Evaluation of Railway Subgrade Problems

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The major causes contributing to railway subgrade problems are explained. Repeated dynamic loading, fine-grained soils, and excessive moisture content are indicated to be the major causes. The characteristics of different subgrade problems are discussed. Progressive shear failure, excessive plastic deformation, and subgrade attrition with mud pumping are the major problems for most railway subgrades under repeated traffic loading. The practical approaches for evaluation of subgrade are discussed. To identify potential problem subgrade sites, the recommended approaches include the use of the available soil, geologic, and hydrologic information; visual inspection; study of track maintenance history; and analysis of track geometry car measurements. To assess subgrade conditions for a site known to have track foundation problems, the recommended approaches include the field subsurface inspection, laboratory tests, cone penetration test, and track stiffness test. For each of these approaches its application to the railway subgrade is analyzed and discussed.

Subgrade plays an important role in maintaining satisfactory performance of railway track under repeated traffic loads. Its role becomes even more critical when freight cars with heavier axle loads are introduced. In the past, the role of subgrade as the track foundation was not recognized adequately. Little effort was given to understanding the characteristics of subgrade soils under repeated traffic loading and environmental action. This situation has survived for a long time largely because a subgrade defect was often temporarily compensated for by repeatedly adding more ballast under ties or by frequent track maintenance. Thus, a lack of understanding of the causes of or correcting the causes of subgrade problems is then compensated for by higher track maintenance costs.

The objectives of this paper are to explain the causes and characteristics of subgrade problems and to discuss practical approaches for identifying and assessing them. The emphasis is on the existing soil subgrade or low-fill subgrade under repeated traffic loading.

CAUSES OF SUBGRADE PROBLEMS

Under unfavorable conditions various types of subgrade problems, as will be described later, can commence, develop, and lead to failure or repeated railway track maintenance. The major causes that may contribute to the development of subgrade problems can be categorized into three groups: load factor, soil factor, and environmental factor (soil moisture and soil temperature). Often, however, a subgrade problem is a result of these factors acting together.

Load Factor

The load factor is the external factor that may cause a subgrade problem. There are two types of loads: material self-weights and repeated dynamic loading. The first type of load can be a major factor that may cause consolidation settlement or massive shear failure for a high embankment not properly designed or constructed. For a subgrade, however, the load factor of greatest concern is from repeated traffic loading.

Two features characterize the repeated traffic loading. One is the magnitude of the individual dynamic wheel load. The other is its number of repetitions. The subgrade behaves quite differently under a single static loading than under repeated traffic loading, even though the magnitudes of individual axle loads may be the same. For example, the subgrade, particularly subgrades of fine-grained soils such as silt and clay, will exhibit lower strengths under repeated loadings than under a single loading. Many track subgrade problems are associated with repeated loads. Therefore, it is necessary to take into account both the maximum magnitude of each individual load and the number of repetitions when considering the influence of load factor on subgrade performance.

Another important feature regarding the load factor that should be determined is the combined influence of all levels of repeated dynamic wheel loads. For a track subgrade the influence of repeated dynamic wheel loads smaller than the maximum can also be significant. A simple example is that the subgrade settlement accumulated under smaller magnitudes of wheel loads with large numbers of repeated applications may be significantly larger than that generated under a single application of a larger dynamic wheel loading. For detailed discussions and considerations of dynamic wheel load and repeated load applications, readers are referred to the work by Li (*1*), Li and Selig (*2*), and Raymond and Cai (*3*).

Soil Factor

A problem subgrade will not generally consist of coarse-grained soils (gravel and sand) but most likely will be fine-grained soils (silt and clay) because of the lower strength and permeability of the latter materials. In general, the finer the soil or the greater the plasticity characteristics of the soil, the poorer the anticipated performance of this material as a railway track subgrade.

The influence of soil type on the subgrade performance is closely related to its moisture content and its susceptibility to the effects of moisture change. Most soils would have no problem acting as the subgrade if they could maintain a low enough moisture content. A major reason why subgrade problems are most commonly associated with fine-grained soils is that the fine-grained soils are most susceptible to decreasing in strength and stiffness with increasing water content and do not drain well. On the other hand, the performance properties of most coarse-grained soils are less significantly influenced by the presence of water, and such soils can drain well so that they usually have low moisture contents.

Soil Moisture

Almost every subgrade problem can be attributed to the high moisture content in the fine-grained soil subgrade. The presence of water

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in the subgrade can reduce the strength and stiffness of subgrade soils dramatically. If a subgrade maintains low enough moisture content throughout the year and if it is assumed that the ballast and subballast layers are properly graded and sufficiently thick, the subgrade should not be the cause of the need for excessive maintenance.

A subgrade may become wet or saturated by the infiltration of water from the surface or from groundwater. According to experience gained from work on highways (*4*) the major factor influencing the moisture content of the subgrade is the groundwater if the water table is within approximately 6.1 m (20 ft) of the surface. However, for a subgrade in which the water table is greater than 6.1 m deep, the moisture content in the upper part of the subgrade is determined primarily by seasonal variation caused by rainfall, drying conditions, and soil suction.

