Track Substructure Maintenance--From Theory to Practice

by

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Abstract

The three main components of track substructure are ballast, subballast and subgrade. Their functions and how they are achieved will be reviewed. All three components must be present and functioning satisfactorily for good track performance. Substructure maintenance is mainly concentrated on the ballast and the need is usually dictated by track geometry deterioration. Second in priority for substructure maintenance are drainage ditches. The principles of drainage will be summarized. In practice drainage is often given inadequate attention. The cost of maintenance or, conversely, the deterioration of track components, is directly impacted by the condition of the drainage system. Information on these cost factors will be presented. When normal maintenance operations cannot provide satisfactory track performance, reconstruction will be needed. This usually involves work on the subballast, subgrade or drainage system to repair the defects. Subgrade treatment methods are described. These are more expensive, and more difficult to accomplish tasks, and more disruptive to revenue traffic. Thus a goal of maintenance planning should be to minimize the need for the reconstruction by not allowing chronic problems to develop or persist, to the extent possible. Guidelines for maintenance practice will be presented. The paper also emphasizes the importance of determining the cause of the maintenance problems in order to apply the proper solutions. A follow up investigation is recommended to evaluate the results. Finally education programs are recommended to provide a much needed understanding of the fundamentals of track substructure behavior.
INTRODUCTION

The substructure consists of ballast, subballast, and subgrade. The need for substructure maintenance stems from the development of excessive geometry deviations (track roughness). Track geometry loss results from movements in the ballast, subballast, and subgrade. However, adjustment of geometry is done by rearranging the ballast. There are various causes of geometry loss which need to be identified to know how to improve track performance. The amount of maintenance required is influenced by decisions made during design and construction or rehabilitation of the track. The railroad may choose to correct the geometry faults by tamping as needed. This should only be done where needed, but tamping is often extended to adjacent areas that do not need adjusting. Tamping is appropriate, but it does damage the ballast and may not be economical in frequently reoccurring problem spots. Further, tamping does not correct the root cause of the roughness. Thus the need to find the cause and fix the problem arises (1).

If the tamping improvement does not last long enough, then the ballast condition should be checked. If the fouling is excessive then undercutting with the addition of new ballast as needed will be programmed, or alternatively the track will be raised so that additional ballast can be placed under the ties. If excessive fouling is not the problem or if the undercutting process does not improve the performance, then an examination is required to determine the cause of the reoccurring geometry problem.

The drainage of railway track is recognized as a fundamental, yet often neglected aspect of track design. Track drainage significantly affects track performance and track maintenance requirements. A complete drainage system must include means of handling
water flowing over the ground surface towards the track, shedding or draining water falling onto the track, and controlling water from the subgrade (2).

**SUBSTRUCTURE COMPONENTS**

The ballast is the top structural layer that, among other things, holds the track in place, reduces the stress transmitted to the subgrade, and facilitates the geometry adjustment through tamping (3,4). Fouling is the main cause of ballast problems. Once the cause of the fouling is determined the solutions can easily be identified and applied.

The best choice of ballast for a particular location is the most cost-effective choice, taking into consideration traffic, environmental conditions, and cost of material delivered to the site. The best choice, therefore, will not necessarily be the highest quality material or the material that has the lowest delivered cost. These costs include purchase and transportation of ballast as well as tamping and undercutting/cleaning.

The subballast is the second structural layer that helps the ballast reduce the stress to subgrade, maintains separation between the ballast and subgrade particles, and plays an important role in track drainage (1). Subballast deserves more attention than it gets because of its importance to track performance. Filter fabric (geotextile) has frequently been used to fulfill some of these subballast functions, but investigations have shown that fabric is not generally desirable (1). Asphalt concrete is an alternative or supplement to sand/gravel subballast materials, but the economics will probably limit asphalt to special cases.

Subgrade serves as the platform for the structural layers, and so it must be stable. The subgrade has many modes of failure such as: attrition, squeeze, progressive
compression under repeated loading, consolidation, massive shear, frost heave/thaw
softening and swelling and shrinking from moisture change (1). Investigation is needed to
know which is the cause of the subgrade problem in a specific case in order to choose the
correct cure. This determination may be easy, but often it can be very challenging.

