U.S. Department of Transportation

Federal Railroad Administration

RESEARCH RESULTS
FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

RR 22-32 | **October** 2022

RAINY SECTION TRACK SETTLEMENT MODEL

SUMMARY

In collaboration with the Federal Railroad Administration (FRA), Transportation Technology Center, Inc. (TTCI) used the Rainy Section of the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST) in Pueblo, CO, to develop a new track settlement model. Research was conducted in 2019.

The team developed a track settlement model from the Rainy Section testing and supplemented it with recent laboratory and track-based inspection system research. Compared to other existing track settlement models, the benefit of the Rainy Section model is that it directly incorporates the interaction of two key factors that affect track settlement: the number of fines in the ballast (Ballast Fouling Index, BFI) and moisture levels [1]. The Rainy Section settlement model is not intended to serve as a comprehensive track settlement model that can account for a wide range of conditions; other models such as the Railway Track Lifecycle Model (RTLM) [2] are better suited for that purpose. However, aspects of the Rainy Section model may eventually be incorporated into more comprehensive models.

BACKGROUND

Track settlement is a naturally occurring process during the railroad maintenance cycle, and the settlement cycle restarts itself after each surfacing event. How much and how quickly the ballast settles, however, can vary significantly depending on the ballast condition. A common indicator of ballast condition used in North America is Selig's Fouling Index (FI). This index measures fine amounts in the ballast through gradational analyses. Currently, this measurement is often estimated using ground-penetrating radar (GPR). The output from the GPR estimation is referred to as the BFI to create a distinction from the gradation FI measurement.

For all ballast conditions, high settlement rates occur immediately after surfacing (initial 0.1 million gross tons, or MGT). Settlement occurs because vibrations from train traffic causes the loose ballast that exists after tamping to pack tightly together and increase its density. This is commonly referred to as the "consolidation stage," and the settlement after this initial densification is called the "post-consolidation stage" [1]. If the ballast is clean (BFI < 10), the settlement typically stabilizes in the post-consolidation stage as the ballast particles reach a maximum dense state for the specific axle loading. If the ballast has significant fines (BFI > 30), the track settlement in the post-consolidation stage may vary significantly depending on moisture levels [1, 2]. Figure 1 shows a severe situation with high fine levels (BFI = 40) and a saturated track surface.

Figure 1. Photograph of track with fines and a saturated surface

OBJECTIVES

The objective of this study was to develop an improved track settlement model using the unique capabilities of the Rainy Section at the FRA's Transportation Technology Center. Through this research, the interaction of ballast fines and moisture levels can be effectively considered with real-world field data.

METHODS

RAINY SECTION

As detailed in other publications [3, 4], researchers developed the Rainy Section at FAST in 2016 to investigate the interaction between fine-filled ballast and moisture. This distinctive test section allows teams to control the amount of moisture on a 20 foot track section that contains over 40 percent fines from natural ballast degradation (BFI = 40). Researchers then can monitor settlement from heavy-axle-load (HAL) traffic. Previous testing has shown that the presence and amount of moisture has a strong influence on ballast settlement and a fully saturated and fine-filled section may produce settlement rates up to 15 times greater than its dry counterpart [3, 4].

SETTLMENT MODEL

Model Characteristics

Researchers developed the Rainy Section settlement model from Rainy Section testing supplemented with information from recent laboratory and track-based inspection system research. While other models, like the RTLM, are better suited for comprehensive track settlement, the Rainy Section settlement model is set up to explain the range of potential settlement responses due to ballast degradation and moisture.

To make the Rainy Section model as representative as possible for known track settlement behavior, the following characteristics of the model were included:

- The settlement model matches Rainy Section results at BFI = 40 for dry and saturated conditions.
- The relationship between the BFI and settlement are non-linear as observed from track-based inspection data [5].
- The influence of moisture occurs between 25 and 75 percent saturation as observed from recent laboratory testing [6].
- Post-ballast consolidation and a linear settlement trend are assumed with MGT [5].

