TECHNOLOGY DIGEST
Timely Technology Transfer

EFFECTS OF HEAVY AXLE LOADS ON SOFT-SUBGRADE PERFORMANCE

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Summary

Extensive tests and investigations conducted by the Association of American Railroads (AAR) have provided valuable insights into — and possible remediation methods for — the rapid track-geometry deterioration that occurs in soft subgrades under 39-ton heavy axle loads. The tests were conducted on a Low Track Modulus (LTM) test zone with a track modulus less than 2,000 to 2,500 lb/in./in. installed at AAR's Facility for Accelerated Service Testing. It was concluded that heavy axle load-induced stresses are too high for soft subgrades with an industry-standard granular layer thickness of 12 to 24 inches beneath conventional ballasted track structure.

If poor track geometry is due to excessive soft-subgrade deformation, ballast tamping will not fix the geometry problem for the long term. Load-induced subgrade stresses may increase as a result of ballast tamping. For the LTM track, the increased subgrade stresses required up to 5 MGT of tonnage to return to pretamping levels.

Subgrade performance is a result of subgrade soil strength resisting repetitive load-induced stress applications. Clay soil strength is always lower under repeated loading than under a monotonic static loading, and decreases with progressive subgrade deformation. Subgrade deformation is generally progressive under traffic. However, decreases in subgrade soil strength due to repeated loading and progressive soil deformation may lead to rapid track-geometry deterioration under heavy axle loads (1 to 2 MGT surfacing cycles in the LTM case), particularly when coupled with an increase in subgrade stresses due to various causes including tamping.

Test results from the LTM study indicate it is critical to ensure an adequate subgrade support for heavy-axle-load transport. To avoid frequent track maintenance due to excessive subgrade deformation and failure, investigation and assessment of subgrade conditions is essential for determining the best remedies for soft subgrade support. The AAR's cone penetrometer vehicle is a state-of-the-art approach to subgrade assessment. Currently the AAR is evaluating alternative remedies to minimize the effects of HAL on subgrade maintenance regulations.

Suggested Distribution:

- ☐ Track Maintenance
- ☐ R&T Department
- ☐ Maintenance of Way
- ☐ Bridges & Roadway

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INTRODUCTION AND CONCLUSIONS

Under the Heavy Axle Load (HAL) program the Association of American Railroads (AAR) has conducted extensive subgrade performance tests over the Low Track Modulus (LTM) test zone at the Facility for Accelerated Service Testing (FAST) of the Transportation Technology Center near Pueblo, Colorado. The main conclusions concerning soft-subgrade performance under HAL are:

- A track built on a soft subgrade with a track modulus less than 2,000 to 2,500 lb/in./in. will experience rapid track-geometry deterioration under 39-ton heavy axle loads due to excessive subgrade deformation. With a conventional ballasted track structure and an industry-standard granular layer thickness (12 to 24 inches), heavy axle load-induced stresses in the subgrade are too high for soft subgrades.
- If poor track geometry is due to excessive soft subgrade deformation, ballast tamping will not fix the geometry problem for the long term. Load-induced subgrade stresses may increase as a result of ballast tamping. For the LTM track, the increased stresses required up to 5 million gross tons (MGT) to return to pretamping levels.
- Subgrade deformation due to heavy axle loads is generally progressive. However, the more a clay subgrade deforms, the more subgrade soil strength decreases due to increasing volume of the remolded (sheared) soil. Decrease in subgrade soil strength due to repeated loading and progressive soil deformation may lead to rapid track-geometry deterioration under heavy axle loads (1 to 2 MGT surfacing cycles in the LTM case), particularly when coupled with an increase in subgrade stresses due to various causes including tamping.
- It is the difference between the vertical stress and confining stress in the subgrade (i.e., deviator stress), instead of either alone, that influences subgrade performance. For the LTM subgrade, the measured deviator stress at the track center was at least 50 percent lower than the deviator stress measured under the rail seat and under the tie end. This is consistent with observed subgrade progressive shear failures (squeezing) which often result in the largest depressions between the rail seat and the tie end, but little deformation at the track center.

This digest discusses the effects of heavy axle loads and ballast tamping on soft subgrade performance. Other factors such as track drainage and subballast characteristics are also significant, but are not discussed here.

SOFT-SUBGRADE DEFORMATION AND FAILURE

The LTM test zone located at FAST was installed in 1991 by excavating a 600-foot-long, 12-foot-wide by 5-foot-deep trench. The trench was backfilled with buckshot clay with an average moisture content of 33 percent. Track modulus for the LTM zone ranged from approximately 2,000 to 2,500 lb/in/in. Exhibit 1 shows the LTM cross section.

Since the LTM installation in 1991, more than 150 MGT has been accumulated over this test zone. However, under 39-ton axle loads the LTM track required frequent surfacing and three track rebuildings (or three phases) in order to maintain an acceptable track geometry for normal train operation. During each phase for an accumulation of 40 to 60 MGT, the subgrade deformed and track geometry deteriorated progressively in the early to mid portion of the testing phase, and the track required surfacing at intervals of 10 to 30 MGT. However, towards the end of each phase, track geometry deterioration would become so rapid that track surfacing was required every 1 to 2 MGT, and eventually traffic had to be stopped for complete track rebuilding.

