be inspected for signs of seepage. Seepage may follow these structures especially where compaction during construction was poor. Water appearing at the downstream end of a culvert while the inside of the culvert itself is dry, is a sign that seepage is following the exterior of the culvert.

**Evaluating the Severity of Seepage**

Not all cases of seepage will lead to the failure of an embankment. Several factors should be considered in assessing the risk of active seepage.

The primary danger to embankments from seepage is the removal of soil particles. Muddy seepage flow is a sure indication that embankment material is being lost to piping and seepage erosion. It may be difficult to distinguish between seepage flow which is transporting embankment material and normally muddy storm runoff. Even though the appearance of sand boils along the toe of an embankment is very unsettling, the flow should be observed to see if soil particles are being removed. Clear water flowing from a sand boil is not as critical as muddy water.

Even though not usually as critical, clear running seepage flow should be monitored for changes. Slight changes in head, soil saturation or disturbances can initiate seepage erosion. Seepage flows should also be monitored for changes in volume, especially increases. The reaction of seepage volume to the upstream water level gives
an indication of the continuity of the seepage through the embankment. Seepage which responds quickly to changes of the impounded water level indicate direct continuity with the water source.

Seepage may also induce slides and slips on the embankment slope.

Destabilization of the slope is due to the saturated condition resulting from seepage.

Seepage which is observed to cause slope stability problems should be addressed quickly. It is extremely difficult to accurately assess impending slope failure in a saturated embankment.

**REMEDIAL ACTIONS**

Many methods can be taken to stop or control seepage and its effects. These various measures may be implemented as seepage is occurring, post-event, or as proactive preventive maintenance activities.

**Immediate Actions**

The most effective means of halting seepage is to remove the source of water. This can be as simple as removing blockage in a plugged culvert, or ditching to allow standing water to drain away. Other means such as pumps or siphons may be used effectively to reduce the amount of impounded water. Even a small decrease in the water level may reduce the head sufficiently to slow or halt seepage flow. This is a very effective means in cases of isolated ponding.

If the water against an embankment is actually a river which is flowing out of its banks, it may not be practical to eliminate the source of water. The railroad embankment is essentially acting as a levee. Remedial measures must then focus on controlling seepage on the downstream side of the embankment.
Sand boils are often a sign of through seepage, or underseepage, where a railroad embankment is functioning as a levee. The primary concern is to halt the loss of embankment material due to the development of pipes and internal seepage erosion. Ring dikes made of sand bags can be built around sand boils. Water from the sand boil will begin to pool within the confines of the ring dike. The increasing water depth in the ring dike reduces the head driving the seepage. Ring dikes are illustrated in Figure 4. It may not be possible to completely stop the flow of water, but it is often possible to halt the removal of soil particles.

Effective ring dikes will sometimes cause the seepage to appear in another location forming a new sand boil. The soil conditions may also be such that numerous small sand boils appear over a widespread area. In this situation, it may be necessary to construct a seepage blanket or berm. A seepage blanket is a layer of granular material designed to function as a filter. The seepage blanket will not prevent seepage, however if properly designed, it will prevent the loss of soil particles from within the embankment and foundation. A seepage berm is a layer or granular material placed generally along and in contact with the toe of an embankment. The seepage berm functions like a seepage blanket. Seepage berms may also be constructed to resist heave along the toe of an embankment. It is very important that a seepage blanket or berm be constructed of materials which allow seepage flow to pass through. Otherwise, pore water pressures will increase and contribute to instability in the embankment and foundation.

Geotextiles may be used in the construction of seepage blankets and berms. A layer of geotextile is placed on the ground surface and then covered with a layer of coarse
grained material such as gravel or ballast. The geotextile filters out and halts the loss of soil particles, yet allows the seepage flow to pass through.

A very common reaction to observed slope instability is dumping riprap or other material onto the embankment from the top. In principle, it is desirable to place additional material along the toe of the embankment and form a stabilizing berm. However, much of the riprap typically stays on the embankment slope right where it is initially dumped further adding to forces driving a slope failure. Indeed, the initial impact of many tons of rock impacting the upper portion of a saturated embankment may induce slope failure as pore water pressures instantaneously increase. The fact of the matter is that there may not be many options for access to place material at the toe of a flooded embankment. In that case, an effort should be made to distribute and place as much of the material at the base of the embankment as possible. Excavators can be used to accomplish this.