The duration of water contact with a subgrade soil may make a large difference in the resulting strength of the soil. A clay subgrade exposed to the air with occasional rain showers and dry periods may stay strong, whereas a subgrade covered by ballast and subballast (which cuts off evaporation) may get weak. The ballast and subballast allow water to penetrate, but they do not allow it to evaporate. As a result a subgrade that is not free-draining invariably can be saturated.

Soil Temperature

Soil temperature is of concern when it causes cycles of freezing and thawing. Under certain combinations of temperature, soil suction, soil permeability, and availability of water, ice lenses will form when the soil freezes, causing ground heave. When the soil thaws again excess water from the ice lens will cause weakening of the soil.

CHARACTERISTICS OF SUBGRADE PROBLEMS

Subgrade problems can be divided into three groups in terms of their major causes. The first group includes those problems primarily caused by repeated traffic loading. The second group includes those problems primarily caused by the weight of the track structure, subgrade, and train. The third group includes those problems primarily caused by the environmental factors such as freezing soil temperature and changing soil moisture content. In general, the traffic load-induced subgrade problems occur at shallower depths in the subgrade. The environmental subgrade problems also occur at shallower depths or occur at the surfaces of subgrade slopes. The weight-induced subgrade problems caused by the track structure, subgrade, and train, on the other hand, involve massive movement of the subgrade soils and are generally more deep-seated in nature.

Table 1 summarizes the subgrade problems, their causes, and their features that were categorized. The first four types are primarily caused by repeated traffic loading. The second two types are those mainly caused by the weight of the train, track, and subgrade. The last four types are those related to environmental factors. The following provides a detailed discussion of the first three types of subgrade problems, that is, those major problems for an existing low-fill subgrade under repeated traffic loading.

Progressive Shear Failure

Progressive shear failure is the plastic flow of the soil caused by overstressing at the subgrade surface by the repeated loading. The subgrade soil gradually squeezes outward and upward following the path of least resistance. This type of failure is illustrated in Figure 1 (*5*) and has been observed in both revenue service tracks and the FAST test track in the United States. This is primarily a problem with fine-grained soils, particularly those with a high clay content. Such soils soften as their moisture content increases and reduce in strength because of remolding and the development of increased pore water pressure from repeated loading.

As shown in Figure 1 heave of material at the track side is matched by a corresponding depression beneath the track. This depression is reflected at the surface as a depression in the track substructure, which is corrected by the addition of ballast beneath the ties. The addition of more ballast results in an increase in ballast depth and a corresponding reduction in soil stress at the subgrade level, which tends to improve subgrade stability. However, the depression traps water, which tends to cancel the potential improvement. Therefore, only adding more ballast without correcting the distorted subgrade surface configuration to provide drainage will not correct the stability problem caused by the progressive shear failure.

Excessive Plastic Deformation

Although progressive shear failure is accompanied by progressive shear deformation in the subgrade, excessive plastic deformation is classified here as a separate type of subgrade problem. It includes not only the vertical component of progressive shear deformation but also the vertical deformation caused by progressive compaction and consolidation of subgrade soils under repeated traffic loads.

The development of cumulative plastic deformation in the subgrade is a function of the repeated loading. The plastic deformation produced by a single axle load is essentially negligible under normal conditions. However, the plastic deformation in the subgrade may accumulate to such a significant level with repeated load applications that it can severely affect the performance of the track. Moreover, the development of plastic deformation is usually nonuniform along and across the track. Hence, excessive plastic deformation can lead to unacceptable track geometry change.

The development of excessive plastic deformation is more rapid for a newly constructed subgrade and for a cohesive soil subgrade with access to water. In the latter case, with the same mechanism as that for the progressive shear failure, when a depression at the subgrade surface occurs, it collects water, causing an increased softening of the subgrade near the depression. With repeated loading the clay squeezes out and the underlying clay in turn softens; thus, the depression deepens and the ridges of soft subgrade material collect around the pocket, which forms a larger water-filled pocket.

To offset the loss of track elevation caused by the excessive plastic deformation in the subgrade, more ballast material generally must be added to the track, which results in an increased depth of ballast material. When ballast continues to replace the subgrade soil and as it is repeatedly added under the ties, a severe manifestation of accumulated subgrade plastic deformation, termed *ballast pocket,* can form. Figures 2(*a*) and 2(*b*) illustrate examples of a ballast pocket across and along the track. As discussed earlier, although adding more ballast increases the ballast depth, this cannot completely solve the problem of excessive plastic deformation development since the ballast pocket traps water, which in turn leads to softening of the subgrade soils. Furthermore, the ballast may become contaminated with the subgrade soil particles, thereby degrading the characteristics of the ballast or the granular material.