Subgrade problems are clearly more difficult to correct, than ballast or subballast
problems, especially after the track has been constructed. But there are a lot of possible
solutions to subgrade problems.

**BALLAST FOULING**

Over a period of time in track the ballast gradation typically becomes broader and finer
than the initial condition because the larger ballast particles will break into smaller
particles and additional smaller particles from a variety of sources will infiltrate the voids
between the ballast particles. This process is known as fouling. Fouling deteriorates
ballast performance and eventually requires undercutting/cleaning or track raising with
ballast replacement when tamping improvements do not last long enough

Five categories of fouling material have been identified: 1) particles entering from
the surface such as wind blown sand or coal falling out of cars; 2) products of wood or
concrete tie wear; 3) breakage and abrasion of the ballast particles; 4) particles migrating
upward from the granular layer underlying the ballast; and 5) migration of particles from
the subgrade (1). The main causes of ballast fouling must be identified if proper steps are
to be taken to reduce the rate of fouling. The most frequent cause of ballast fouling is
ballast breakdown, but there are individual situations in which each one of the other
categories predominates.
Geotextiles (filter fabrics) generally have not been found to be useful in solving ballast fouling problems. A proper subballast layer is the best cure for fouling from the underlying granular layer and from the subgrade. When subgrade is the source of fouling material one of two main mechanisms usually is present: 1) abrasion of the subgrade surface by ballast particles in contact with the subgrade, or 2) hydraulic erosion of water-filled cracks in the subgrade subjected to repeated train loading.

**BALLAST/SUBBALLAST LAYER THICKNESS**

The thickness of the ballast layer beneath the ties generally should be the minimum that is required for the ballast to perform its intended functions. Typically this will be 12 to 18 in. The minimum subballast layer thickness beneath the ballast should be 6 in. Thus, the minimum granular layer thickness beneath the ties would be 18 to 24 in. A check then needs to made to determine whether this is enough thickness to prevent overstressing the subgrade (5,6). An overstressed subgrade will result in rapid loss of geometry under train traffic.

**BALLAST CLEANING AND RENEWAL**

Ballast cleaning and renewal is an expensive and time-consuming process which is also highly disruptive to train traffic. Thus, the need for this process must be considered carefully. Basically ballast cleaning and renewal is required when the ballast becomes so fouled that it cannot fulfill its functions.

Care must be taken during ballast cleaning to prevent removing or damaging the existing subballast layer. Care must also be taken to ensure that the width and inclination of the cut surface are such that the water collecting in the cleaned ballast is able to flow.
freely across the cut surface and into the track side drainage system. Effort made to achieve a geometrically smooth cut surface will also improve the stability of the track geometry under subsequent traffic after the cleaning and renewal process is completed.

The economic benefit of ballast cleaning and renewal will not occur unless the drainage system is functioning as well (7). Thus, a ballast cleaning and renewal program should also accommodate installing or repairing the drainage system. It is also desirable to evaluate the cause of the ballast fouling and consider taking steps to correct the cause of the fouling in order to reduce the amount of future undercutting.

Shoulder cleaning can lengthen the time before undercutting cleaning is required (7). The shoulder cleaning must include the full depth of the shoulder all the way out to the ballast toe. Shoulder cleaning improves drainage by shortening the drainage path of water out from under the ties and increases the depth of drainage below that which is typically achieved with undercutting/cleaning. Partial depth undercutting will not result in effective drainage of water from the uncleaned lower portion of the ballast layer.

Shoulder cleaning also allows migration of fouling materials out from under the track into the clean voids in the shoulder in order for the fouling material to migrate, the fouling particles must be much smaller than the voids in the ballast and need a forcing mechanism such as flowing water or pumping by repeated train loading. When the fouling material results from breakdown of the ballast in a way that produces a broad range of particle sizes, migration of the fouling material is not likely to be significant.