**Post Event**

Once the initial event is over and traffic has been restored, the embankment must be evaluated for remaining damage. Sinkholes or washouts due to piping, may be quickly filled with soil or ballast in order to restore traffic. However, numerous partial pipes and voids will still exist. Ballast is often used in emergencies to fill sinkholes and washouts in track. The porous, coarse-grained nature of ballast, when used as fill material for a significant depth within an embankment, will aid the establishment of through seepage during subsequent events.

Ideally, an embankment compromised by seepage and piping should be rebuilt to eliminate voids, pipes and loose areas. However, complete reconstruction is seldom
practical. Pressure grouting is an effective means of treating an embankment suspected to contain voids, pipes and other potential seepage paths. Grout can also be used to effectively fill large pockets of ballast placed as fill in sinkholes and washouts.

If a plugged culvert caused water to pond, the culvert should be cleaned and siltation removed. Often a structure will become plugged due to aggradation of the stream channel. If this is the case, significant channel cleaning downstream may be required to keep the culvert flowing. Removal of drift and trash within the upstream channel will also reduce the chances of blockage due to accumulation of drift and sediment. If a collapsed culvert is the culprit, it should be repaired or replaced. Jacking and boring a new culvert is an effective way to replace a collapsed culvert with little disturbance to train traffic. Note that it is very important that the old culvert (if left in place) be pressure grouted completely full so that it does not become part of a seepage path. Pipes which have been jacked and bored should also be grouted to seal any voids along the side of the pipe.

**Preventive Maintenance**

Many of the factors which contribute to seepage in an embankment can be minimized, or eliminated entirely, by preventive maintenance. Culverts should be kept clean and in good repair. Drift, trash and other obstructions should not be allowed to accumulate on bridges and culverts. Wind borne debris, such as tumbleweeds, can also accumulate on culverts and should not be overlooked. Even the slightest obstruction in a culvert will promote the deposition of silt and sediment. Existing drainage structures must be maintained to allow free drainage. Right of way ditching should also be maintained.
Inadequate ditching will allow water to pond or runoff slowly, rather than flow quickly through intended drainage structures.

Activities both upstream and downstream of the right of way can affect the amount of water reaching an embankment and the ability of water to pass as intended. Downstream activities which cause channel aggradation will reduce the effectiveness of culverts. Repeated cycles of plant growth and siltation may also cause a channel to slowly build. Upstream activities may increase the runoff arriving at the embankment. Urbanization typically results in increased runoff which may overwhelm a drainage structure designed when the surrounding area was rural.

Employee training on seepage recognition can prove invaluable. Knowledgeable employees will be able to recognize the signs of seepage and evaluate the severity. Many state and federal emergency response and disaster preparedness agencies offer such training. The US Army Corps of Engineers provides flood fight training, which includes seepage recognition and response. State agencies tasked with dam safety and inspection can also provide information on seepage and piping.

CONCLUSION

Dam and levee designers, builders and operators are familiar with the risks and hazards associated with seepage. Considerable effort is devoted to managing it. Their structures depend on it. Railroads may sometimes find their embankments unintentionally functioning as dams and levees. Railroad embankments are seldom designed with this in mind, yet the risks are just the same. The risks can be minimized proactively through preventive maintenance, inspection and monitoring of suspected trouble spots. Severe damage and failure may also be averted through timely response and remedial measures.
The initial step is recognition of the signs and accurate assessment of the condition followed by application of appropriate repairs.
REFERENCES

LIST OF FIGURES

Figure 1 – Initiation of Seepage
Figure 2 – Development of Piping
Figure 3 – Photo of Sandboils and Sequence of Sandboil Formation
Figure 4 – Ring Dikes Built Around Sandboils
Figure 1. Initiation of Seepage
The pipe begins to form as seepage exits the downstream toe. The pipe erodes embankment materials within the zone of saturation as it proceeds upstream toward the source of water. The volume of water entering the pipe increases along with its flow velocity, removing more and more embankment material.
a. Seepage exiting the ground surface.

b. Finer soils are dislodged and carried away.

c. Pipe begins to form as sand boil grows.

Figure 3. Photo of Sandboils (left) and Sequence of Sandboil Formation (above)
Sand bag ring dikes constructed around sand boils will pond seepage water above the sand boil. The increased head within the ring dikes will reduce the head which is driving flow from upstream. The goal is to reduce the flow sufficiently that embankment material is no longer transported. Note that seepage may continue to flow.

Figure 4. Ring Dikes Built Around Sand Boils