TABLE 1 Major Subgrade Problems and Their Features

Type	Causes	Features
Progressive shear failure	- repeated over-stressing - fine-grained soils - high water content	- squeezing near subgrade surface - heaves in crib and/or shoulder - depression under ties
Excessive plastic deformation (ballast pocket)	- repeated loading - soft or loose soils	- differential subgrade settlement - ballast pockets
Subgrade attrition with mud pumping	- repeated loading of subgrade by ballast - contact between ballast and subgrade - clay rich rocks or soils - water presence	- muddy ballast - inadequate subballast
Liquefaction	- repeated loading - saturated silt and fine sand	- large displacement - more severe with vibration - can happen in subballast
Massive shear failure (slope stability)	- weight of train, track and subgrade - inadequate soil strength	- high embankment and cut slope - often triggered by increase in water content
Consolidation settlement	- embankment weight - saturated fine-grained soils	- increased static soil stress as from newly constructed embankment
Frost action (heave and softening)	- periodic freezing temperature - free water - frost susceptible soils	- occur in winter/spring period - rough track surface
Swelling/Shrinkage	- highly plastic soils - changing moisture content	- rough track surface
Slope erosion	- running surface and subsurface water - wind	- soil washed or blown away
Soil collapse	- water inundation of loose soil deposits	- ground settlement

Subgrade Attrition with Mud Pumping

Subgrade soil attrition by ballast followed by mud pumping of soil particles into the ballast voids is a combined result of repetitive dynamic load applications, free water, and the existence of fine soil particles at the subgrade surface. This type of distress occurs when ballast is placed directly on fine-grained soils and soft rock (*5*). The high degree of stress at the ballast-subgrade interface causes the wearing away of the soil or rock subgrade surface. In the presence of water [Figure 3(*a*)] the products of attrition and water combine to form mud. Under repeated loading this mud pumps upward into the ballast voids [Figure 3(*b*)]. This process will cause settlement of the track and loss of drainage capacity in the ballast, which in turn decreases the shear resistance and the resilience performance of the ballast layer.

The mud in the ballast generally consists of particles of silt and clay. This attrition has been observed in cuts with subgrades of siltstone, shale, slate, or sometimes sandstone, which have durability problems under repeated loading, as well as in soft subgrades. Subgrade strength is not a basis for determining whether this problem will occur.

Mud in ballast can also be formed from products of ballast or subballast breakdown or from particles entering from the surface. They do not represent subgrade problems. Care must be taken to distinguish the sources of mud because the remediation for these problems is quite different from the remediation for the subgrade attrition.

Mud pumping from the subgrade can be prevented by placing a layer of properly graded subballast as shown in Figure 3(*c*) to prevent the formation of a slurry by mechanically protecting the subgrade from attrition and penetration by the overlying coarse-grained ballast. It also prevents the upward migration of a slurry that forms at the subballast-subgrade interface by virtue of the filtering properties of the subballast. The mud pumping problem can be reduced by providing adequate drainage to ensure that water does not remain in the ballast and at the ballast-subgrade interface.

Other Subgrade Problems

In addition to the three major types of subgrade problems discussed earlier, other subgrade problems may also lead to track subgrade failure or excessive track maintenance. The characteristics of those subgrade problems are also summarized in Table 1. For more detailed discussion readers are referred to the work of Selig and Waters (*5*) and Selig and Li (*6*).

EVALUATION OF SUBGRADE PROBLEMS

For an existing subgrade two different situations need to be considered. The first situation is when an existing track line is planned to carry more traffic or heavier axle loads. A track that performs well without subgrade problems under current axle loads and traffic

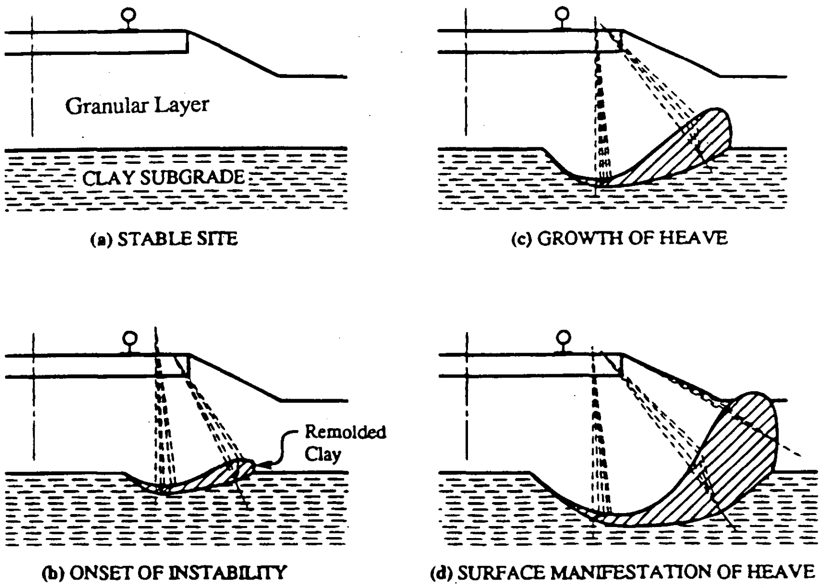

FIGURE 1 Development of progressive shear failure.

density may not perform as well after the change in traffic. Thus, an evaluation of the supporting capacity of the subgrade is required with the planning of a traffic change. In this situation the major objective is to assess the overall conditions of the entire length of the track subgrade and identify those sites with potential problems. The second situation takes place when a specific track site is constantly plagued by track foundation problems. In this situation the major objective of the evaluation is to determine the major causes of the problem and consequently design remedial measures to correct the problem.