Subsequent investigations of subgrade failure always indicated significant subgrade squeezing (progressive shear failure) for the test zone. Subgrade surface soil from under the rail to the tie end was pushed outward and upward to the ballast shoulder. Exhibit 2 shows an example of the surveyed subgrade profile across the track

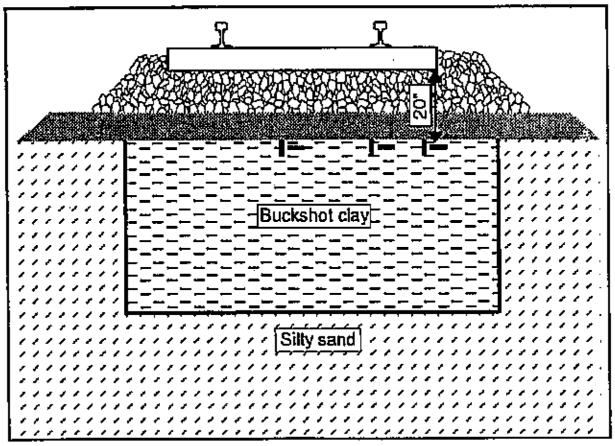

Exhibit 1. LTM Cross Section and Stress Cells

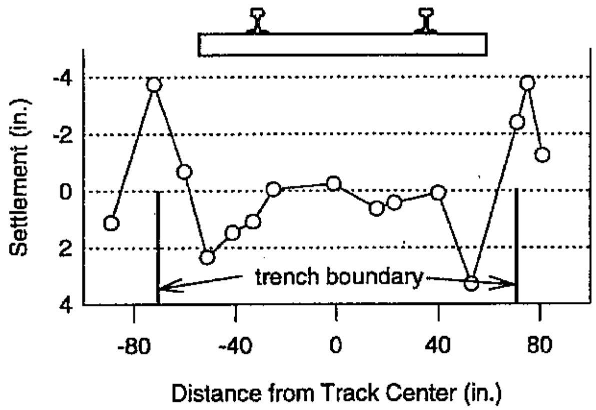

Exhibit 2. Subgrade Settlement due to Progressive Shear Failure

due to progressive shear failure. As shown, the subgrade accumulated significant deformation under the rail seat to the tie end. In this example, the maximum settlements were approximately 2 and 3.5 inches under the two tie ends respectively. The subgrade squeezing into the ballast shoulders is evident by the subgrade heaves shown in this exhibit above the walls of the trench. As a result of significant subgrade deformations, track-surface, cross-level and twist-geometry deviations were unacceptable for normal train operations. Also, as reported in a separate document,[1] track-geometry deterioration was directly related to track modulus and would increase significantly as a result of low track modulus of less than 2,000 to 2,500 lb/in./in.

Another obvious problem associated with subgrade squeezing is that the depression formed at the subgrade surface can easily trap water entering from the track above, thus aggravating subgrade failure.

SUBGRADE STRESSES UNDER HAL

Extensive measurements of subgrade stresses were taken in the LTM test zone.[1] It was concluded that 10 to 20 psi subgrade vertical stress can be generated under 39-ton axle loads and subgrade vertical stresses can increase by 30 to 50 percent as a result of ballast tamping. The following, however, presents measurements of both vertical and lateral confining stresses in the LTM subgrade. As illustrated in Exhibit 1, subgrade vertical and confining stresses were measured at the track center, under the rail seat and under the tie end.

Exhibit 3 shows an example comparison of vertical, confining, and deviator stresses for the three measurement locations. The deviator stress is defined as the difference between the vertical and confining stresses and has a physical meaning of shear stress. As can be seen in Exhibit 3, the vertical stress was the highest under the rail seat, while the confining stress was the highest at the track center and the lowest under the tie end. The deviator stress was the lowest at the track center, but was significantly higher under the rail seat and tie end. The distribution of measured deviator stresses across the track is consistent with observed subgrade deformation distributions as shown in Exhibit 2. In other words, although vertical subgrade stress gives a reasonable indication of subgrade stress state, it is the deviator stress which influences subgrade performance. For example, measured vertical stresses were generally similar in magnitude at the track center and under the tie end, but the subgrade deformed much more under the tie end. Obviously, the smaller deformation at the track center was due to a much lower deviator stress at this location (at least 50 percent lower than the deviator stress under the rail seat and under the tie end).

