INTRODUCTION

Most of the heavy haul railways that are operating in the world today are doing so on lines that were constructed in the late 1800s. These railways have invested significant dollars to increase the asset life of rail, ties, and ballast. However, the most neglected part of the track section has been drainage management. Probably the three most important parts of maintaining heavy haul track are drainage, more drainage, and better drainage. I will discuss aspects of drainage from ditches, ballast, subballast, and subgrade, and will focus on the maintenance of a freely draining track structure.

DITCH AND SHOULDER MAINTENANCE

Since the railways were built, the most neglected areas of the drainage system of track are the ballast shoulder, the subgrade shoulder, and the ditch sections. They have not been maintained for years for several reasons, including inadequate budget allowances for drainage, insufficient support for drainage maintenance programs in overall maintenance planning, and lack of clear understanding that drainage failures significantly impact asset life. Many ditches have not been maintained and have become clogged with debris. When this occurs, the ditch holds water at a higher level, obstructing drainage from the track section. This water retention weakens the subballast and subgrade. Often track inspectors do not notice the drainage problem until mud starts to appear in the ballast section. By that time, in most cases water has saturated the subgrade. Then, under normal loading, the subgrade is overloaded and begins to displace. When this occurs, ballast pockets begin to form. This has proven to be a dilemma world-wide and has become the number one problem in maintaining a heavy haul railway. When the railways were constructed in the late 1800s, the drainage design was generally very good. This also applies to most recent track construction. However, adequate design is not enough when drainage issues are neglected on a continuing basis. This lack of care has contributed to increasing railway track failures.
The photo illustrates a track segment where drainage management has been largely neglected. Twenty years ago when the track was built, most likely the proper drainage system was designed and constructed. Since that time, silt has run into the ditches and vegetation has also blocked the drainage. In addition, the ballast shoulder is extremely wide, and that also affects the drainage. Furthermore, since the shoulder is higher than the bottom of the tie, the track is left in a “bath tub” situation which causes the track section to remain saturated most of the time. When this occurs, the ballast breaks down more quickly and the resultant residue fouls the ballast section. It will not be long before the subgrade becomes saturated and starts to move, initiating shear.
This photo shows typical subgrade shear. Also, the ballast section is greatly fouled, restricting it from draining. When the ballast section cannot drain, the subballast or top formation becomes saturated and the subgrade displacement occurs. Also of concern is the fact that the ballast formation is beginning to shift. During heavy rains, the ballast pocket holds water and continues to get deeper when the track is loaded. Another major problem on heavy haul railways is that there is often insufficient ballast under the ties.

**RECOMMENDED CORRECTION OF INFERIOR DRAINAGE OUTSIDE THE TRACK SECTION**

It is highly recommended that the drainage system as originally designed and constructed be maintained. Likewise, it is very important that any vegetation on the subgrade shoulder be controlled, since it hinders proper drainage. Over time, the shoulders get higher and further block the drainage. The same thing occurs with vegetation in the ditch sections, causing them to silt in and restrict the water runoff.
It is very important that the shoulders are kept sloped so the water will drain away from the track. This can be accomplished with a variety of mechanized equipment. One such machine, the Jordan Spreader, is popular in the USA, because it does a high-quality job of maintaining the proper shoulder. To provide proper drainage, the subgrade should fall a minimum of 100 mm (4 in) from the toe of the ballast section to the outside edge of the subgrade shoulder. If the slope is too steep, the shoulder will start to erode. Where there is adequate width, a motor grader can be used to maintain the shoulders as well. It is common practice to use the shoulder as a maintenance roadway alongside the track. While the roadway is important in accessing the track to perform maintenance activities, it is very important to keep the roadway sloped away from the track so that the water will not run back into the track section.

There are various pieces of equipment, such as the Badger ditcher and slot train that can be used to maintain the ditch line and grade for proper drainage. It is recommended that all ditches be maintained so the water will flow away from the track. However, in heavy haul operations, it is difficult to gain track occupancy in order to operate on-track equipment. In these cases, off-track equipment like grade-alls and excavators can be used to maintain the proper flow. If the proper drainage outside the ballast section is maintained, most track section drainage problems are eliminated. Remember, when performing a track inspection, the primary focus must be drainage, more drainage, and better drainage.