The focus of a subgrade evaluation is different between these two situations. The investigation in the first situation needs to cover a much larger area and is more concerned about the overall conditions of the subgrade in terms of strength and stiffness properties. On the

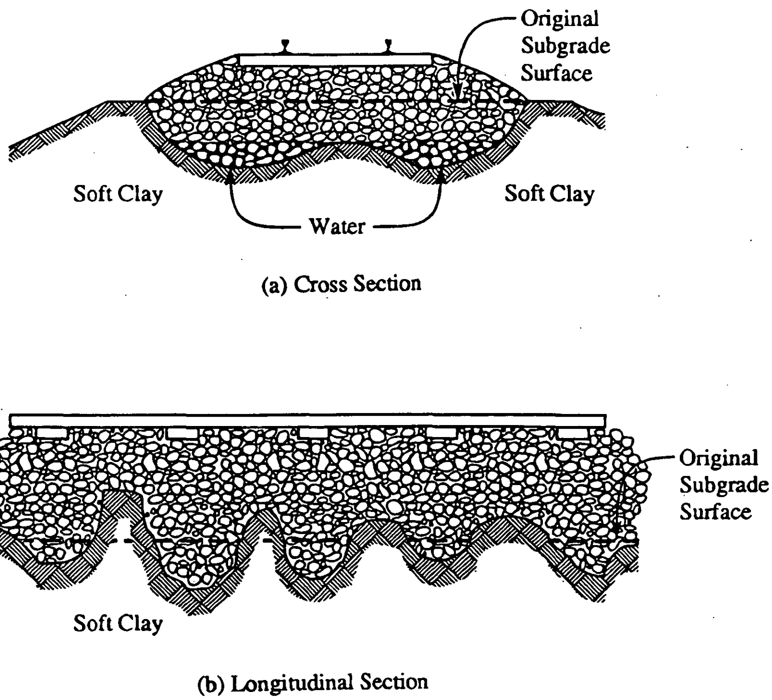

FIGURE 2 Ballast pockets.

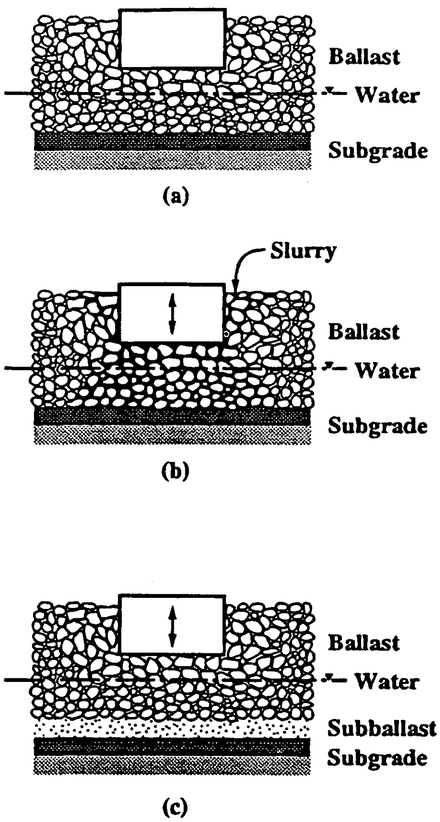

FIGURE 3 Causes and prevention of subgrade attrition with mud pumping.

other hand, the investigation in the second situation is more specific in that it focuses on finding the causes of problems at already identified problem locations.

In this paper the term *identification* is used to represent the subgrade evaluation for the first situation, whereas the term *assessment* is used to represent the subgrade investigation for the second situation.

Identification of Potential Problem Sites

The recommended approaches include the use of soil, geologic, and hydrologic information for the track route to be considered, combined with visual inspection in the field, review of track maintenance history, and a study of track geometry car measurements.

Soil, Geologic, and Hydrologic Information

Although subgrade conditions may vary over short distances along the line, it is important to recognize that a valid determination of general conditions and the subgrade problems inherent to such conditions can be deduced from information covering large areas in less detail. This information includes soil, geologic, and hydrologic maps and reports. The principal sources of this information include the U.S. Geologic Survey, the U.S. Department of Agriculture Soil Conservation Service, state and municipal highway departments, and public works departments.

The proper use of this information can provide for the identification of soil deposits, the definition of geologic conditions, and the influence of environmental factors for the track route to be investigated. Particularly important is identification of those subgrade sites with soft soil types.

Figure 4 shows a simplified soil distribution map in terms of the supporting strength of the subgrade soils that the authors developed. In Figure 4, five levels of soil strength are used to categorize the soils in different regions of the United States. The areas with a strength level below medium should be considered areas with potential subgrade problems.

Witczak (*7*) gave more examples of the distributions of poor subgrade support areas in the United States. In general in the western part of the United States most areas have a severity rating of nonexistent to limited poor subgrade support. Only a small area has a rating of medium to widespread or more severe. In contrast in the eastern part of the United States a significant portion of the area has a rating of medium to widespread or more severe. Other maps such as the annual precipitation map (*7*) and the freezing index contour map (*4*) can also be used to evaluate the effects of water and temperature on the subgrade. A report by Selig and Li (*6*) provides a more detailed discussion on the use of this information. This information provides a valid and quick estimation of subgrade conditions for a large area, and use of this information is the most practical way for the preliminary evaluation of subgrade conditions. Thus, each railroad district would benefit from establishing a file of such information for its territory.