Mathematical Model

The model uses a power function relationship between the BFI and the settlement rate (uRS, [mm/MGT]) and then a correction factor to account for moisture, as shown in the equation:

$$u_{RS} = [b * BFI^{a}] * w_c$$

Where:

u_{RS} = settlement rate [mm/MGT]

BFI = Ballast Fouling Index

a,*b* = constants

w_c = moisture correction factor

BFI input should use GPR or sampling (Selig's FI) results. The constant for *a* is 1.4 and *b* is 0.0045 and were determined from fitting the field measurements. The moisture correction factor (w_c) assumes 1.0 is 50 percent saturation as shown in Figure 2.

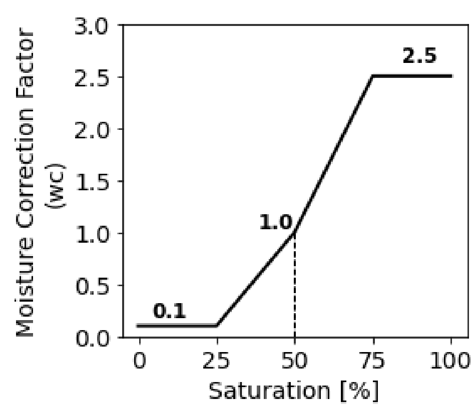
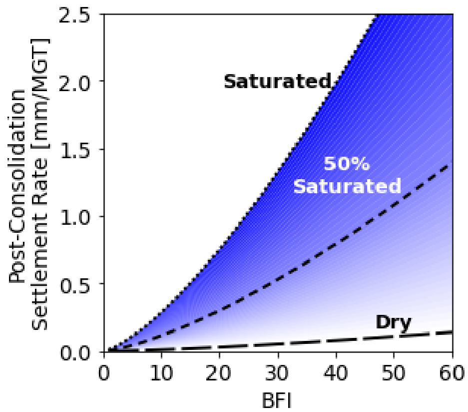


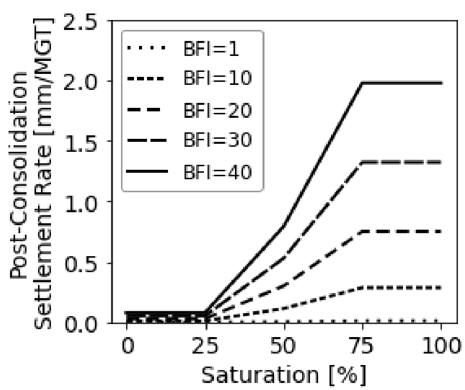
Figure 2. Moisture correction factor value with saturation

Model Projections

The track settlement projection from the Rainy Section model varies significantly by the inputs of the BFI and moisture. Figure 3 emphasizes the influence of each input. Figure 3a plots the range in response with the BFI and shows that moisture plays an increasingly significant role with a higher BFI. In other words, the range in behavior (amount of potential scatter from a median best fit line) is anticipated to be greater for higher BFI locations. Figure 3b shows the variation with moisture (saturation levels) and again emphasizes that the increase in settlement from moisture is dependent on the BFI levels.



(a)



(b)

Figure 3. Model projections varying by (a) the BFI and (b) moisture (saturation)

MODEL DEMONSTRATION

To demonstrate how the Rainy Section model performs against field data, the model projections were compared with both a Rainy Section test and track inspection data from a Class I railroad.

Rainy Section

The first demonstration compares the Rainy Section model with Rainy Section tests. Because the model was calibrated with Rainy Section test data, the goal of this demonstration is not to show accuracy but to emphasize how moisture affects track settlement in a real-world scenario.

Figure 4 shows the measured track settlement and model projections from the center of the Rainy Section. The first 4 MGT had dry ballast conditions. The Rainy Section was then wetted until about 8.5 MGT to a saturated surface condition and then allowed to dry completely before accumulating another approximately 2 MGT. The measured and projected results show settlement occurred mainly while the ballast was saturated. These results agree with the model.