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 away from the track, the less water available to infiltrate and potentially weaken the track structure.

Recommended maintenance practices include:

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

• Divert surface water prior to it reaching problem area.

• Keep surface water as surface water. Do not let it pond or infiltrate the embankment or ground upslope of the embankment.

• Deepen ditches to 305 mm (12 inches) below the bottom of the subballast (do not over deepen ditches such that support is lost for the track section).

• Grade ditch bottoms to improve runoff.

• Clean ditches and culverts.

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

• Replace culverts that are too small with culverts of adequate capacity

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

• Remove from embankment shoulders any debris produced by maintenance activities such as undercutting, shoulder ballast cleaning, and ditch cleaning.

• Grade shoulders to drain water over the side of the embankment without restricting the flow. Erosion protection measures may be required on the slope.

A common misconception with construction of ditches is that deeper is better. This is not always the case. Ditching 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 ditches so that the ditches serve to drain the track area, not adjacent fields. In some cases, installation of near-track subsurface drains is more appropriate.

DRAINAGE OF BALLAST AND SUBBALLAST

As mentioned earlier, in heavy haul operations, if the shoulders and ditches are properly drained, they will contribute to better drainage of the ballast and subballast. Ballast drainage has to be maintained to keep the proper resiliency under the tie. This area is affected when there is not sufficient ballast under the ties. With the heavy axle loads, the ballast breaks down and along with dirt blown into the ballast section, it becomes heavily fouled. Also, it is affected by improper tamping cycles for heavy haul operations. If the track loses its resiliency, it affects the asset life of rail, fasteners, ties, and ballast. In concrete tie tracks, if the ballast bed is not resilient, the ties will begin to crack or become center bound more quickly. When this occurs, it puts excessive force on the pads and fasteners. As it starts to affect the rail, spaulding and surface cracks appear, reducing the life of the rail.

Every railway has engineering standards relating to depths of ballast and shoulder ballast widths. A common standard requires that the ballast shoulder will be 305mm (12 in) wide from the end of the tie and either have a 1 1/2 to 1 or a 2 to 1 slope, although there are some exceptions on curves. Many heavy haul lines have excessive amounts of ballast on the shoulder. Instead of providing a benefit, excessive ballast restricts the drainage of the ballast section.

In most heavy haul operations, the expected ballast life is 12 to 18 years. However, this does not mean that all ballast has to be removed at the end of its expected life. But it does mean that procedures for maintaining the ballast section must be employed. In order to preserve resiliency under the ties, the track must be surfaced on repeated cycles. The recommended cycles are more
frequent on concrete than they are on wood. Maintenance programs involving shoulder ballast cleaning as well as full ballast bed cleaning should be planned as well. These cycles can fit well with the heavy haul ballast life recommendations. When concrete ties are initially placed on existing mainline track, it is recommended that the full ballast bed be cleaned. Then new ballast should be added until there is a recommended thickness of 254 to 305 mm (10 to 12 in) under the ties. It is further recommended that one year following concrete tie installation, the track is surfaced.

In most heavy haul operations, it is very important to establish surfacing cycles based on gross tonnage. Tracks with concrete ties should be surfaced every 150 to 200 million gross tons of traffic. Tracks with wood ties should be surfaced every 200 to 250 million gross tons of traffic. This will promote resiliency and help maintain a high-quality, live ballast bed for the ties.

**FOULED BALLAST**

[Figure 3] Fouled Ballast

In many locations, localized stretches of fouled ballast form in the track structure. Fouled ballast may be caused by a number of sources, including ballast breakdown, contamination by subballast or subgrade soils, and contamination by soils carried into the ballast by wind, water,
vehicles crossing the track, materials dropped from train cars, or other sources. Except in heavy coal dust areas, ballast breakdown is generally 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 engine 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. 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 tie 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.