Visual Inspection

Regular and careful inspection of superstructure and substructure conditions of the track by experienced personnel can help to identify areas of subgrade deficiencies.

If mud is observed on the ballast surface an investigation should be conducted to determine the source of the mud. The mud can be from many sources, including the subgrade. Without verification the mud should not be assumed to be an indication of subgrade problems.

Distorted ballast shoulders and drainage ditches accompanied by difficulty in maintaining a stable track geometry is an indication of soft subgrade problems. Minor difficulties with subgrade are likely to become more severe when axle loads are increased.

Embankment and cut slopes should be examined for symptoms of instability such as erosion, water seepage, and slope movement. Shear failure and excessive deformation of an embankment will be accompanied by a track dip. Symptoms such as these may signal a potential future massive failure and so should be given urgent follow-up attention.

Visual inspection in the field can become more effective in identifying a potential subgrade problem if it is performed regularly over each season and after each rainfall. A careful examination of track surface conditions over time provides a good understanding of the influences of the traffic loading and environmental factors such as rainfall.

Visual inspection is just the first step in identifying the causes of substructure-related problems. Because most of the substructure is hidden from view the visual inspection will mainly serve to identify areas requiring follow-up testing and will suggest the type of investigation required. Furthermore, visual inspection alone cannot reveal all potential problem sites when the axle load is to be increased.

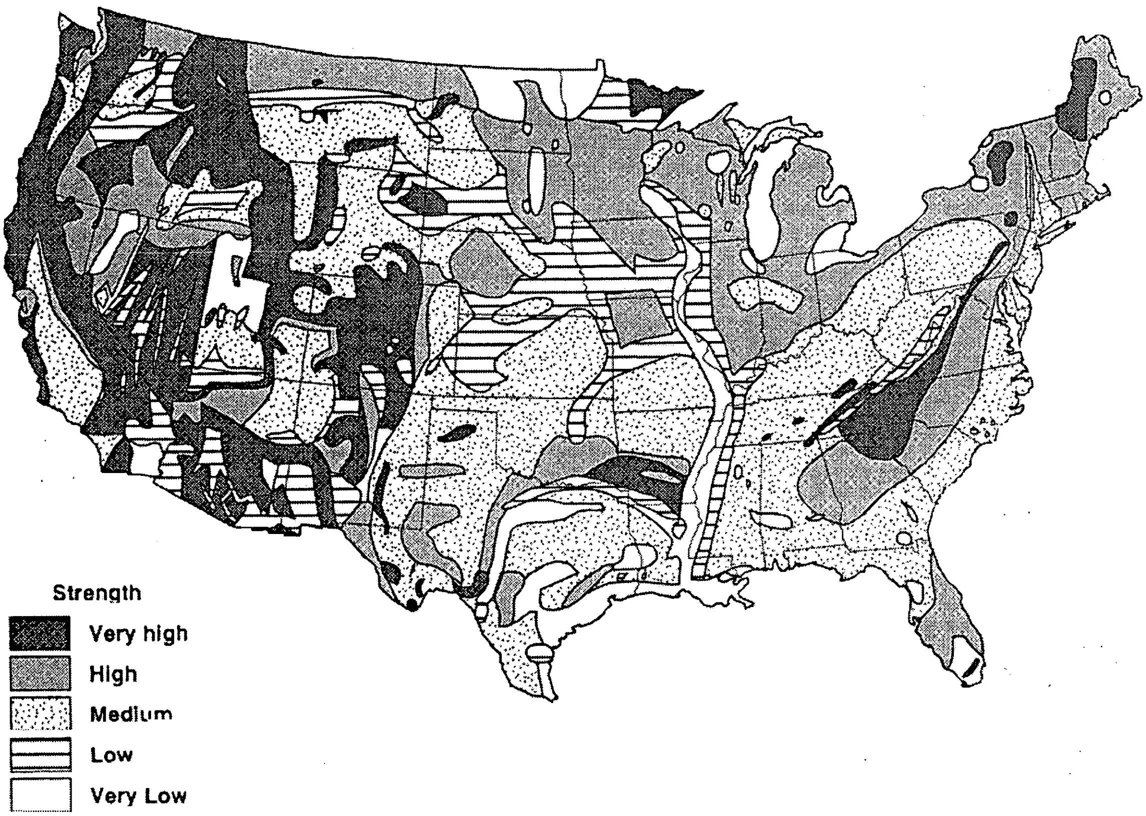

FIGURE 4 Soil strength distribution.

Track Maintenance History

Access to information on track maintenance history is valuable in identifying problem areas. The desired information includes (a) superstructure characteristics, (b) tamping frequency, (c) ballast type, (d) ballast cleaning or renewal records, (e) traffic characteristics, and (f) other maintenance activities. Some of this information is readily available, whereas other aspects are not. Railroads are encouraged to establish a track maintenance history data base that can be upgraded with information collected during follow-up substructure testing.