**SUBGRADE TREATMENT METHODS**

The following are a few examples of subgrade remedial treatment methods:
1. **Grouting**--Some grouts penetrate the voids of the soils (permeation grouting) and strengthen them or reduce water seepage. Other grouts compact and reinforce the soils (compaction grouting) to strengthen them or displace the soils to compensate for settlement. Jet grouting mixes cement with soil to form columns of strengthened soil.

2. **Soil mixing**--A process in which soil is mixed with augers and paddles to create a mixture of soil and cement based grout. Soil mixing creates a column of strengthened soil for compression and shear reinforcement.

3. **Lime modification of clay properties**--Lime can be used to improve the properties of clay. Techniques for mixing lime with clay include mechanical mixing (admixture stabilization) and quicklime piles. Injecting lime into clay in slurry form has been performed with the expectation of improving the clay properties. This is a common but not usually effective treatment with often undesirable side effects, e.g. slurry injection can fracture clay instead of penetrating the voids and also solidifies ballast (8).

4. **Reconstruction**--Compaction of existing soils or replacing them with better soils will give improved subgrade. Chemicals can also be mechanically mixed with the soils in layers which are then recompacted to form a stronger or less reactive soil. The chemistry of the soils should be checked or tests performed to verify the effectiveness of the treatment, because some combinations can be harmful.

5. **Reinforcement**--Various plastic grids, metal strips or cellular materials placed in the soils give tensile reinforcement. Alternatively, steel reinforcing can be installed in the subgrade soils through techniques such as soil nailing, soil doweling and micropiling.
6. **Stress reduction**—Increasing the thickness of the ballast and subballast will reduce the pressure on the weaker subgrade caused by the train loading. Contrary to the AREMA engineering manual, the allowable pressure is not constant, but varies widely and must be determined in each case for correct design. The correct strength considers the magnitude of the repeated loading from the trains and the number of repetitions. For a given axle load, a high tonnage line would have a much lower apparent strength than a low tonnage line. Thus the high tonnage line needs a greater ballast/subballast thickness for the same subgrade properties (5,6).

**IMPORTANCE OF PROPER INVESTIGATION**

A fundamental limitation of common railroad practice regarding substructure remedial work is the lack of a proper investigation to diagnose the cause of the problem before attempting a solution. A proper investigation includes using trained personnel who understand the fundamentals of what is being observed and recognize appropriate solutions.

This limitation of inadequate investigation is compounded by not following up to evaluate the results of the remedial work. Thus, sometimes improvements occur but for reasons other than the ones expected. Other times improvements do not occur, and sometimes the problem gets worse. In these cases the reasons will not be known without a follow up investigation. One consequence of inadequate follow up is that the decision about whether or not to use the same method elsewhere cannot be reliably made.

The inevitable result of investigation deficiencies is inefficient use of maintenance resources or a poor return on the investment. An example is that mud in the ballast is
commonly thought to derive from subgrade soil particles. This has led to the inappropriate use of filter fabric. Investigations have shown that subgrade is rarely the source of the mud and even in cases where it was, the fabric did not stop the mud. Although the filter fabric can usually be omitted some other action is still needed to fix the problem.

**NEED FOR GOOD TECHNOLOGY**

For reasons of safety, reliability, and profitability railroads need to use the best technology available. This challenge increases with increasing traffic, increasing axle loads and higher speed trains, as well as decreasingly available work windows. Mixing these together on the same track is even a bigger challenge. Another challenge is the problem of track transitions that occur at turnouts, bridges, and tunnels for example.

A lot of substructure technology is available that is not being applied. One reason for this situation is the insufficient use of education programs to learn about the possibilities. Another reason often mentioned is that the investigation and the remedial work are too expensive. The answer to this is to do a complete cost/benefit evaluation. Proper use of good technology will improve the economics, and no doubt pay for its implementation (9).

**SOLUTIONS START WITH DRAINAGE**

It is usually a good idea to start the investigation by examining the track drainage since drainage is often a factor causing chronic problems. Achieving proper drainage is not simply a matter of digging a cross trench and letting water out of the track. If not used properly, these trenches become longitudinal discontinuities that can cause roughness
increase. They can also allow water to reach further in to the subgrade soil causing more softening. Furthermore if the trench is filled with ballast, subgrade attrition may occur, thus creating a new problem.