Ballast contamination can also occur as a result of pumping of sub-grade soils into the ballast or pushing of ballast into the sub-grade. These situations most commonly occur in areas with lack of a suitable subballast layer.

[Figure 4] Subgrade Pumping
BALLAST MAINTENANCE ACTIVITIES TO INCREASE BALLAST DRAINAGE

An out-of-face surfacing cycle should be established based on gross tonnage. Tracks with concrete ties should be surfaced out-of-face every 150 to 200 million gross tons and those with wood ties every 200 to 250 million gross tons. This will promote resiliency and help to maintain a high-quality, live ballast bed for the ties. Where there are concrete ties, it is recommended that the ballast shoulder be cleaned every other out-of-face surfacing cycle. On wood tie track, run the shoulder ballast cleaner in advance of wood tie renewals, and then every three to four years following the tie installations.

Assuming the service life of ballast is approximately 12 to 18 years; the full ballast section should be undercut and cleaned every 12 years on concrete tie track. This schedule should keep the ballast bed clean and allow the ties to attain their expected life. It is suggested that wood tie track in heavy haul operations be undercut and cleaned every 15 to 18 years. This will help maintain the proper ballast drainage and extend the life of the wood ties. It is likely that with the continued increase of axle loads, more railways will enlist the use of subgrade rehabilitation machines similar to those used in Europe and China.

[Figure 5] Subgrade Rehabilitation
The photo shows track that was rehabbed in 1999 in Austria with the AHM 800 subgrade rehabilitation machine. The different strata layers in the cross section are obvious: The good ballast section, the protective layer, the geotechnical fabric, and the subgrade. The purpose for cutting the track was in connection with a line change. Note that the subgrade is losing its shape, but the top of the subballast is not. This particular segment of track has had 1.6 billion gross tons of traffic since it was rehabbed. There are locations in Europe that were rehabilitated in the mid-80’s.

**SUBSTRUCTURE DRAINAGE**

Before failing 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 most unstable track situations. However, while water may not have been the initial cause of a particular situation, the development of the instability generally leads to the retention 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:

- Rainfall or snowmelt directly on the track structure
- Surface water flowing toward and infiltrating the track structure
- Water flowing within the track structure, e.g., within ballast pockets or fill used to construct the embankment
- Groundwater

Techniques used to reduce infiltration when constructing new track include sloping the upper surface of the subgrade and subballast, placement of clean ballast, construction of ditches below the bottom of the subballast, and shaping embankment shoulders so that water flows away from the track. Periodically regrading the top of the subgrade and subballast is not a practical track maintenance operation. However, ballast and embankment drainage are areas that can be addressed by maintenance programs. Maintenance personnel can make a difference by:

- Maintaining ditch bottoms at least 305 mm (12 in) below the bottom of subballast
- Keeping ditches clean and properly graded
- Keeping embankment shoulders clean and sloped to drain

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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 track failure conditions. Draining this water from the track section and embankment is fundamental to improving track and embankment performance.

Water tends to accumulate in track locations where the drainage is impaired such as road crossing approaches, bridge approaches, low points in vertical curves, and at other locations where track settlement has occurred and the track has been raised on additional ballast.

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 below the ballast.
- 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 drains.

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 unstable track conditions. Interception and removal of this water and lowering of the water table to a satisfactory depth 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 ditches or on slopes during dry times of the year, especially in regions of the country with dry climates.

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Gravel-filled trench drains may be constructed to intercept and drain near-surface groundwater flowing toward the track. 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. 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, and property ownership. In the vast majority of situations, a geotechnical professional should be consulted to assist with locating and installation of these trench drains.

Depending on the groundwater depth, topography, and geology, other drainage systems may be required. Horizontal drains, small diameter perforated pipes installed in holes drilled into the ground, 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 railways for landslide stabilization in some locations of the USA during the 1960s and 1970s. The assistance of a geotechnical professional is recommended for horizontal drain applications.

High groundwater conditions and springs are also common contributors to landslides. In landslide susceptible terrain, trench drains, 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 professional is recommended.