Track Geometry Car Measurements

Track geometry cars provide frequent, repeatable measurements of track geometry such as gage, surface alignment, twist, curvature, and superelevation of the rails. These measurements provide the most efficient means of surveying track conditions on a routine basis and provide an objective, quantitative measurement of the functional conditions of the track that relate directly to train operation.

The recorded geometry car data need to be processed to make the data suitable for evaluating problem areas. These processed data can identify areas with severe roughness characteristics and quantify the rate of geometry deterioration. Research in progress at the University of Massachusetts is seeking to assess the ability to use geometry data for diagnosing the cause of track roughness problems.

Figure 5 shows an example of how the processed track geometry car measurement data can help to distinguish between good and bad subgrade conditions. The measurements for the processing were taken from two track locations at the FAST test site in Pueblo, Colorado (*8*). One section of track was built directly on a stiff subgrade consisting of natural silty sand. The other section of track, however, was built on a soft subgrade consisting of a 1.5-m (5-ft) clay layer with a high moisture content overlying the natural silty sand soil. Except for the subgrade the other components of track superstructure and substructure were similar between these two tracks. Thus, any significant difference in track performance between these two tracks was caused by the difference in subgrade.

The vertical profiles of rails, as represented by the midchord offset, were measured over a 9.4-m (31-ft) chord length. The roughness (R^2) is calculated by $R^2 = \Sigma d_i^2/n$, where d_i is the midchord offset, and n is total number of midchord offset measurements.

Figure 5 compares the rail vertical midchord ordinate profiles after 60 million gross tons (MGT) of traffic. As can be seen, the track built on the soft subgrade became much rougher than the track built on the strong natural silty-sand subgrade. The difference is even more obvious in terms of the roughness calculation. In fact, the roughness for the track built on the silty-sand subgrade became almost constant after the initial roughness development. On the other hand, the roughness for the track built on the soft subgrade (clay section) grew gradually before 30 MGT and then developed very rapidly.

Assessment of Subgrade Problems

Assessment of a subgrade problem as defined in this paper deals more specifically with a particular subgrade site. The major objec-

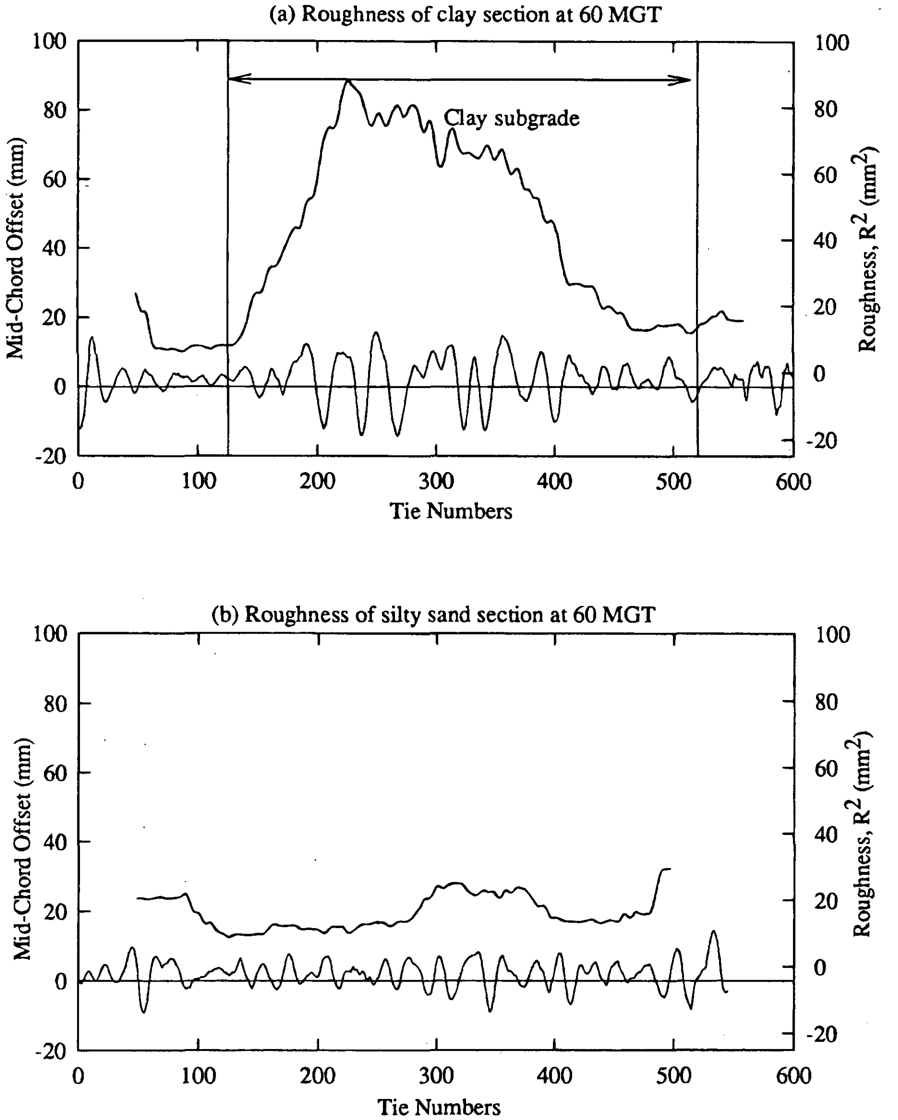

FIGURE 5 Roughness comparison at 60 MGT: (*a*) clay section; (*b*) silty sand section.

tive of the assessment is to determine the major causes of the problems at an identified high-maintenance track site or to predict where problems might develop with increased axle load. In addition, the assessment of a subgrade also includes the determination of soil properties important for the evaluation of subgrade performance.