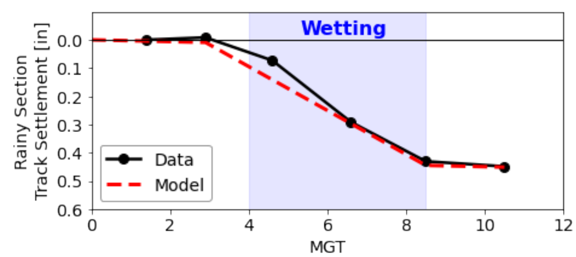


Figure 4. Model demonstration with rainy section data

Track Inspection Data

The second model demonstration shows the potential range in behavior from moisture compared with track-based inspection data collected from related projects [5]. The purpose of this demonstration is to show the range in behavior from the Rainy Section model generally agrees with behavior observed in revenue service.

Figure 5 plots the data as the relationship between the BFI and the 62-foot surface profile degradation rate in units of inches per 100 MGT. A conversion factor of 0.3 was used to convert settlement rate to surface profile degradation [5].

The model range and field results show good agreement in the overall trend where the scatter from a median fit (e.g., 50 percent saturated, median dashed line) is minimal at low BFI values and has larger amounts of scatter at high BFI values. It is highly likely that other factors beyond moisture are included in the scatter of the field track inspection data, but the purpose of this demonstration is to show the overall trend agreement.

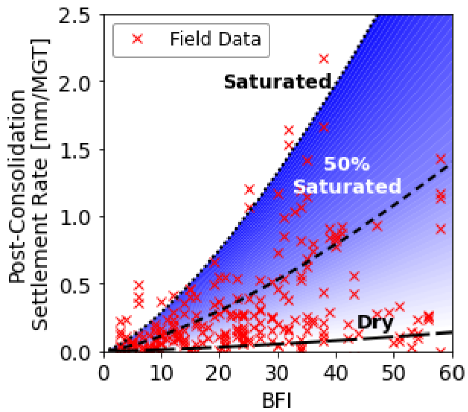


Figure 5. Model demonstration with track-based inspection data

CONCLUSIONS

The team developed a track settlement model from Rainy Section data that matches general trends observed in revenue service. While the Rainy Section model is not intended to serve as a comprehensive track settlement model, it does allow for the consideration of both ballast fines and moisture. The demonstrations showed that the Rainy Section model agrees with field results. As such, this can provide a valuable addition to more comprehensive models.

REFERENCES

1. Li, D., Hyslip, J., Sussmann, T., & Chrismer, S. (2016). *Railway Geotechnics*. CRC Press
2. Chrismer, S.M. & Selig, E.T. (1994). Mechanics-Based Model to Predict Ballast-Related Maintenance Timing and Costs. *R-863. Association of American Railroads Research and Test Department.*
3. Wilk, S., Basye, C., Brice, M., & Baillargeon, J. (2019). Influence of rain events of fine-contaminated ballast. *Proceedings of the International Heavy Haul Conference* (pp. 393-400). Narvik, Norway.
4. Wilk, S. and Li, D. (2021). A Deep investigation into the mechanisms and factors producing mud pumping. *Proceedings of the Fourth International Conference on Transportation Geotechnics (ICTG).* Virtual.
5. Wilk, S. Demonstration of mechanics-based track geometry deterioration model. *In press.*
6. Qian, Y. (2022). Quantitative Assessment of the Influence of Drainage on Track Support. *Presented at FRA RPD Virtual Track Support and Substructure Research Symposium. Virtual.*

ACKNOWLEDGEMENTS

TTCI conducted this research as part of the cooperative HAL revenue service research program between FRA and AAR. TTCI team members included Dr. Steve Wilk and Dr. Dingqing Li.

CONTACT

Jay Baillargeon
Program Manager
Federal Railroad Administration
Office of Research and Development
55000 DOT Road
Pueblo, CO 81001
(719) 584-7155
jay.baillargeon@dot.gov

Stephen (Sean) Woody
Chief, Track Research Division
Federal Railroad Administration
Office of Research and Development
1200 New Jersey Avenue SE
Washington, DC 20590
(202) 573-3252
sean.woody@dot.gov

KEYWORDS

Ballast, ballast fouling index, track inspection, forecasting models