Drainage is a complex problem (2). Factors to consider include: ballast fouling condition, subballast gradation, slope of subgrade surface, ditch or pipe depth ditch or pipe longitudinal slope and expected rainfall characteristics. Remember too that water drains by gravity and so can only flow to outlets at a lower elevation. Also clay soils will not drain because of their low permeability.

It would be desirable to have the subballast shed the water draining down from the ballast to keep the water from the subgrade, but the subballast must also be permeable enough to drain water which gets in to it. These are contradictory requirements which can not be met with a single subballast layer.

Drainage of railway tracks is essential to acceptable track performance. Water in the track substructure originates from three potential sources: 1) precipitation onto the track, 2) surface flow from areas adjacent to the track, and 3) groundwater flow. A complete drainage system must include provisions for handling water from all three sources (2).

Precipitation onto the track will enter the ballast. It will then flow laterally out of the ballast into ditches or enter the subballast. This water will either drain laterally out of the subballast or continue downward into the subgrade. Surface ditch drains can collect water from the ballast and subballast. Subsurface drains are needed to collect water flowing through the subgrade and may also be needed to help drain the subballast.
Particularly difficult is drainage of water between adjacent tracks or from tracks surrounded on both sides by other tracks. Not only is the drainage path to the side longer, but a suitable drainage path is more difficult to maintain. Cross-drains under the outer tracks or longitudinal drains between tracks may be needed.

Ballast can become saturated from rainfall by a high degree of fouling, which holds water, or by restricted drainage at the edge of the ballast. Causes of this restricted drainage include, for example:

- Ballast pocket formation from subgrade settlement
- Fouled ballast shoulder
- Low permeability boundary at edge of ballast
- Ponding of water next to the track from lack of a ditch to carry water away from the track after exiting the ballast
- Inadequate lateral slope on the subballast surface to direct water to the side of the track.

The ability of water to drain laterally also requires that the drainage path at the edge of the ballast and subballast layers not be blocked (2). Two conditions need to be met to achieve this requirement: 1) the ballast shoulder and the edge of the subballast must be free draining, and 2) discharged water must be able to flow away from the track that the toe of the ballast slope is the most critical zone for achieving drainage of water out of the ballast.

CONCLUSIONS

Clearly there are a lot of remedial techniques for subgrade problems to draw upon. An investigation is necessary to select the correct solution for each specific case. In most
cases, it is not until the underlying cause of a problem is known can a lasting and economical solution be found. The subject is complex, but information is available to help.

Ballast is an important part of track maintenance. It is also a re-occurring part, and so is designed to be maintained. Furthermore, ballast is the only part of the substructure which is easily maintained. To keep costs and disruption to traffic low, ballast maintenance should be minimized.

Ballast properties change over time in track and the ballast becomes increasingly fouled. The causes of fouling need to be understood in order to reduce the rate of ballast performance deterioration. Undercutting/cleaning is needed to restore the desired ballast properties after becoming fouled. However, undercutting/cleaning will not be cost-effective unless track drainage is functioning properly as well. Shoulder cleaning can lengthen the time until undercutting/cleaning is needed.

Tamping is needed for geometry corrections. However, tamping should only be done when and where it is needed to minimize ballast damage and temporary reductions in track stability.

Ballast and subballast contribute to protection of subgrade from overstressing. However, subballast, which is always needed, is preferred for completing the total granular layer thickness beyond the minimum ballast layer thickness required for fulfilling the other ballast functions.

No factor is more important to track performance than drainage, yet drainage is often inadequate or neglected.
When unstable subgrade conditions exist, the cost of maintaining track geometry will be much higher than normal. A number of effective remedial solutions are available. Even though the cost of these repair methods is often high, low cost solutions may be ineffective and even detrimental and so may not be cost effective.

Track substructure technology is complex. Its importance both requires and deserves education programs.

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