The assessment plan should consider the following trends:

1. Some subgrade problems, such as progressive shear failure and subgrade soil attrition with mud pumping, are governed by soil type, soil moisture content, and soil strength within the near-surface portion of the subgrade.
2. Track vertical deformation (both plastic and resilient) is governed by the soil stiffness primarily within the top of 3 to 4.5 m (10 to 15 ft) of the subgrade strata (*1*).
3. In order to have low bearing capacity or significant deformation from rail loading a soft condition must exist within the top 3 to 4.5 m of the subgrade. Such a soft subgrade would most likely consist of a saturated, fine-grained silt or clay soil.
4. A subgrade problem is related to the strength and stiffness properties of the subgrade soils. Thus, laboratory and field soil property tests can be of help in evaluating the subgrade performance and can supplement direct observations of subgrade performance.

The following briefly discusses four major types of assessment approaches: subsurface inspection, laboratory tests, in situ tests, and track stiffness test.

Subsurface Inspection

The subsurface inspection requires some type of excavation. The major purpose of a field excavation related to subgrade is to examine the conditions between the ballast and subgrade interface and to identify the subgrade soil characteristics and groundwater conditions.

A preliminary investigation of the subgrade can be conducted by using inspection holes dug by hand or by machine at the side of the track [(Figure 6(*A*)]. Generally, 1 m or so is about the practical limit for digging depth below the subgrade surface. Because conditions at the top part of the subgrade are often different below the track than at the side of the track, a better inspection can be conducted by removing the ballast shoulder [Fig. 6(*B*)]. This permits inspection of the ballast and subballast layers as well, which is usually necessary whenever subgrade information is required.

The next level of investigation involves excavating a cross trench from one side of the track to the other [Figure 6(*C*)]. This is important in fully evaluating the ballast, subballast, and upper subgrade conditions because the conditions often vary with position across the track and with depth.

A cross trench will reveal a progressive shear failure of the subgrade. For this type of subgrade failure subgrade heave can often be found penetrating into the ballast shoulders, with depression under the ends of ties. These are important observations that will not be detected without at least a partial-width cross trench. Depths of excavation to at least 1.2 m below the top of the tie are often quite possible.

On the basis of the authors' experience excavating a shallow cross trench is also a good approach for distinguishing subgrade mud pumping from the mud pumping originating from ballast breakdown. For subgrade mud pumping a proper subballast will be absent, and at the subgrade surface fines mixed with water should be observed. With severe cases of subgrade mud pumping subgrade depressions can also be observed. These are produced by the constant attrition of the subgrade surface by ballast particles and the ensuing migration of the subgrade particles into ballast voids.

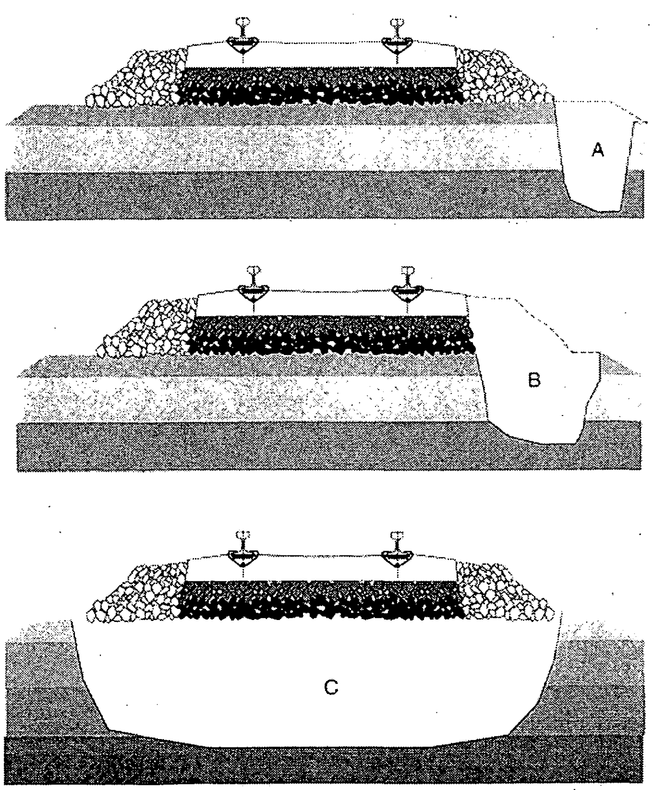

FIGURE 6 Types of subsurface inspection.

Laboratory Tests

Laboratory testing can be used to measure subgrade soil properties on disturbed or undisturbed soil samples obtained from beneath the tracks. Such soil properties include strength, stiffness, grain size, permeability, and moisture content. Recovered soil samples are also used for soil identification and classification. These properties are directly related to subgrade performance.