Exhibit 4a shows the effects of traffic and ballast tamping on subgrade stresses under the rail seat. Measurements were taken over an accumulated traffic of 50 MGT. As shown, the measured subgrade stresses were lower at the beginning, due to the "bridging" effect of the track granular layer over the measurement locations (i.e., at the beginning the track was in loose contact with the subgrade over the stress cell locations). More uniform contact between the granular layer and the subgrade led to an increase in subgrade stresses. After initial increase, subgrade stresses stabilized approximately until a ballast tamping operation. Immediately following tamping, both vertical and confining stresses increased greatly. For example, a 40-percent increase in vertical stress and two-fold increase in confining stress can be

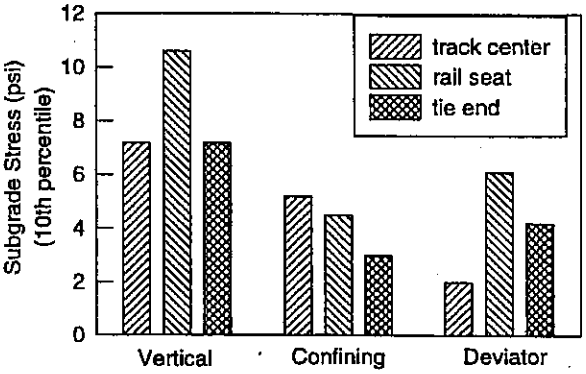

Exhibit 3. Comparisons of Subgrade Stresses

seen in this exhibit. Subsequent traffic led to decreasing of subgrade stresses. However, it took roughly 5 MGT of traffic for the vertical stress to return to its pretamping level. The confining stress returned to its pretamping level much faster (the second measurement following tamping was 3.5 MGT from the first measurement, and the confining stress may have returned to its pretamping level with less than 3.5 MGT). The increase in subgrade stresses due to tamping can be explained by subgrade stress redistribution causing more concentration in local areas. The tamper tines may concentrate more ballast support under the tie, and the stiffness of the ballast layer may decrease due to tamping, thus allowing the stress to be passed over a smaller area (higher intensity).

Exhibit 4b shows the deviator stress determined with traffic and maintenance. As shown, ballast tamping caused an immediate decrease followed by a large increase in deviator stress. The increase in deviator stress from the pretamping value was approximately 50 percent, which can be very detrimental to subgrade performance.

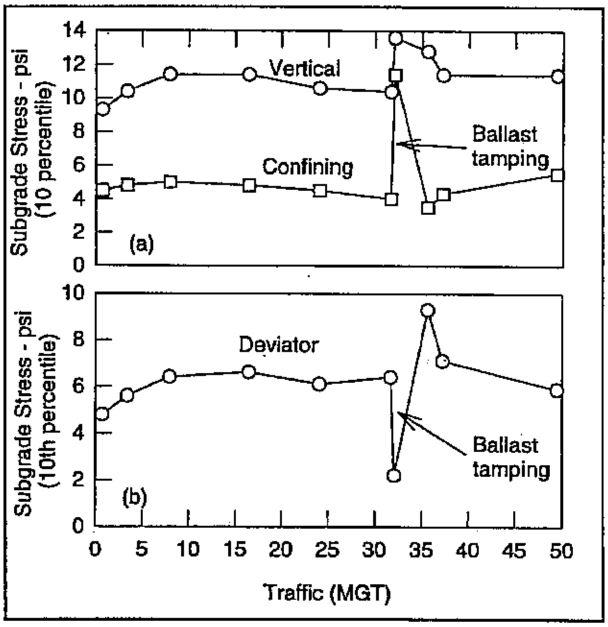

Exhibit 4. Subgrade Stresses under Rail Seat Influenced by Traffic and Tamping

SUBGRADE STRENGTH

Subgrade performance depends upon both repetitive load-induced stresses and soil strength. Except for the LTM test zone, the rest of the FAST track experienced little profile and cross-level geometry deviations under 39-ton axle loads. This is because the rest of the FAST track is built on a strong subgrade consisting of a silty sand soil (track modulus is 4,000 to 6,000 lb/in./in.). The clay subgrade in the LTM zone not only possesses low soil strength at high moisture content (roughly 13 psi unconfined soil strength, compared to roughly pretamping 11 psi vertical stress shown in Exhibit 4a), but also exhibits lower strength under repeated loading.

Exhibit 2 shows a deformed subgrade surface profile due to subgrade progressive shear failure. One consequence of subgrade squeezing development is the sheared and remolded soil for the top layer of the subgrade. With progressive deformation, more and more soil in the subgrade is sheared or remolded. A remolded clay possesses lower strength than an undisturbed clay. Therefore the subgrade soil strength will gradually decrease as a result of subgrade progressive deformation. Once the subgrade strength decreases below the stresses induced by heavy axle loads, the subgrade will fail rapidly. This may explain why towards the end of each phase, the track geometry deteriorated so rapidly, requiring surfacing every 1 to 2 MGT. To better understand this type of subgrade performance under repeated heavy axle loads, a laboratory investigation is currently being conducted on the soil samples taken from the LTM subgrade, using the triaxial test technique under the condition of repeated stress applications.

REFERENCE

1. Read, D., Trevizo, M. and Li, D. "Low track modulus and load path evaluation experiment summary," *1st Annual AAR Research Review*, Vol. 1: FAST/HAL Test Summaries, Association of American Railroads, Transportation Technology Center, Pueblo, Colo., pp.123-131.

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A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH THE AAR, PUBLICATION ORDER PROCESSING, 50 F STREET, NW, 5TH FLOOR, COG, WASHINGTON D.C., 20001