Soil identification and classification are the single most important laboratory tasks, and often these can be adequately done in the field. It provides a way of estimating the behaviors of subgrade soils. For example, it is critical for identifying the existence of fine-grained soils in a subgrade.

Although the in-place moisture content of a subgrade soil will vary with seasonal conditions, determination of its natural moisture content is always desirable. Often it is possible to determine the suitability of subgrade materials solely on the basis of moisture content and soil classification. For example, since the liquid limit is the moisture content at which the soil begins to become liquid when disturbed, a field moisture content at about the liquid limit will indicate a sensitive soil of very low strength. If the natural moisture content during the wet seasons of the year is less than the plastic limit, a relatively firm material can be anticipated.

A comparison of the physical and chemical properties of the fouling materials present in ballast, of the ballast material itself, and of the subgrade soil underneath the ballast and subballast will help reveal the sources of the fouling materials in the ballast.

In Situ Tests

Since the traffic load has an influence on a substantial depth of the subgrade it is important to investigate the performance characteristics of all subgrade layers to a depth at which the traffic loads have an insignificant influence. This depth can be considered to be 4.5 to 8 m (*1*). One way of acquiring this information is to obtain soil samples at various depths and locations by boring methods. These samples are then transported to the laboratory for testing. Alternatively, the properties can be estimated in the field by various in situ testing techniques.

In situ tests for predicting subgrade performance offer a rapid means of evaluating subgrade conditions over a large geographic area at a relatively low cost. However, in situ tests should not be thought of as a complete subgrade investigation in that no single test can provide all of the answers for every situation. The in situ tests should always be considered in conjunction with visual observations in the fields, soil, geologic and hydrologic, information; and expected behavior based on soil classification.

A number of in situ tests are suitable for the evaluation of railway subgrade. A brief summary of the applicability of these test techniques under different soil conditions can be found in work by Selig and Waters (*5*). The selection of in situ tests and the development of a site investigation plan are often difficult tasks in view of the large number of test methods available and the specific subgrade problems and soil types for each site.

The electric cone penetration test (CPT) is particularly suitable for railway subgrade investigations. The test allows rapid assessment of the strength and stiffness of soil at a site by measuring the pushing force required to advance the cone probe into the soil. At the same time the friction force acting on a cylindrical portion of the instrument behind the tip is measured, which helps to estimate soil composition. With a pressure transducer installed a CPT may also be able to indicate the groundwater table position.

Track Stiffness Test

A track stiffness test provides a measure of the vertical stiffness of the rail track foundation. It is a measure of the structural condition of the track and, as such, is related to track performance. Since the subgrade has a strong influence on the magnitude of track deflection under load (*9*), a measurement of track deflection permits an estimate of the subgrade soil stiffness.

A comparison of test results between a stiff subgrade and a soft subgrade, all other factors being equal, is illustrated in Figure 7. A track with a stiff subgrade support has a higher track stiffness (or track modulus) than a track with a soft subgrade.

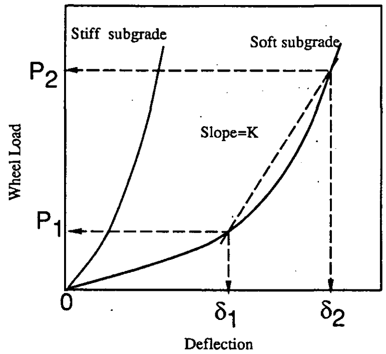

FIGURE 7 Comparison of track modulus tests between stiff and soft subgrades.

SUMMARY

The major causes leading to subgrade problems include repeated heavy axle loading, the existence of fine-grained subgrade soils, and the existence of excessive water in the subgrade. It is important to realize that (a) not only the maximum dynamic wheel load but also all repetitive load applications with all magnitudes of wheel load contribute to the development of subgrade problems, (b) a problem subgrade is often constructed of fine-grained soils, (c) the possibility that a subgrade will experience any severe problems will be much lower if a low enough moisture content can be maintained in the soil all of the time, and (d) a subgrade problem is often a result of several causes acting together.

Ten different subgrade problems were described in this paper. However, the major subgrade problems for an existing subgrade under repeated heavy axle loading are progressive subgrade shear failure, excessive plastic deformation, and subgrade attrition with mud pumping.

Subgrade conditions are evaluated to identify potential problem sites when planning an upgrade of traffic. Because of the nature of this type of investigation for covering large regions, the subgrade evaluation approaches need to be quick and economical. The approaches that can be used thus include the use of available soil, geologic, and hydrologic information; visual inspection; study of track maintenance history; and analysis of track geometry car measurements.

Field subsurface inspection, laboratory tests, CPT, and the track stiffness test can be used to investigate the geotechnical conditions of the subgrade and the major causes of subgrade problems. Through these methods of investigation detailed information directly related to subgrade performance and conditions can be obtained. They are recommended for use at locations where track maintenance is constantly required or the subgrade is deteriorating rapidly so that a subgrade stabilization program is required.

ACKNOWLEDGMENT

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